

Altitudinal Assessment of Grassland Vegetation Based on Vegetation Indices. Case Study: the Banat Mountains

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Abstract. Grasslands are essential agro-pastoral ecosystems in the Banat Mountains, contributing both to maintaining biodiversity and to supporting traditional land use activities. The purpose of this work is to evaluate the altitudinal distribution and vegetation cover of grasslands included in protected areas, by integrating spatial analyses with indicators derived from satellite images. The methodology included three stages: delimitation and quantification of grassland areas on altitudinal levels, identification of grasslands located above 500 m altitude and superimposed on protected natural areas, analysis of the degree of concentration at the area level and evaluation of the vegetation cover based on the NDVI (Normalized Difference Vegetation Index). The results show that an overwhelming proportion of grasslands (over 80% of the total 70,335 ha) are concentrated at altitudes below 700 m, while areas above 1100 m amount to less than 2%, indicating the strong dependence on the conditions of the lower mountain level. The grasslands included in the protected areas and located above 500 m cover 7,834.38 ha and present an uneven distribution between the TAUs, which is confirmed by the high value of the Herfindahl-Hirschman concentration index ($HHI=0.80$), which suggests a marked degree of polarization of the pastoral resource in only a few territories. The NDVI values, between 0.04 and 0.74 (mean = 0.56), show a generally favorable state of vegetation, almost 60% of the area being characterized by large and very high coverage. The study underlines the need for continuous monitoring of mountain grasslands in order to substantiate effective management measures for pastoral ecosystems in the Banat Mountains.

Keywords: grasslands, Banat Mountains, NDVI, protected areas, HHI, spatial analysis, GIS

INTRODUCTION

Mountain grasslands represent some of the most valuable agro-pastoral ecosystems in the temperate zone, through their role in sustaining biodiversity, storing carbon, protecting soils and maintaining traditional cultural landscapes (Simon et al., 2020; Vidican et al., 2020). Recent studies highlight that temperate natural grasslands have suffered massive surface losses on a global scale, being considered among the most transformed and least protected terrestrial biomes; only about 4–5% of native temperate grasslands today are included in official networks of protected areas, and the pressures generated by land conversion and increased use continue to affect their ecological integrity (Carbutt et al., 2017). In mountainous areas, grasslands are of particular importance due to the diversity of species and adaptations to harsh climatic conditions, where alpine grasslands constitute major nuclei of biodiversity and ecosystem services (Magiera et al., 2017; Dong et al., 2023). The relationship between floristic diversity and the stability of grassland ecosystems, demonstrated in long-term studies, supports the argument for the conservation of these habitats as a key element for ecosystem resilience in the face of climate change and anthropogenic disturbances (Cojocariu et al., 2010; Călușeru et al., 2013; Chen et al., 2017; Xiong et al., 2019).

At the same time, numerous studies highlight that, despite their ecological value, grasslands are underrepresented in protected areas and often poorly integrated into conservation policies, which have historically privileged forest ecosystems (Carbutt et al., 2017). Recent assessments show that grasslands located within protected areas can maintain a high level of plant diversity, even under grazing intensities comparable to those outside protected areas, if management is adapted to local conditions (Kachler et al., 2023). At the same time, semi-natural grasslands in European protected areas are considered habitats of priority interest, but remain vulnerable to abandonment, intensification or changes in land use, which calls for integrated management models that combine biodiversity conservation with traditional pastoral use (Copăcean et al., 2020; Gigante et al., 2024). In this context, the assessment of the spatial distribution of grasslands, including in relation to altitudinal staging and the network of protected areas, becomes essential for defining territorial management and planning strategies in mountainous areas.

Recent advances in remote sensing have made it possible to monitor grassland vegetation in detail, spatially, at low cost and over large areas (Ali et al., 2017; Taravat et al., 2019; Reinermann et al., 2020; Simon et al., 2021). Vegetation indices derived from satellite imagery, in particular the Normalized Difference Vegetation Index

(NDVI), are widely used to characterize vegetation condition, vegetation cover, cover, and green biomass (Ma et al., 2019; Verrelst et al., 2019; Zhao, Qu, 2024). A recent synthesis on grassland productivity monitoring shows that more than 80% of studies use NDVI as the primary or auxiliary indicator for estimating productivity and biogeophysical parameters, confirming the central role of this index in the analysis of grassland ecosystems (Bangira et al., 2023).

NDVI has been validated as an effective tool for assessing pasture quality (moisture, crude protein, fiber) in Mediterranean silvo-pastoral systems, by correlating satellite values with field measurements over several years (Serrano et al., 2024), but also for monitoring vegetation response to grazing and phenological changes in heterogeneous landscapes, where grass, shrub and arboreal vegetation coexist on small spaces (Balata et al., 2022). At regional and continental scales, long time series of NDVI are used to analyze spatiotemporal trends of grassland vegetation and the climatic or socio-economic factors that drive these changes (Wang et al., 2025).

In Europe, including in the Carpathian area, the use of NDVI vegetation indices in the monitoring of mountain grasslands has experienced an accelerated development, being applied both for the assessment of vegetation cover and productivity, as well as for the identification of areas at risk of degradation or change of use. Recent studies in the Poiana Rusca Mountains, located in the vicinity of the Banat Mountains, have demonstrated the usefulness of NDVI for monitoring grassland vegetation cover during the growing season, providing an objective basis for the analysis of the spatial and temporal dynamics of the vegetation cover (Zhang et al., 2016; Măgureanu et al., 2023). In this context, the Banat Mountains represent a particularly relevant area for the integrated analysis of grasslands, due to the combination of mountain and submountain relief, the presence of extensive protected natural areas and the persistence of traditional pastoral uses. However, studies explicitly correlating the altitudinal distribution of grasslands, their degree of inclusion in protected areas and the state of vegetation assessed on the basis of NDVI are still limited.

