HIGH NATURE VALUE (HNV) GRASSLANDS IN THE APUSENI MOUNTAINS: A SYNTHESIS OF BIODIVERSITY, TRADITIONAL LAND USE AND CURRENT PRESSURES WITHIN A CULTURAL MOUNTAIN LANDSCAPE

Ioan ROTAR[1] and Ioana GHEȚE[*1],

[1]Faculty of Agriculture, Department of Plant Crops. University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Manăștur street, 3-5, 400372,Romania
**corresponding author: ioana.ghete@usamvcluj.ro*

Abstract

High Nature Value (HNV) grasslands in the Apuseni Mountains represent some of Romania's most valuable agro-pastoral ecosystems, maintained through traditional land-use practices and characterized by high biodiversity. This paper provides a comprehensive synthesis of the distribution, floristic characteristics, ecological dynamics and current pressures affecting HNV grasslands in the Apuseni, integrating results from long-term research conducted in the region. The main grassland types, indicator species and functional groups are described, with particular emphasis on sensitive habitats associated with species such as Arnica montana, Gentiana lutea and other oligotrophic forbs. The analysis highlights the impact of agricultural abandonment, localized intensification, climate change and tourism-related pressures on ecosystem structure and functioning. Results show that extensive management (annual mowing, moderate grazing, reduced organic fertilization) is the only strategy compatible with maintaining the ecological and conservation value of HNV grasslands. Mineral fertilization and abandonment lead to declining diversity, accelerated succession and the loss of sensitive species. The study underscores the importance of an integrated landscape-scale approach that includes support for traditional management, active interventions in abandoned areas and conservation of species-specific habitats for Arnica montana. HNV grasslands in the Apuseni Mountains remain key systems for biodiversity, cultural identity and the socio-economic sustainability of mountain communities.

Keywords: *HNV grasslands; biodiversity; traditional management; abandonment; mountain landscapes; Apuseni Mountains; socio-ecological systems.*

INTRODUCTION

High Nature Value (HNV) grasslands represent one of the most valuable types of agro-pastoral ecosystems in Europe, characterized by high biodiversity, traditional low-input land use and strong integration into the rural culture of mountain regions (Lomba et al., 2014; Herzon et al., 2020). At the European scale, these systems are recognized as major providers of essential ecosystem services—from maintaining floristic and faunistic diversity to regulating ecological processes and supporting cultural landscapes (Bengtsson et al., 2019).

Romania is among the countries with the largest extent of HNV grasslands in the European Union, totaling approximately two million hectares, most of them located in the Carpathian region, where agro-pastoral traditions have persisted uninterrupted for centuries (PNDR,

2019; PNS 2023). Within this context, the Apuseni Mountains constitute a major nucleus of HNV grasslands due to the geographical, climatic and socio-cultural conditions that have favored the development of mosaic landscapes in which forests, grasslands, hay meadows and small agricultural parcels coexist.

The unique character of Apuseni grasslands derives from the long-term interaction between human activities and the mountain environment: low-intensity manual or mechanized mowing, moderate organic fertilization, balanced grazing and intergenerational transmission of traditional practices. These elements have contributed to the maintenance of species-rich plant communities dominated by associations such as *Festuca rubra–Agrostis capillaris* or *Trisetum flavescens*, as well as to the conservation of representative and sensitive species including *Arnica montana, Campanula serrata* and *Gentiana lutea* (Michler et al., 2005; Păcurar et al., 2023).

The Apuseni Mountains do not constitute a homogeneous unit, but rather a complex ensemble of intramontane depressions, karst plateaus, forested ridges and traditional hay meadow and grazing areas, resulting in high variability among HNV grassland types. Within the massif, both oligotrophic and mesotrophic or eutrophic grasslands occur, differentiated by altitude, lithological substrate, grazing pressure and land-use history. Part of this mosaic is included today in protected areas (e.g., Apuseni Natural Park), yet HNV grasslands extend far beyond these boundaries, covering a considerable territory.

In recent decades, socio-economic transformations affecting mountain regions—including the decline in the number of active households, rural depopulation, localized intensification of land use and, conversely, agricultural abandonment—have triggered rapid changes in the dynamics of HNV grasslands. These shifts threaten the stability of traditional agro-pastoral systems and accelerate succession toward closed habitats, leading to the loss of oligotrophic species and degradation of the ecological and cultural values of the landscape.

The aim of this paper is to provide an updated synthesis on HNV grasslands in the Apuseni Mountains, drawing on scientific literature and studies conducted in the region over the past two decades. The paper examines the structure and distribution of habitats, the floristic and ecological characteristics of HNV grasslands, current pressures acting upon them, their socio-economic functions, and the main directions for sustainable management within a mountain cultural landscape undergoing significant transformation.

THE NATURAL FRAMEWORK OF THE APUSENI MOUNTAINS

The Apuseni Mountains represent a complex unit of the Western Carpathians, characterized by high geomorphological, climatic and biogeographical diversity. From a physical–geographical perspective,

the Apuseni stand out through their moderate altitudes, predominantly fragmented relief and a cultural mountain landscape shaped by centuries of interaction between agro-pastoral activities and the natural environment (Păcurar, 2005). This interdependence has generated a mosaic of habitats in which natural and semi-natural grasslands occupy significant surfaces, integrated among forests, traditional agricultural plots and scattered rural settlements.