The present paper aims to contribute to this research direction through an integrated analysis of the grasslands of the Banat Mountains, in which the altitudinal distribution, overlap with protected areas and the state of the vegetation cover, assessed by NDVI, are approached unitarily, in order to provide relevant information for the regional management of mountain pastoral ecosystems. This integrated approach aims to substantiate effective directions for the management and conservation of mountain pastoral resources, with relevance for the protection of biodiversity and the sustainability of land use in the Banat Mountains.

MATERIAL AND METHODS

1. Study area

The study area includes the meadows located in the Banat Mountains (figure 1), delimited according to the provisions of the Mountain Law no. 197/2018 and the region made by Posea and Badea (1984), for establishing the boundaries of the mountain subunits. The Mountain Law establishes the limits of the Banat Mountains, included in Mountain Group 8 and based on the administrative-territorial units. They are made up of the mountains: Almăjului, Dognecei, Locvei, Semenice and Aninei, to which is added a restricted area of the Cerna Mountains, the Mehedinți Mountains, the Țarcu Mountains and the Little Mountain, generated by the administrative overlap. This region also includes some depressions and marginal hilly areas. The study focuses exclusively on grasslands in these mountain units, given their ecological importance and role in sustainable land use and management.

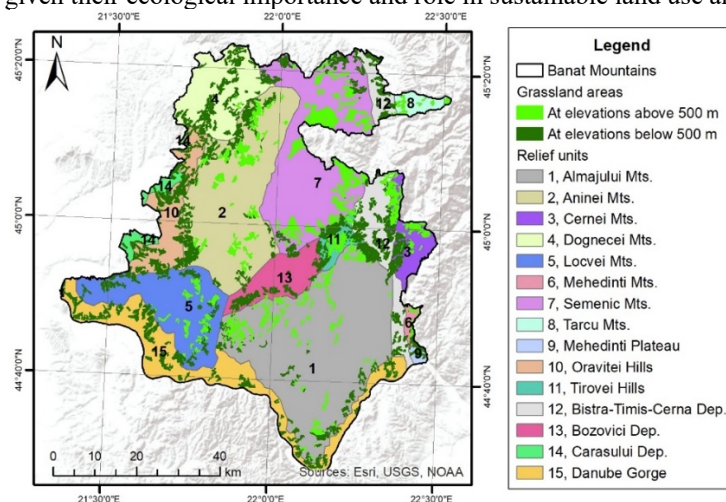


Figure 1. Spatial distribution of grasslands in the Banat Mountains by relief units (Posea, Badea, 1984; Legea nr. 197/2018; Geospatial, 2021; Copernicus Land Monitoring Service, 2022; Ministry of Agriculture and Rural Development, 2025)

In the Banat Mountains, the total area of the meadows taken in the study is 7,834.38 ha (Copernicus Land Monitoring Service, 2022).

2. Research methodology

The research methodology was structured in three main stages, corresponding to the subsections of results: (1) characterization of the altitudinal distribution of grasslands at the scale of the Banat Mountains, (2) delimitation of grasslands located above 500 m altitude and superimposed on protected areas and their analysis at TAU level, respectively (3) evaluation of the vegetation status of the selected grasslands, based on the NDVI index.

1. Characterization of grasslands on elevational steps

In the first stage, the spatial database on the grasslands of the Banat Mountains was created. Vector data on land cover (Copernicus Land Monitoring Service, 2022) and the boundaries of the Banat Mountains (Posea, Badea, 1984; Law no. 197/2018), which were redesigned in the same coordinate system. Based on a Digital Elevation Model (DEM), with spatial resolution at 25 m (EEA, 2016), elevation classes were generated, in accordance with the vertical flooring used in the analysis (54–500 m, 501–700 m, 701–900 m, 901–1100 m, 1101–1300 m, 1301–1500 m, 1501–1700 m, 1701–1980 m). The vector layer with the grassland geometries was intersected with the reclassified altitudinal raster, resulting in grassland polygons framed in each altitudinal step. For each class, the area in hectares and the share in the total grasslands were calculated, the values being then synthesized in tables and graphically represented in the form of an altitudinal pyramid.

2. Delimitation of meadows located above 500 m altitude and superimposed on protected areas

In the second stage, only grasslands located at an altitude of more than 500 m and overlapping with protected natural areas were selected. For this purpose, the vector boundaries of protected areas (Ministry of Environment, Water and Forests, 2025) and grassland areas were used, previously filtered based on altitudinal ranges >500 m. The intersect/overlay GIS operations allowed the extraction of exclusively those grassland polygons located simultaneously within the protected areas and in the targeted altitudinal levels. The resulting area was aggregated at the level of the administrative-territorial unit (TAU), using the vector layer with the limits of the TAU (Geospatial, 2021) and calculating both the absolute values (ha) and the share of each TAU in the total area of selected grasslands.

For the evaluation of the degree of territorial concentration of the pastoral resource, economic-statistical indicators were used. The Herfindahl–Hirschman index (HHI) was calculated, based on the proportions of the grassland area in each TAU in the total of the analyzed subset (Relation 1):

$$HHI = \sum_{i=1}^n p_i^2$$

where: p_i - the share (proportion) of the grassland area in the TAU i in the total analyzed area; n - the total number of TAUs included in the analysis

The Lorenz curve was plotted, along with the Gini coefficient (IMB, SPSS, 2025), to highlight the inequality of distribution. Based on the percentage weights, a classification of the TAUs into four classes of importance (very high, high, moderate, very low) was also made, subsequently graphically represented. These procedures allowed the comparison of the situation between the TAUs and the identification of units with a major role in the conservation of protected mountain grasslands.