Geology and landforms

The geology of the Apuseni Mountains is complex, with alternating calcareous formations, conglomerates, crystalline schists and volcanic rocks, which explains the diversity of lithological substrates and, implicitly, the variety of HNV grassland types. Extensive karstic areas, especially in the Central Apuseni, have generated plateaus characterized by shallow soils and oligotrophic edaphic conditions, favorable for the development of plant associations such as *Festuca rubra–Agrostis capillaris*, or for *Nardus stricta* grasslands at higher elevations (Păcurar & Rotar, 2014). In transitional areas between plateaus and broad valleys, mesotrophic grasslands occur, traditionally used as hay meadows.

Climate

The climate of the Apuseni Mountains is temperate-continental with mountain influences, including oceanic effects and considerable spatial variability. Annual precipitation ranges from about 800 mm in lower areas to over 1,200 mm at higher elevations, conditions that support communities with moderate productivity and high floristic diversity. Interannual climatic variability, documented in recent studies on oligotrophic grasslands, shows that fluctuations in temperature and precipitation regimes directly influence species composition—particularly sensitive species such as *Arnica montana*—and may even affect the co-dominance between the species shaping the vegetation structure, such as *Festuca rubra–Agrostis capillaris* (Păcurar et al., 2014).

Soils and edaphic conditions

Grassland soils in the Apuseni are predominantly cambisols, rendzinas and acidic brown soils, with naturally low to moderate fertility, which confers a high potential for maintaining oligotrophic plant communities. Rendzinas on calcareous substrates favor the occurrence of species characteristic of xeromezophilous habitats, while acidic brown soils support the development of oligotrophic grasslands with high specific diversity. This edaphic diversity is a key factor explaining the mosaic of HNV grassland types throughout the massif.

Traditional socio-economic structure

The Apuseni region possesses a distinct demographic and economic structure, characterized by scattered settlements, small household farms, seasonal livestock mobility and an economy historically based on animal husbandry and forest resource use (Plăiaș, 1994; Auch et al., 2001). Grasslands have played a central role in this system, providing the primary fodder resource for cattle and sheep (Rotar et al., 2016), as well as an important source of

medicinal plants, particularly *Arnica montana* (Păcurar, 2005; Michler et al., 2005; Rotar et al., 2010).

This traditional socio-economic structure has contributed to the maintenance of low-input management favorable to biodiversity. However, recent transformations—including depopulation, the decline in the number of active farmers and changes in land-use systems—now threaten the stability of these habitats.

HNV grasslands as a central element of the cultural mountain landscape

The Apuseni Mountains are considered a representative example of Romania's cultural mountain landscape. HNV grasslands form a key component of this system, being distributed across intramontane depressions, intermediate ridges and calcareous plateaus. Habitat diversity reflects the interaction between traditional practices (annual mowing, moderate grazing, organic fertilization) and natural conditions, which explains the persistence of species-rich communities with indicator species of low fertilization and high conservation value.

A well-documented example of grassland structure and dynamics is found within the Apuseni Natural Park, where the Management Plan (2023) provides a detailed picture of land-use patterns. Here, both natural and secondary grasslands form one of the most extensive open-habitat nuclei in the Western Carpathians, while recent assessments (Moș & Brînzan, 2024) highlight an accelerated process of abandonment in certain areas. This local example illustrates a broader trend affecting the entire massif—the rapid transformation of the traditional landscape under the pressure of socio-economic changes.

CHARACTERISTICS OF HNV GRASSLANDS IN THE APUSENI MOUNTAINS

High Nature Value (HNV) grasslands in the Apuseni Mountains reflect remarkable floristic, ecological and functional diversity, shaped both by the varied natural conditions of the massif and by traditional land-management practices. Their distribution is closely linked to the region's agro-pastoral heritage, where extensive mowing and grazing systems have shaped open mountain landscapes for centuries.

Grassland types and floristic particularities

The plant communities characteristic of HNV grasslands in the Apuseni belong mainly to mesotrophic and oligotrophic associations, developing on soils with low to moderate fertility and traditionally managed through annual mowing or moderate grazing. Among the most frequent grassland types are:

- mesotrophic hay meadows dominated by *Trisetum flavescens*,
- oligotrophic *Festuca rubra–Agrostis capillaris* grasslands, widespread throughout the Central Apuseni,

- oligotrophic *Nardus stricta* grasslands characteristic of higher elevations or acidic soils,
- habitats associated with sensitive species such as *Arnica montana*, *Gymnadenia conopsea*, *Campanula serrata*, which indicate reduced fertilization levels and stable traditional use.

Studies conducted in the Apuseni (Gârda et al., 2010; Păcurar et al., 2008) confirm that these meadow types exhibit complex floristic structures, hosting numerous rare species and indicators of low fertilization such as *Briza media*, *Carex pallescens*, *Carlina acaulis*, *Polygala vulgaris*, *Gentiana lutea*, and others. The highest diversity is found in extensively managed grasslands, where traditional interventions maintain habitat openness and prevent succession towards shrublands or young forests.

Biodiversity and characteristic species

HNV grasslands in the Apuseni are renowned for their high concentration of oligotrophic species and for the balanced representation of the three main functional groups: grasses, legumes and forbs. This diversity results from low-input management, which limits the competitiveness of nitrophilous species and allows the coexistence of floristic groups adapted to moderate fertility conditions.

Representative species of high ecological and conservation value include:

- *Arnica montana* – an umbrella species for oligotrophic habitats, extremely sensitive to intensification and eutrophication (Michler et al., 2005; Vârban et al., 2011; Păcurar et al., 2023);
- *Gentiana lutea*, *Plantago media*, *Gymnadenia conopsea*, indicators of extensive management (Păcurar et al., 2025);
- legumes such as *Trifolium pratense*, *T. repens*, and *Medicago lupulina*, occurring in balanced proportions in well-managed grasslands.