3. Assessment of grassland vegetation status based on the NDVI index

In the third stage, the state of the vegetation cover of the grasslands located above 500 m and superimposed on the protected areas was analyzed, through the NDVI vegetation index (Normalized Difference Vegetation Index). Sentinel 2A multispectral satellite imagery (Copernicus Open Access Hub, 2024) was used, from which, after NDVI was calculated according to relation 2:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where: NIR - near-infrared reflectance; RED - the reflectance in the red band.

The NDVI raster was masked with the layer of grasslands selected in the previous stage, so that the analysis would target exclusively the areas of interest. For the entire set of NDVI values, descriptive statistics (minimum, maximum, average, standard deviation) were calculated, and to highlight the variation on altitudinal stages, the values were extracted and aggregated on the altitude intervals used in the previous section.

The differences between the averages on elevational steps were tested by the Kruskal–Wallis nonparametric test, given the deviation from normality of the NDVI distribution, and the significance of the differences between pairs of floors was analyzed by appropriate post-hoc tests (IMB, SPSS, 2025). For the analysis of the structure of the vegetation carpet, the NDVI raster was classified into five classes of coverage (very weak, weak, moderate, high, very high), based on the thresholds established according to the distribution of values and the literature (Ma et al., 2019; Serrano et al., 2024). The areas corresponding to each class were calculated in hectares and transformed into percentages of the total grasslands analyzed, the results being synthesized tabular and

cartographically for the interpretation of the conservation status and agronomic potential of the grasslands in the Banat Mountains.

RESULTS AND DISCUSSIONS

1. Distribution of grassland areas on altitudinal steps in the Banat Mountains

The total area of the grasslands in the Banat Mountains is 70,335 ha, and their distribution on altitudinal steps (figure 2) reflects a net concentration in the lower area. Thus, most of the grasslands are found between 54 and 500 m altitude, where 41,856 ha are present, representing 59.5% of the total. The particular importance of this step is determined by the physical-geographical conditions favorable to agricultural use, such as increased accessibility, lower slopes and the expansion of human settlements, which facilitated the traditional practice of grazing and mowing.

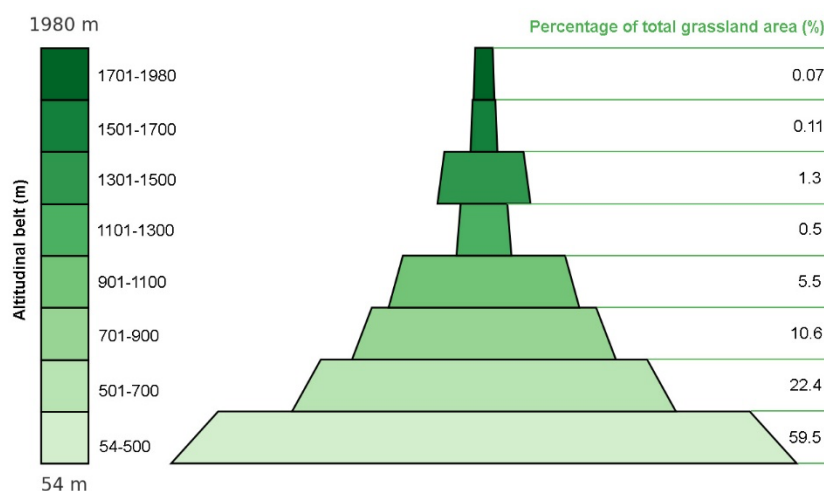


Figure 2. Altitudinal distribution of grasslands in the Banat Mountains expressed as percentage of the total grassland area

Between 501 and 700 m, another 15,763 ha of grassland are concentrated, i.e. 22.4% of the total area, which raises the cumulative proportion of lower steps below 700 m to over 80% of the total. This dominant altitudinal concentration highlights the direct relationship between the intensity of anthropization and the maintenance of grasslands as active agro-ecosystem systems.

A clear decrease in the areas is observed above 700 m, these floors being dominated by forest areas. In the range 701–900 m, grasslands total 7,448 ha (10.6%), and between 901 and 1100 m only 3,894 ha, representing 5.5% of the total, pastoral areas gradually becoming more fragmented by mountain forests (Figure 2).

At higher altitudes, restrictive conditions on grassland vegetation increasingly predominate. Between 1101 and 1300 m there are only 323 ha (0.5%), and between 1301 and 1500 m – 927 ha, respectively 1.3%. In the high mountain area, above 1500 m, grasslands appear only in isolation, totaling 77 ha between 1501–1700 m and 46 ha between 1701–1980 m, i.e. below 0.2% cumulatively. This rarity is explained by lower temperatures, often rocky lithological substrate and reduced bioproductivity, factors that limit the development of vegetation characteristic of grasslands.

Overall, the altitudinal structure of the grasslands in the Banat Mountains reveals a profoundly asymmetrical distribution, in which the lower floor and the submontane peripheral regions concentrate almost the entire pastoral area. This configuration is the result of the combination of natural factors, especially climatic and geomorphological conditions, with the historical use of land for agro-pastoral purposes. At the same time, the decrease of grasslands at high altitudes reflects the expansion of mountain forests, but also the reduced pressure of human activities on alpine and subalpine landscapes.

The analysis of the distribution of grasslands by mountain units in the Banat Mountains (figure 3) highlights a significant concentration of grasslands in the massifs and depressions located in the central and south-eastern sector of the mountainous region. The largest area of grasslands is found in the Semenice Mountains, where 13,004 ha are located, representing 18.49% of the total grasslands, followed by the Anina Mountains (9,946 ha, 14.14%) and the Almaj Mountains (8,009 ha, 11.39%). Together, these three units account for almost 45% of the total grassland area, which confirms their major role in the agro-pastoral structure of the Banat Mountains.

Significant areas are also recorded in the Bistra–Timiș–Cerna Depression (9.56%), the Oravița Hills (7.94%), the Danube Gorge (7.87%), as well as in the Locvei Mountains (6.86%). These territories are

characterised by the high density of traditional rural settlements and a long history of the use of grasslands for pastoral purposes, which has contributed to the maintenance and expansion of these ecosystems.

In the upper part of the pyramid, with a lower weight, are the high mountain units and peripheral areas: the Cerna Mountains (6.37%), the Dognecea Mountains (5.75%) and the Tirovei Hills (4.46%), followed by the Bozovici Depression (3.76%). The grasslands in these units have a more fragmented distribution, being frequently separated from forested areas.

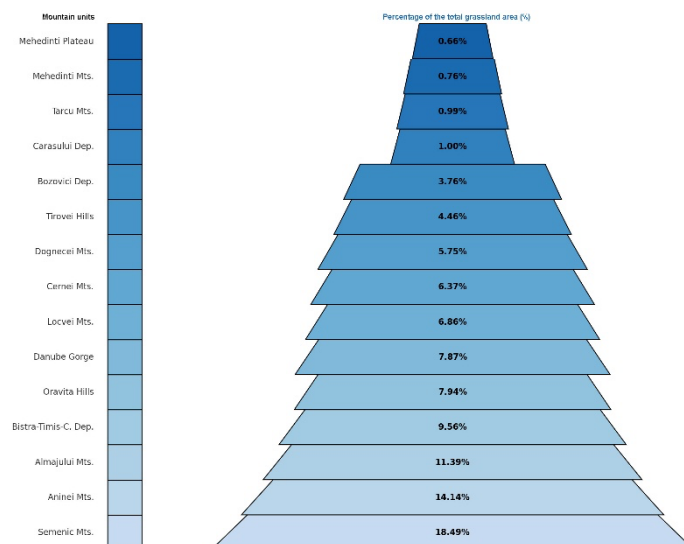


Figure 3. Distribution of grassland areas by mountain units in the Banat Mountains, expressed as a percentage of the total grassland surface

The lowest values are found in the Țarcu Mountains (0.99%), the Mehedinti Mountains (0.76%) and the Mehedinti Plateau (0.66%), where the topographical and climatic conditions favor the development of the forest to a greater extent or formations dominated by rocky substrate appear. These areas represent less than 4% of the total grasslands, which underlines their peripheral character from the perspective of mountain agroecosystems.

The distribution of grasslands in the Banat Mountains is profoundly uneven, with mountain units with low and medium morphological development concentrating over 80% of the total grassland area, while high mountain massifs and plateau areas contribute low percentages, less than 5% each.

2. Delimitation of meadows located above 500 m altitude and superimposed over protected areas

In continuation of the spatial-altitudinal assessment of the grasslands, only those areas located at an altitude of over 500 m and which overlap with the protected natural areas of the Banat Mountains were considered relevant for the study (figure 4). This selection aims to highlight those pastoral ecosystems in a representative mountain context and included in conservation regimes, where natural processes and anthropogenic pressures are managed differently from unprotected areas. Of the total of 70,335 ha of grasslands identified in the region, the area that complies with these cumulative criteria is 7,834.38 ha, which represents a significant segment of the mountain pastoral fund, with high ecological importance and conservation.

The selection of grasslands located over 500 m above the protected natural areas reveals a heterogeneous spatial distribution within the Banat Mountains. The map in Figure 4 indicates that these pastoral areas are not evenly distributed, but are predominantly concentrated in the central and southern part of the region, especially in the area of limestone massifs and intramontane depressions favourable to traditional pastoral activities. The largest areas are found in the Semenec - Cheile Carașului National Park and in the protected area Locvei Mountains - Almajului, while in the northern sector of the Banat Mountains the protected grasslands have a much smaller extension, due to the predominance of forests and the massive mountain relief.

The analysis at the level of the administrative-territorial units highlights a marked contrast between the TAUs. Carașova has the largest area of grasslands included in the protected areas and located at over 500 m (1547.97 ha), representing almost 20% of the total analyzed subset, followed by Gârnici (9.21%), Lăpușnicu Mare (8.30%), Bozovici (6.67%) and Șopotu Nou (6.58%). The first five TAUs account for over 50% of the total area analysed, outlining key areas for the conservation of mountain grassland habitats. On the other hand, there are TAUs such as Oravița, Buchin, Brebu Nou, Coronini or Prigor where the surfaces are minimal, signaling low connectivity and a high potential for ecological vulnerability. The differences between the TAUs are generated

both by the particularities of the relief (petrographic structure, altitude, slope inclination) and by the socio-economic dynamics and history of the traditional use of grasslands.