In areas where traditional management persists, plant communities reach high alpha-diversity values, and the ratio between Poaceae : Fabaceae : forbs remains within the ranges considered optimal for HNV systems. Conversely, under intensification or abandonment, community structure shifts rapidly, with declines in sensitive species and increases in competitive or nitrophilous ones.

Recent studies on other sensitive species from HNV grasslands in Romania, such as *Adonis vernalis* in native extracarpathian habitats (Păcurar et al., 2025), highlight the potential of density-based quantitative approaches for evaluating population status—approaches that may also be relevant for mountain species such as *Arnica montana*.

Effects of fertilization and land use on diversity

Long-term research in the Apuseni Mountains, including experimental

studies documented in the habilitation thesis, demonstrates how fertilization inputs and agricultural practices influence the floristic composition and functioning of HNV grasslands.

Moderate organic fertilization

Organic fertilization (e.g., 10 t/ha of farmyard manure) maintains or even increases floristic diversity, supporting both moderate-competitive grasses and perennial legumes and a variety of forbs. In certain experiments, the Shannon index increased when moderate manure application was combined with mulching (Rotar et al., 2005; Păcurar et al., 2018).

Intensive mineral fertilization

High mineral inputs lead to:

- rapid declines in species richness,
- increased dominance of nitrophilous grasses (e.g., *Dactylis glomerata*, *Festuca pratensis*),
- reduction of low-fertility indicator species,
- homogenization of the vegetation structure (Rotar et al., 2013).

These effects are incompatible with maintaining HNV character.

Absence of fertilization and minimal management

The unfertilized variant (control) favors the persistence of oligotrophic communities with a high number of indicator species. However, in areas with reduced mowing/grazing pressure, lack of intervention leads to biomass accumulation and triggers succession towards closed habitats (Păcurar & Rotar, 2011).

Agricultural abandonment

Studies indicate that abandonment leads to:

- increases in Cyperaceae and Juncaceae species,
- gradual disappearance of sensitive species (*Arnica*, *Carex pallescens*, oligotrophic forbs),
- changes in the vertical structure of vegetation,
- encroachment by shrubs (*Rubus*, *Juniperus*) and pioneer trees (Păcurar et al., 2015).

These transformations rapidly reduce the conservation value of habitats.

PRESSURES ON HNV GRASSLANDS IN THE APUSENI MOUNTAINS

High Nature Value (HNV) grasslands in the Apuseni Mountains are currently subjected to multiple ecological, socio-economic and territorial pressures. The accelerated transformations of recent decades reflect profound changes in traditional agro-pastoral systems, with direct implications for biodiversity, ecosystem functioning and the stability of the cultural mountain landscape.

The most significant pressures identified in the scientific literature and in studies carried out in the Apuseni region include agricultural abandonment, localized intensification of land use, climate change and various territorial and tourism-related pressures.

Agricultural abandonment — the dominant pressure in the Apuseni Mountains

Grassland abandonment represents the strongest and most widespread pressure on HNV grasslands in the Apuseni, with deep ecological and landscape-level consequences (Păcurar et al., 2015).

Across the massif, the decline in the number of active households, depopulation of mountain villages, reduced livestock numbers and land fragmentation have led to diminished traditional use of grasslands. Abandonment results in biomass accumulation, reduced interspecific competition and rapid onset of secondary succession.

Long-term experiments conducted in the Apuseni show that abandonment drives the transition of oligotrophic grasslands toward early shrub stages (genera *Rubus*, *Crataegus*, *Juniperus*) and subsequently toward natural forest regeneration (Păcurar, habilitation thesis). At the same time, indicator species of open habitats—such as *Arnica montana*, *Thymus pulegioides*, *Festuca rubra*, *Potentilla erecta*, *Carlina acaulis*, *Scorzonera rosea*, among others—gradually decline in frequency or disappear completely (Gârda et al., 2009; Păcurar et al., 2015).

Floristic and ecological analyses in the Apuseni have also identified indicator species for abandonment stages, such as *Silene nutans*, *Plantago media* and various Cyperaceae and Juncaceae species, which establish preferentially in unmown or ungrazed vegetation (Păcurar, 2005; Rotar et al., 2013).

Abandonment affects not only floristic composition but also ecosystem functioning, leading to:

- decreased alpha- and beta-diversity,
- loss of ecosystem services (forage, medicinal plants),
- reduced habitat connectivity,
- degradation of the traditional cultural landscape,
- increased fire risk due to the accumulation of dry biomass.

Land-use intensification

In contrast to abandonment, some accessible areas of the Apuseni have undergone agricultural intensification. Although these zones are limited in extent, their impact on HNV grasslands is substantial.

The main forms of intensification include:

- repeated mineral fertilization (NPK),
- overseeding with competitive species such as *Dactylis glomerata*,
- use of heavy agricultural machinery,
- increased grazing pressure in restricted areas.

Results from experiments conducted in the Apuseni (Morea et al., 2008; Păcurar et al., 2012; Rotar et al., 2014) consistently demonstrate that intensification leads to:

- reduction of floristic diversity through exclusion of sensitive species,
- increased dominance of nitrophilous grasses,
- decreased proportion of perennial legumes,
- altered Poaceae–Fabaceae–forb ratios,

- homogenization of the vegetation cover and loss of conservation value.

Ecologically, intensification produces a predictable type of grassland dominated by a few robust species with high short-term pastoral value but low long-term conservation value.

Climate change — interannual variations with significant ecological impact

Climate exerts a direct influence on the dynamics of HNV grasslands. Studies conducted in the Apuseni Mountains (Păcurar et al., 2014; Sângeorzan et al., 2018) show that interannual variability in precipitation and temperature significantly affects biomass production, floristic composition and species distribution.

Observed effects include:

- reduced productivity in dry years, especially on shallow soils,
- increased dominance of xerophilous species during periods of low precipitation,
- large fluctuations in the abundance of sensitive species such as *Arnica montana*,
- decreased resilience of grasslands in areas already affected by abandonment.

Climate change amplifies the effects of other pressures—particularly abandonment—by accelerating succession toward closed habitats.

Territorial and tourism pressures, and landscape fragmentation

The Apuseni Mountains are among the most visited mountain regions in Romania, and tourism pressure together with infrastructure development has increased significantly in recent decades.

Moș & Brînzan (2024) highlight several risks:

- expansion of tourist facilities into sensitive areas,
- habitat fragmentation caused by roads and utility networks,
- intensified motorized traffic in mountain zones,
- aggressive tourism affecting fragile habitats (e.g., *Arnica montana* sites),
- degradation of the cultural landscape through replacement of managed grasslands with unused or afforested land.

Landscape fragmentation and loss of ecological connectivity reduce the long-term capacity of HNV grasslands to persist, especially in areas dependent on continuous traditional human intervention.

THE SOCIO-ECONOMIC ROLE OF HNV GRASSLANDS IN THE APUSENI MOUNTAINS

High Nature Value (HNV) grasslands in the Apuseni Mountains hold significant socio-economic importance and are deeply embedded in the way of life of mountain communities. For centuries, they have formed the foundation of traditional agro-pastoral systems, providing forage resources, agricultural products, medicinal plants, as well as cultural identity and landscape stability.

Although recent socio-economic transformations have altered the rhythm of their use, the functions fulfilled by these grasslands remain essential both for local communities and for maintaining the characteristic landscape of the Apuseni region.

Pastoral importance and the forage base of mountain communities

In the Apuseni, semi-natural grasslands constitute the central element of traditional livestock-raising systems. Households have historically depended on mesotrophic hay meadows and secondary pastures to provide fodder for cattle and sheep, and this model still persists in many mountain villages (Păcurar, 2005).

Extensive management, characterized by:

- annual mowing,
- moderate grazing,
- reduced organic fertilization,

has endowed these grasslands with moderate productivity but high forage quality, well suited to the needs of local pastoral systems.

Studies on digestibility, chemical composition and the nutritional value of traditional hay from the Apuseni (Dale et al., 2012; Dale et al., 2013) show that extensively managed grasslands provide balanced fodder rich in high-quality fiber, carotenoids and functional compounds important for animal nutrition. These characteristics confirm the high pastoral value of HNV grasslands despite their moderate productivity compared with intensified systems.

In many mountain villages—including Gârda de Sus, Horea, Poiana Vadului and Vidra—grasslands remain essential for sustaining livestock production, even though the number of active households is declining.

Medicinal plant resources and local economic value

HNV grasslands in the Apuseni are among the most important natural sources of medicinal plants in Romania. The most emblematic species is *Arnica montana*, which has high economic value and a long tradition of use.

Studies carried out in the Apuseni (Michler et al., 2005; Păcurar et al., 2023) show that:

- *Arnica montana* is strictly dependent on oligotrophic grasslands,
- it is highly sensitive to mineral fertilization and intensification,
- it is severely affected by abandonment and the encroachment of woody vegetation,
- it represents a significant economic resource for households in areas such as Gârda–Gheţari, Horea and Albac.

The collection, drying and commercialization of *Arnica montana* inflorescences represent a traditional activity with important economic relevance for many families in a mountain context where alternative income sources are limited. In addition, Apuseni grasslands provide several other medicinal resources (e.g., *Colchicum autumnale*, *Viola tricolor*, *Euphrasia roskoviana*), contributing to the diversified socio-economic value of the region.

Cultural and identity-related role of HNV grasslands

HNV grasslands are not only functional ecosystems but also identity-forming elements of the traditional mountain landscape. In the Apuseni, they are deeply integrated into local lifestyles, village organization and the agricultural calendar, contributing to:

- preservation of traditions related to mowing, haymaking and seasonal livestock movements,
- maintenance of seasonal farm structures (hay barns, mountain shelters),
- perpetuation of traditional architecture in pastoral-cultural landscapes,
- transmission of local knowledge across generations (Păcurar, 2005).

The resulting landscape—characterized by a harmonious alternation of forests, grasslands, hay meadows and scattered settlements—is perceived as a defining feature of the Apuseni Mountains and represents one of the region's major tourist attractions.

Fragmentation, abandonment and agricultural intensification affect not only the ecological structure of grasslands but also the cultural heritage of local communities. In the long term, the loss of the mountain cultural landscape may diminish both local identity and the tourist appeal of the region.

Ecosystem services and broader economic value

HNV grasslands provide numerous ecosystem services, including:

- **provisioning services** (fodder, medicinal plants, water),
- **regulating services** (carbon sequestration, erosion control, microclimate regulation),
- **cultural services** (landscape value, recreation, traditional practices),
- **supporting services** (nutrient cycling, soil and biodiversity maintenance).