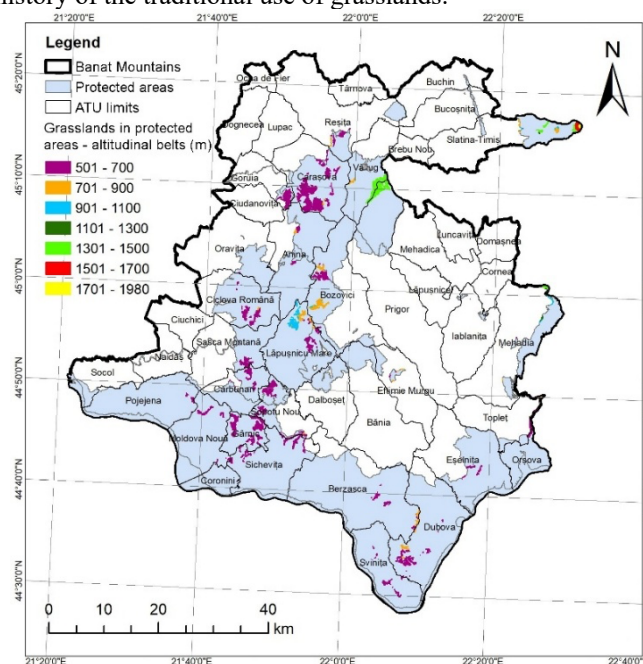


Figure 4. Spatial distribution of grasslands above 500 m located within protected areas in the Banat Mountains, grouped by altitudinal belts ((Posea, Badea, 1984; Legea nr. 197/2018; Geospatial, 2021; Copernicus Land Monitoring Service, 2022; Ministry of Agriculture and Rural Development, 2025; Ministry of Environment, Water and Forests, 2025))

The Lorenz curve (figure 5) confirms an unequal distribution of grasslands above 500 m and overlapping protected areas between the 29 TAUs analysed. The Gini coefficient = 0.53 indicates a significant differentiation, suggesting that a small number of TAUs hold high proportions of the total area analyzed, while most contribute marginally.

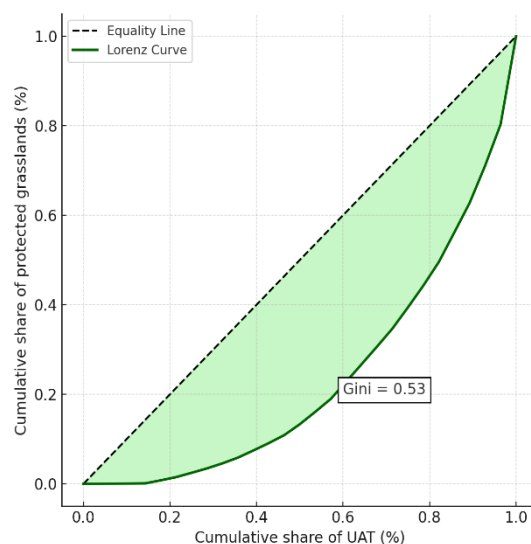


Figure 5. Lorenz curve and Gini coefficient for the distribution of protected grasslands (>500 m) across UAT in the Banat Mountains

In order to quantify the degree of dependence of mountain grassland conservation on certain TAUs, the Herfindahl–Hirschman index (HHI) was calculated, based on the weights of grassland areas >500 m in protected areas. The value obtained ($\text{HHI} \approx 0.08$) falls into the category of low concentration, indicating that, although there are a few dominant TAUs, all protected grasslands remain relatively well distributed at territorial level. This result reduces the risk that changes in land use in a single local administration will disproportionately affect the entire

mountain pastoral heritage. However, the major importance of certain TAUs requires increased attention in conservation planning to ensure the functioning of grassland ecosystems on a regional scale.

The classification of the administrative-territorial units according to the share of grasslands located above 500 m and overlapping the protected areas (Figure 6) highlights a highly hierarchical territorial structure. Carașova is the only TAU in class I (>10%), accumulating almost 20% of the analyzed area, which gives it a crucial role in the conservation of mountain grassland habitats. In class II (5–10%) there are five TAUs, located mainly in the central-southern part of the region (Gârnici, Lăpușnicu Mare, Bozovici, Șopotu Nou, Dubova), contributing together with over 35% of the area. The majority of TAUs ($n = 14$) are in class III (1–5%), characterizing a relatively uniform distribution, but with moderate areas at the local level. On the other hand, 8 TAUs belong to class IV (<1%), indicating a very low importance and an increased vulnerability of the pastoral resource in these territories.

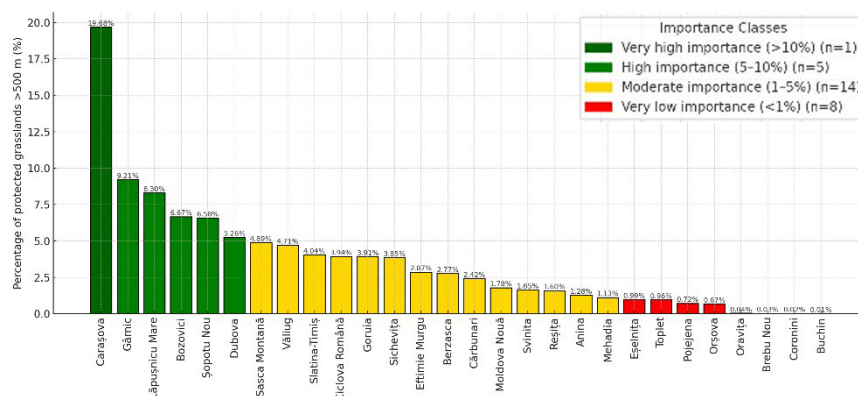


Figure 6. Spatial importance classes of UAT based on their share in the protected grasslands located above 500 m altitude in the Banat Mountains (very high, high, moderate and very low importance)

The distribution by classes confirms the general statistical results provided by the HHI index (0.08) and the Gini coefficient (0.53): although the resource is relatively well distributed on a regional scale, the internal structure shows a moderate polarization towards a small group of TAUs with a dominant role in maintaining the functionality of protected mountain grassland ecosystems.