The stability of these services depends on maintaining traditional low-input management. Abandonment, intensification and climate change reduce the ability of HNV grasslands to deliver these benefits to communities and ecosystems.

MANAGEMENT AND CONSERVATION

Management of HNV grasslands in the Apuseni Mountains is essential for maintaining biodiversity, ecosystem stability and the socio-economic functions of the cultural mountain landscape. These systems are extremely sensitive to changes in land use, and research conducted in the region shows that both intensification and abandonment lead to rapid and often irreversible transformations (Păcurar & Rotar, 2011; Rotar et al., 2013).

The results of long-term studies in the Apuseni allow the development of clear scenarios for adaptive management based on low-input agriculture, preservation of local traditions and conservation of

indicator species characteristic of high natural value.

Extensive (low-input) management — the foundation of HNV maintenance

High Nature Value grasslands are, by definition, ecosystems created and maintained through extensive management. In the Apuseni Mountains, this model is characterized by:

- annual or biennial mowing,
- moderate grazing,
- occasional organic fertilization,
- avoidance of mineral inputs.

Experiments carried out in the Apuseni over more than 20 years confirm that low-input management:

- maintains the highest levels of floristic diversity,
- promotes indicator species of oligotrophic conditions,
- supports the presence of conservation-interest species (e.g., *Arnica montana* and rare forbs),
- ensures a functional balance among grasses, legumes and forbs,
- provides stability in the face of climatic variability.

Extensively managed hay meadows have also demonstrated high resilience during dry years due to their complex vegetation structure and well-developed root systems.

Moderate organic fertilization — a tool compatible with HNV conservation

Experimental results from the Apuseni indicate that moderate organic fertilization (10 t/ha of farmyard manure), applied periodically, is compatible with the maintenance of HNV characteristics.

Benefits of moderate organic fertilization include:

- moderate increases in productivity,
- maintenance of diversity (with increases in Shannon index in some treatments),
- support for Fabaceae and mesotrophic species,
- limitation of nitrophilous grass expansion.

The combination of organic fertilization and mulching, tested in long-term experiments, has resulted in a more balanced vegetation structure, enhanced diversity of perennial species and reduced interannual fluctuations in floristic composition.

However, excessive or overly frequent organic fertilization remains incompatible with HNV status.

Mineral fertilization — intensification effects and loss of HNV value

Mineral fertilizers (NPK), even when applied at moderate doses, lead to:

- reductions in species diversity,
- increased dominance of competitive grasses (*Agrostis capillaris*, *Dactylis glomerata*, *Festuca pratensis*),
- decreases in legumes and oligotrophic species,
- profound alteration of the functional structure of vegetation.

The effects are rapid and predictable: grasslands shift to a different successional trajectory, becoming productive systems but losing their conservation value.

These findings confirm the broader European literature and underline that mineral fertilization is not compatible with the maintenance of HNV grasslands.

Managing abandonment — the need for active intervention

Abandonment is the most frequent issue in the Apuseni and requires an intervention plan adapted to the stage of succession. Observations and floristic analyses show that the first signs of abandonment include:

- accumulation of plant litter (felt),
- decline of oligotrophic species,
- increases in Juncaceae and Cyperaceae species,
- appearance of *Rubus*, *Juniperus*, *Crataegus*,
- reduced abundance of indicator species (*Arnica montana*, *Gymnadenia conopsea*, *Plantago media*, etc.).

Recommended actions for abandoned areas include:

1. Reintroduction of periodic mowing

Ideally annually or biennially, to reduce biomass accumulation.

2. Controlled extensive grazing

With low stocking rates and well-defined grazing periods to prevent overgrazing.

3. Removal of shrubs and pioneer trees

Through mechanical or manual interventions in sensitive zones.

4. Gradual ecological restoration

Especially in oligotrophic grasslands where sensitive species have drastically declined.

Studies show that if intervention occurs in the early years of abandonment, grasslands can significantly recover their structure and functionality.

Protecting species-specific habitats for *Arnica montana*

Arnica montana is a key indicator species of HNV grasslands in the Apuseni. Management of its habitats requires:

- avoiding mineral fertilization,
- avoiding excessive manure application,
- late mowing (after seed maturation),
- moderate grazing pressure,
- protection from woody vegetation encroachment,
- periodic monitoring of populations.

Arnica habitats are among the most sensitive to intensification and abandonment. Any change in traditional management results in direct effects on plant density and vitality.

Integrated landscape-level management

Conservation of HNV grasslands cannot be achieved solely at the plot or farm level. The Apuseni region requires an integrated landscape approach because:

- pressures are unevenly distributed (abandonment in remote areas, intensification in accessible ones),
- habitat connectivity is essential,
- tourism development may conflict with conservation goals,
- socio-economic dynamics directly influence land use.

Effective management should include:

- landscape-scale conservation plans,

- financial support for low-input practices (agri-environment measures, HNV payments),
- involvement of local communities in decision-making,
- integration of scientific research into land-use regulations.

The model proposed by Moș & Brînzan (2024) confirms that the cultural mountain landscape can be maintained only through continuity of traditional use, diversification of income sources and adoption of management adapted to new socio-economic conditions.

CONCLUSIONS

High Nature Value grasslands in the Apuseni Mountains represent an ecological and cultural system of major importance, characterized by high floristic diversity, traditional low-input use and deep integration into the identity of mountain communities. The bibliographic analysis and the results of long-term research carried out in the region confirm that the functioning of these systems depends on the maintenance of traditional agro-pastoral practices, particularly annual mowing, moderate grazing and limited organic fertilization.

The variability of grassland types—from mesotrophic hay meadows to oligotrophic *Nardus stricta* communities and those associated with sensitive species such as *Arnica montana*—reflects the complex interaction between natural conditions and traditional management. The high biodiversity, pastoral value and socio-economic role of HNV grasslands are closely tied to this interdependence.

Current pressures—agricultural abandonment, localized intensification, climate change and landscape fragmentation—strongly affect the stability of these ecosystems. Abandonment, in particular, leads to rapid succession towards closed habitats, with the loss of indicator species and conservation value. Intensification produces opposite but equally problematic effects by homogenizing the vegetation cover and reducing floristic diversity. These processes highlight the vulnerability of HNV grasslands and the need for adapted conservation measures.

Research conducted in the Apuseni Mountains shows that low-input management, based on moderate organic fertilization, controlled grazing and periodic mowing, is the most effective strategy for maintaining grassland biodiversity and ecological functioning. Active interventions in abandoned areas, including shrub removal and the reintroduction of mowing, are essential for restoring sensitive habitats, while the protection of species-specific habitats for *Arnica montana* requires targeted measures and continuous monitoring.

In the context of socio-economic and climatic changes, conservation of HNV grasslands in the Apuseni cannot be ensured solely at the plot level; instead, it requires an integrated landscape-scale approach

that includes adequate financial support, involvement of local communities, coherent territorial planning and the integration of scientific research into management decisions.

This study underscores the necessity of preserving and revitalizing traditional agro-pastoral systems as the foundation for maintaining biodiversity, cultural values and the ecosystem functions of HNV grasslands in the Apuseni Mountains. Their conservation represents not only an ecological responsibility but also a social and economic one, with direct implications for the future of mountain communities and the cultural landscape characteristic of this region.

REFERENCES

1. Auch E., F. Păcurar, A. Goia, 2001, Economic and Technological Aspects of the Agricultural Systems in Ţara moţilor (Gheţar, Gârda de Sus), în Buletinul USAMV, Seria Agricultura, vol. 55-56: 215
2. Balázsi, Á., Pacurar, F., Mihu-Pintilie, A., & Konold, W. (2018). How do public institutions on nature conservation and agriculture contribute to the conservation of species-rich hay meadows? *International Journal of Conservation Science, 9*, 549–564.
3. Balázsi, Á., Păcurar, F., Rotar, I., & Vidican, R. (2016). Alternative management for oligotrophic grassland conservation in the Apuseni Mountains. In *Proceedings*, 678–680.
4. Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., ... & Lindborg, R. (2019). Grasslands — more important for ecosystem services than you might think. Ecosphere, 10(2), e02582.
5. Brinkmann, K., Pacurar, F., & Reif, A. (2009). Secondary succession and fluctuations in meadows of the Apuseni Mountains (Transylvania, Romania) under different fertilisation regimes. *Transylvanian Review of Systematical and Ecological Research, 7*, 41–58.
6. Corcoz, L., Păcurar, F., Pop-Moldovan, V., Vaida, I., Stoian, V., & Vidican, R. (2021). Mycorrhizal patterns in the roots of dominant *Festuca rubra* in a high-natural-value grassland. *Plants, 11*, 112.
7. Dale, L. M., Thewis, A., Boudry, C., Rotar, I., Păcurar, F. S., Abbas, O., Dardenne, P., Baeten, V., Pfister, J., & Fernández Pierna, J. A. (2013). Discrimination of grassland species and their classification in botanical families by laboratory scale NIR hyperspectral imaging: Preliminary results. *Talanta, 116*, 149–154.
8. Dale, L., Fernandez, J. A., Vermeulen, P., Lecler, B., Bogdan, A. D., Pacurar, F., Rotar, I., Thewis, A., & Baeten, V. (2012). Research on crude protein and digestibility of *Arnica montana* L. using conventional NIR spectrometry and hyperspectral imaging NIR. *Journal of Food, Agriculture & Environment, 10*(1).