3. Assessment of the vegetation status of grasslands above 500 m altitude in protected areas based on NDVI

Based on the delimitation and evaluation of the spatial distribution of the mountain grasslands included in the protected areas, the next step is the analysis of the quality of the vegetation in these areas, using the NDVI values to identify the degree of development and vitality of the vegetation carpet (Figure 7).

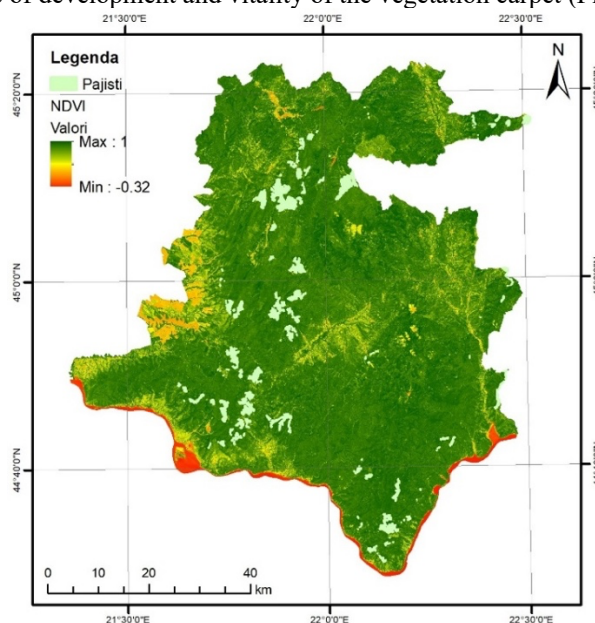


Figure 7. Spatial distribution of NDVI values for grasslands located above 500 m altitude in the Banat Mountains

The analysis of the NDVI index allowed the evaluation of the state of the vegetation cover of the grasslands located above 500 m altitude and superimposed on the protected natural areas of the Banat Mountains (Figure 7). The NDVI values for these areas range from 0.04 to 0.74, with an average of 0.56 and a low standard deviation (0.06), reflecting an evenly distributed and well-developed carpet. These characteristics are specific to mountain and submontane grasslands, where the moderate climatic regime and high level of atmospheric humidity favor a high productivity of biomass.

The NDVI values for the grasslands in the Banat Mountains show significant variations depending on altitude, which is confirmed by the Kruskal–Wallis test ($H = 23.54$; $p < 0.001$). The averages obtained have the highest values at floors 901–1100 m and 1101–1300 m, and the lowest at 1301–1500 m. Post-hoc analyses show that the differences are particularly significant between the submontane and upper mountain floors, suggesting that the vigor of the vegetation carpet varies with altitude, reaching a maximum at the intermediate levels and decreasing in the higher floors.

The NDVI values of the grasslands in the Banat Mountains correlate with the climatic conditions specific to the altitudinal levels. On the 501–700 m floor, the high average temperatures ensure a long growing season, but the variability of rainfall makes the productivity of the grasslands oscillating. At intermediate altitudes (701–1300 m) there is a balanced climate, with moderate temperatures and abundant rainfall, which favors the highest NDVI values and the highest agronomic value of the grasslands. Above 1300 m, although rainfall remains high, the drop in temperatures reduces the growing season and implicitly NDVI, the grasslands being used mainly for summer grazing. On the highest floors (1500–1980 m), the cold climate and short vegetation period severely limit productivity, which makes grasslands have low productivity.

The data resulting from the classification of the NDVI map into five classes (table 1) show a clear distribution of grasslands in the Banat Mountains according to the density and vigor of the vegetation carpet. Grasslands with large and very high cover represent almost 60% of the total area ($46.4\% + 13.2\%$), which confirms the existence of a well-developed vegetation carpet with high agronomic potential on a large part of the territory. About a third of grasslands (33.9%) fall into the moderate category, reflecting areas with medium productivity and stable use, but more sensitive to climatic variations and anthropogenic pressure. On the other hand, grasslands with poor and very poor cover together occupy only 6.2% of the area, which shows that areas with low vegetation are limited in extension. They can be associated with high altitudes, poorer soils or areas degraded by slope processes (erosion, landslides, flows or collapses, etc.).

Table 1. Distribution of grasslands in the Banat Mountains by NDVI-based vegetation cover classes

Classes of grasslands with cover	Surface (ha)	% of total
Very weak	67.56	0.8
Weak	426.94	5.4
Moderate	2657.55	33.9
Large	3632.64	46.4
Very Large	1037.35	13.2

Overall, the NDVI values highlight a favorable general state of the vegetation of the grasslands located above 500 m altitude and overlapping the protected areas, which indicates the maintained ecological functionality of these ecosystems, their important agronomic role and the high potential to support the biodiversity specific to the pastoral habitats of the Banat Mountains.

The results obtained in the Banat Mountains, which show a clear altitudinal concentration of grasslands, a generally good state of vegetation cover in grasslands located in protected areas (especially at intermediate altitudes) and the usefulness of the NDVI index for differentiating cover classes, are consistent with recent studies on the productivity and distribution of mountain grasslands in topographically complex protected areas (Filippa et al., 2022), with research demonstrating the relevance of multi-source remote sensing in assessing the ecological status of mountain grasslands (Ayvazyan et al., 2024), as well as with syntheses showing that NDVI is the most widely used vegetation index in monitoring grasslands and pastoral systems on a regional scale.

Although the study provides a clear picture of the altitudinal distribution, concentration in the TAU and vegetation status of the protected grasslands in the Banat Mountains, it is limited by the exclusive use of the Normalized Difference Vegetation Index (NDVI), which, in the grassland context, may suffer from mixed pixels or moderate resolution of satellite images (as Bangira et al. point out, 2023) and the lack of field validation for all altitudinal levels, which reduces the accuracy of interpretation in complex mountain areas. For the future, it is recommended to integrate hyperspectral sensors or high-resolution imaging, use deep learning-based models, and temporarily extend the analysis to highlight grassland vegetation trends over time (Wang et al., 2022).

CONCLUSIONS

In the Banat Mountains, grasslands are overwhelmingly concentrated at low altitudes, so that over 80% of the total area of 70,335 ha is below 700 m, while altitudes above 1100 m amount to less than 2%, which highlights the strong dependence of these ecosystems on the favorable conditions of the lower mountain level.

The grasslands located at altitudes above 500 m and overlapping the protected areas are unevenly distributed among the ATUs in the Banat Mountains. A small number of administrative units concentrate the majority of the area, which is evidenced by the large areas of Carașova, Bozovici, Sasca Montană and Berzasca, which together form an important central nucleus for the conservation of grassland habitats. In contrast, several TAUs have small areas, often located on a single altitudinal floor, suggesting poorer connectivity and increased vulnerability of these ecosystems.

The results of the grassland analysis based on NDVI show a favourable general condition of the vegetation of grasslands located above 500 m and included in protected areas, where NDVI values vary between 0.04 and 0.74, with an average of 0.56, and almost 60% of the area (46.4% grasslands with high cover and 13.2% with very high cover) indicate a well-developed and functional vegetation carpet, while only 6.2% of the territory has a low level of vegetation cover. In this context, the results obtained underline the importance of continuous monitoring of pastoral resources through quantitative indicators and remote sensing, providing essential information for substantiating effective territorial management and biodiversity conservation measures in the Banat Mountains.

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REFERENCES

1. Ali I.; Cawkwell F., Dwyer E., Green S. Modeling managed grassland biomass estimation by using multitemporal remote sensing data – a machine learning approach. *IEEE J Sel Top Appl Earth Obs Remote Sens* 2017, 10:3254–3264.
2. ArcGIS Documentation, 2022, <https://desktop.arcgis.com/en/documentation/> (accessed on 25.10.2022)
3. Ayvazyan G., Muradyan V., Medvedev A., Khlghatyan A., Asmaryan S. Exploring multisource remote sensing for assessing and monitoring the ecological state of the mountainous natural grasslands in Armenia. *Appl Sci*, 2024, 14:10205.
4. Balata D., Gama I., Domingos T., Proença V. Using satellite NDVI time-series to monitor grazing effects on vegetation productivity and phenology in heterogeneous Mediterranean forests. *Remote Sens*, 2022, 14:2322.
5. Bangira T., Mutanga O., Sibanda M., Dube T., Mabhaudhi T. Remote sensing grassland productivity attributes: a systematic review. *Remote Sens*, 2023, 15:2043.
6. Carbutt C., Henwood W.D., Gilfedder L.A. Global plight of native temperate grasslands: going, going, gone? *Biodivers Conserv*, 2017, 26:2911–2932.
7. Călușeru A.L., Cojocariu L., Horablaga M.N., Bordean D.M., Horablaga A., Cojocariu A., Borozan A.B., Iancu T. Romanian National Strategy for the conservation of biodiversity 2013–2020 – integration of European environmental policies. *SGEM Conf Proc*, 2013, 2:723–728.
8. Chen H., Shao L., Zhao M., Zhang X., Zhang D. Grassland conservation programs, vegetation rehabilitation and spatial dependency in Inner Mongolia, China. *Land Use Policy*, 2017, 64:429–439.
9. Cojocariu L., Horablaga M., Marian F., Bostan C., Mazăre V., Stroia M.S. Implementation of the ecological European network Natura 2000 in the area of grasslands and hayfields. *Res J Agric Sci*, 2010, 42:398–404.
10. Copăcean L., Cojocariu L., Simon M., Zisu I., Popescu C. Geomatic techniques applied for remote determination of the hay quantity in agro-silvo-pastoral systems. *PESD*, 2020, 14(2):89–101, <https://doi.org/10.15551/pesd2020142006>.
11. Copernicus Land Monitoring Service, 2022, Corine Land Cover - CLC. Available online at: <https://land.copernicus.eu/pan-european/corine-land-cover> (accessed on 20.05.2022).
12. Copernicus Open Access Hub, 2025, <https://scihub.copernicus.eu/dhus/#/home> (accesat în martie, 2024).
13. Dong S., Zhang Y., Shen H., Li S., Xu Y. Grassland biodiversity and conservation. In: *Grasslands on the Third Pole of the World*. Springer, Cham, 2023. https://doi.org/10.1007/978-3-031-39485-0_5 European Environment Agency (EEA) (2016) Digital Elevation Model (DEM). Available online: <https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem> (accessed on 13.11.2016).
14. Filippa G., Bayle A., Choler P., Bassignana M., Piccot A., Poggio L., Oddi L., Gascoin S.; Costafreda-Aumedes S.; Argenti G.; Dibari C.; Cremonese E. On the distribution and productivity of mountain grasslands in the Gran Paradiso National Park, NW Italy: a remote sensing approach. *Int J Appl Earth Obs Geoinf* 2022, 115:102718. <https://doi.org/10.1016/j.jag.2022.102718>.