9. Dale, L., Thewis, A., Rotar, I., Boudry, C., Păcurar, F. S., Lecler, B., Agneessens, R., Dardenne, P., & Baeten, V. (2013). Fertilization effects on the chemical composition and in vitro organic matter digestibility of semi-natural meadows as predicted by NIR spectrometry. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 41*, 58–64.
10. Gaga, I., Pacurar, F., Vaida, I., Plesa, A., & Rotar, I. (2022). Responses of diversity and productivity to organo-mineral fertilizer inputs in a high-natural-value grassland, Transylvanian Plain, Romania. *Plants, 11*, 1975.
11. Gârda, N. T., Păcurar, F., Rotar, I., & Bogdan, A. (2010). The floristic and stational characterisation of the grassland subtype *Agrostis capillaris + Trisetum flavescens* from Apuseni Mountains, Romania. *Research Journal of Agricultural Science, 42*, 454–457.
12. Gârda, N., Rotar, I., Păcurar, F., & Vidican, R. (2009). The role of pastoral landscape in defining the mountainous space in Apuseni Mountains. *Lucrări Ştiinţifice vol. 52. Seria Agronomie*.
13. Gheţe, I., Rotar, I., Pleșa, A., Gheţe, A., Șerban, C., & Stoian, V. (2025). Effect of mineral fertilization on vegetation of HNV pastures in the Apuseni Mountains (Romania). *Plants, 14*, 3564.
14. Gliga, A., Rotar, I., Vidican, R., Păcurar, F., & Balazsi, A. (2013). Evolution of semi-natural grasslands in Europe (bibliographical paper). *Romanian Journal of Grasslands and Forage Crops, 16*, 17–22.
15. Herzon, I., Aakkula, J., & others. (2020). The role of High Nature Value (HNV) farmland in the EU's biodiversity and rural development policies. Journal of Environmental Management, 261, 110214.
16. Lomba, A., Guerra, C., Alonso, J., Honrado, J. P., Jongman, R. H. G., & McCracken, D. (2014). Mapping and monitoring High Nature Value farmlands: Challenges in European landscapes. Journal of Environmental Management, 143, 140–150.
17. Mălinas, A., Rotar, I., Vidican, R., Iuga, V., Păcurar, F., Mălinas, C., & Moldovan, C. (2020). Designing a sustainable temporary grassland system by monitoring nitrogen use efficiency. *Agronomy, 10*, 149.
18. Mălinaș, A., Rotar, I., Vidican, R., Păcurar, F., & Balazsi, A. (2013). Phosphorus in grassland systems. *Romanian Journal of Grasslands and Forage Crops, 16*, 23–29.
19. Marușca, T., Păcurar, F. S., Scrob, N., Vaida, I., Nicola, N., Taulescu, E., Dragoș, M., & Lukács, Z. (2021). Contributions to the assessment of grasslands productivity of the Apuseni Natural Park (ROSCI 0002). *Romanian Journal of Grasslands and Forage Crops, 24*, 23.
20. Marușca, T., Păcurar, F. S., Taulescu, E., Vaida, I., Nicola, N., Scrob, N., & Dragoș, M. M. (2022). Indicative species for the agrochemical properties of mountain grasslands soil from the

Apuseni Natural Park (ROSCI 0002). *Romanian Journal of Grasslands and Forage Crops, 25*, 31.

21. Michler, B., Käthe, W., Schmitt, S., Rotar, I., & Pacurar, F. (2005). Conservation of Eastern European medicinal plants: *Arnica montana* in Romania. In *Proceedings of the XXXXVIII Scientific Symposium – Agriculture and Environment*, Iași.
22. Michler, B., Rotar, I., Pacurar, F., & Goia, A. (2006). Biodiversity and conservation of medicinal plants: A case study in the Apuseni Mountains in Romania. *Bulletin of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca: Agriculture, 62*, 86–87.
23. Michler, B., Rotar, I., Păcurar, F., & Stoie, A. (2005). *Arnica montana*, an endangered species and a traditional medicinal plant: The biodiversity and productivity of its typical grasslands habitats. In *Grassland Science in Europe* (Vol. 10, pp. 336–339).
24. Morea, A., Rotar, I., & Păcurar, F. (2008). Drying possibilities of *Arnica montana* flower heads using local resources. *Hop and Medicinal Plants, 16*(1–2), 210–212.
25. Morea, A., Rotar, I., Vidican, R., & Păcurar, F. (2013). The influence of different types of management upon the floristic structure of grassland systems, with special attention on *Arnica montana* L. *Bulletin UASVM Agriculture, 70*(1).
26. Morea, A., Rotar, I., Vidican, R., Păcurar, F., & Stoian, V. (2008). Changes in vegetation in a *Festuca rubra* meadow in Apuseni Mountains due to organic fertilization. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 36*, 120–124.
27. Moș, A., & Brînzan, C. (2024). Dinamica utilizării pajiștilor și tendințe de abandon în Parcul Natural Apuseni. Romanian Journal of Grasslands and Forage Crops, 30, (în curs de publicare / sau paginile când le știi).
28. Păcurar, F. (2005). *Cercetări privind dezvoltarea durabilă a satului Gheţari, comuna Gârda, prin îmbunătăţirea pajiştilor naturale şi a unor culturi agricole* (Teză de doctorat). USAMV Cluj-Napoca.
29. Păcurar, F. S., Rotar, I., & Vaida, I. (2019). The effects of wild boar disturbances on the agronomical value of semi-natural grasslands. *Romanian Journal of Grasslands and Forage Crops, 20*, 27.
30. Păcurar, F. S., Rotar, I., Michler, B., & Vidican, R. (2008). Traditional management of *Arnica montana* grasslands. In *Grassland Science in Europe* (Vol. 13, pp. 297–300).
31. Păcurar, F., & Rotar, I. (2006). The evolution of biodiversity in a *Festuca rubra* meadow following some specific technological inputs to sustainable agriculture. *Bulletin UASVM Agriculture, 62*, 124–127.
32. Păcurar, F., & Rotar, I. (2011). The effect of low-input upon semi-natural grasslands of Apuseni Mountains. *Lucrări Ştiinţifice – Seria Agronomie, 54*(2).