15. Geospatial, 2021, România: seturi de date vectoriale generale. Available online: <http://geospatial.org/vechi/download/romania-seturi-vectoriale> (accessed on 10.11.2021).
16. Gigante D., Angelucci S., Bonini F., Caruso F., Di Cecco V., Donnini D., Morbidini L., Pauselli M., Valenti B., Tassi A., et al. Seminatural grasslands: an emblematic challenge for nature conservation in protected areas. *Land* 2024, 13:386. <https://doi.org/10.3390/land13030386>.
17. IBM SPSS Statistics (versiunea 26), <https://www.ibm.com/products/spss>.
18. Kachler J., Benra F., Bolliger R., et al. Can we have it all? The role of grassland conservation in supporting forage production and plant diversity. *Landsc Ecol*, 2023, 38:4451–4465. <https://doi.org/10.1007/s10980-023-01729-4>.
19. Legea nr. 197/2018 din 20 iulie 2018, Legea muntelui, https://static.anaf.ro/static/10/Anaf/legislatie/L_197_2018.pdf.
20. Ma Q., Chai L., Hou F., Chang S., Ma Y., Tsunekawa A., Cheng Y. Quantifying grazing intensity using remote sensing in alpine meadows on Qinghai-Tibetan Plateau. *Sustainability*, 2019, 11:417.
21. Magiera A., Feilhauer H., Waldhardt R., Wiesmair M., Otte A. Modelling biomass of mountainous grasslands by including a species composition map. *Ecol Indic*, 2017, 78:8–18.
22. Măgureanu M., Sfircoci M., Copăcean L., Cojocariu L. Monitoring the vegetation coverage of the grasslands in the Poiana Ruscă Mountains using different remote sensing indices. *PESD*, 2023, 17:189–199. <https://doi.org/10.47743/pesd202317201>.
23. Ministerul Agriculturii și Dezvoltării Rurale, Harta Grupei de Munți Banat și Poiana Ruscă, <https://azm.gov.ro/harta-grupe-de-munti-banat-si-poiana-rusca/> (accessed on 14.09.2025).
24. Ministerul Mediului, Apelor și Pădurilor, Arii naturale protejate de interes național și internațional, <https://mmediu.ro/portal-gis/date-spatiale/arii-naturale-protejate-de-interes-national-si-international/> (accessed on 14.10.2025).
25. Posea Gr., Badea L. România. Unitățile de relief (Regiunea geomorfologică), Ed. Științifică și Enciclopedică, 1984.
26. Reinermann S., Asam S., Kuenzer C. Remote sensing of grassland production and management — a review. *Remote Sens*, 2020, 12:1949. <https://doi.org/10.3390/rs12121949>.
27. Serrano J., Shahidian S., Paixão L., Marques da Silva J., Paniagua L.L. Pasture quality assessment through NDVI obtained by remote sensing: a validation study in the Mediterranean silvo-pastoral ecosystem. *Agriculture*, 2024, 14:1350. <https://doi.org/10.3390/agriculture14081350>.
28. Simon M., Popescu C.A., Copăcean L., Cojocariu L. Complex model based on UAV technology for investigating pastoral space. *Present Environment and Sustainable Development* 14, 2020, 139-150. 10.15551/pesd2020142011.
29. Simon M., Copăcean L., Popescu C., Cojocariu L. 3D Mapping of a village with a wingtraone VTOL tailsiter drone using pix4d mapper. *Res. J. Agric. Sci*, 2021, 53, 228.
30. Taravat A., Wagner M.P., Oppelt N. Automatic grassland cutting status detection in the context of spatiotemporal Sentinel-1 imagery analysis and artificial neural networks. *Remote Sens*, 2019, 11:711.
31. Verrelst J., Malenovsky Z., Van der Tol C., Camps-Valls G., Gastellu-Etcheberry J-P., Lewis P., North P., Moreno J. Quantifying vegetation biophysical variables from imaging spectroscopy data: a review on retrieval methods. *Surv Geophys* 2019, 40:589–629.
32. Vidican R., Carlier L., Rotar I., Mălinaș A. Exploitation and Management of Low Input Grassland Systems, *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Agriculture*, 2020, Vol. 77, no. 1, pp: 49- 56, DOI:10.15835/buasvmcn-agr: 2019.0031.
33. Wang Z., Ma Y., Zhang Y., Shang J. Review of remote sensing applications in grassland monitoring. *Remote Sens*, 2022, 14:2903. <https://doi.org/10.3390/rs14122903>.
34. Wang Z., Wang J., Wang W., Zhang C., Mandakh U., Ganbat D., Myanganbuu N. An explanation of the differences in grassland NDVI change in the eastern route of the China–Mongolia–Russia economic corridor. *Remote Sens*, 2025, 17:867. <https://doi.org/10.3390/rs17050867>.
35. Xiong Q., Xiao Y., Halmy M.W.A., Dakhil M.A., Liang P., Liu C., Zhang L., Pandey B., Pan K., El Kafraway S.B., et al. Monitoring the impact of climate change and human activities on grassland vegetation dynamics in the northeastern Qinghai-Tibet Plateau of China during 2000–2015. *J Arid Land*, 2019, 11:637–651.
36. Zhang B., Zhang L., Xie D., Yin X., Liu C., Liu G. Application of synthetic NDVI time series blended from Landsat and MODIS data for grassland biomass estimation. *Remote Sens*, 2016, 8:10.
37. Zhao Q., Qu Y. The retrieval of ground NDVI (Normalized Difference Vegetation Index) data consistent with remote-sensing observations. *Remote Sens*, 2024, 16:1212. <https://doi.org/10.3390/rs16071212>.