33. Păcurar, F., & Rotar, I. (2014). *Metode de studiu și interpretare a vegetației pajiștilor*. AcademicPres.
34. Păcurar, F., Balázsi, Á., Rotar, I., Vaida, I., Reif, A., Vidican, R., Rușdea, E., Stoian, V., & Sângeorzan, D. (2018). Technologies used for maintaining oligotrophic grasslands and their biodiversity in a mountain landscape. *Romanian Biotechnological Letters, 23*(10).
35. Păcurar, F., Morea, A., & Gârda, N. (2008). Productivity and biodiversity evolution of *Festuca rubra* grasslands during a seven-year period. *Bulletin UASVM Agriculture, 65*, 5.
36. Păcurar, F., Reif, A., & Rusdea, E. (2023). Conservation of oligotrophic grassland of high nature value (HNV) through sustainable use of *Arnica montana* in the Apuseni Mountains, Romania. In *Medicinal Agroecology*. Taylor & Francis.
37. Păcurar, F., Rotar, I., Balázsi, Á., & Vidican, R. (2014). Influence of long-term organic and mineral fertilization on *Festuca rubra* L. grassland. In *The Future of European Grasslands* (EGF Proceedings), 294.
38. Păcurar, F., Rotar, I., Bogdan, A. D., Vidican, R. M., & Dale, L. (2012). The influence of mineral and organic long-term fertilization upon the floristic composition of *Festuca rubra* L.–*Agrostis capillaris* L. grassland in Apuseni Mountains, Romania. *Journal of Food, Agriculture & Environment, 10*(1).
39. Păcurar, F., Rotar, I., Gârda, N., & Morea, A. (2009). The management of oligotrophic grasslands and the approach of new improvement methods. *Transylvanian Review of Systematical and Ecological Research, 7*, 59.
40. Păcurar, F., Rotar, I., Gârda, N., & Vidican, R. (2009). New directions in the study of oligotrophic grasslands in the mountain area. *Lucrări Științifice – Seria Agronomie* (Iași).
41. Păcurar, F., Rotar, I., Gârda, N., & Vidican, R. (2009). New possibilities for sustainable use of oligotrophic grasslands in Apuseni Mountains. *Bulletin UASVM Agriculture, 66*.
42. Păcurar, F., Rotar, I., Vaida, I., Vidican, R., & Mălinaș, A. (2017). Indicator species of fertilization intensity in mountain grasslands. In *Grassland Resources for Extensive Farming Systems in Marginal Lands* (EGF Proceedings, Vol. 22, pp. 378–381).
43. Păcurar, F., Rotar, I., Vidican, R., & Gârda, N. (2007). Organic fertilization and biodiversity of *Festuca rubra* grasslands. In *Permanent and Temporary Grassland: Plant, Environment and Economy* (EGF Proceedings, Vol. 12, pp. 363–366).
44. Păcurar, F., Rotar, I., Vidican, R., Vaida, I., Pleșa, A., Stoian, V., Tomoș, L., & Gheţe, A. (2025). Density-based assessment of *Adonis vernalis* abundance in native habitats. *Scientific Papers Series A. Agronomy, 68*(1).
45. Păcurar, F., Rotar, I., Pleșa, A., Balázsi, Á., & Vidican, R. (2015). Study of the floristic composition of certain secondary grasslands in different successional stages as a result of abandonment. *Bulletin of*

University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Agriculture, *72*, doi:10.15835/buasvmcn-agr:11165.

46. Plăias I., 1994, Agricultura montană - Societate,Ed. Libris Cluj-Napoca
47. PNDR. (2019). Programul Național de Dezvoltare Rurală 2014–2020 – versiune actualizată. Ministerul Agriculturii și Dezvoltării Rurale, București.
48. Planul Național Strategic 2023-2027 al României (2023). Ministerul Agriculturii și Dezvoltării Rurale, București.
49. Reif, A., Auch, E., Bühler, J., Brinkmann, K., Goia, A. I., Pacurar, F., & Rusdea, E. (2005). Landschaft und Landnutzung im Apuseni-Gebirge Rumäniens. *Carinthia II*, *195*, 161–201.
50. Reif, A., Brinkmann, K., Goia, A., Hoernstein, H., Jaeckle, S., Mohr, B., Păcurar, F., Rotar, I., Rusdea, E., & Schmidt, U. (2008). Differences of development patterns in Central and Eastern European mountain regions: History of land uses and landscapes in the Southern Black Forest (Germany) and the Central Apuseni Mountains (Romania). *Bulletin UASVM Agriculture*, *65*.
51. Reif, A., Rusdea, E., Păcurar, F., Rotar, I., Brinkmann, K., Auch, E., Goia, A., Bühler, J., & Aronsson, M. (2008). A traditional cultural landscape in transformation. *Mountain Research and Development*, *28*, 18–22.
52. Rotar, I., Huygens, D., Vidican, R., Carlier, L., Pacurar, F., & Mălinaș, A. (2013). The effect of low-input grassland management on *Arnica montana* L. species in Apuseni Mountains, Romania. *ProEnvironment/ProMediu*, *6*, 13.
53. Rotar, I., Păcurar, F., Balázsi, Á., Vidican, R., & Mălinaș, A. (2014). Effects of low-input treatments on *Agrostis capillaris L.–Festuca rubra* L. grasslands. In *The Future of European Grasslands* (EGF Proceedings, 17th Meeting, Ghent).
54. Rotar, I., Păcurar, F., Balázsi, Á., Vidican, R., & Mălinaș, A. (2013). The influence of limestone upon the vegetation of *Festuca rubra–Agrostis capillaris* semi-natural grassland type in the mountain regions and on dry matter yield. *Romanian Journal of Grasslands and Forage Crops*, *15*, 31–36.
55. Rotar, I., Păcurar, F., Stoie, A., Gârda, N., & Dale, L.-M. (2010). The evolution of *Arnica montana* L. grasslands depending on the performed management (Apuseni Mountains, Romania). *Scientific Papers Series Agronomy*, *53*, 221–226.
56. Rotar, I., Pacurar, F., Vidican, R., & Morea, A. (2010). The organic-mineral fertilization of a *Festuca rubra* L. grassland in Apuseni Mountains. *Romanian Journal of Grasslands and Forage Crops*, *2*, 55–60.
57. Rotar, I., Păcurar, F., Vidican, R., & Sima, N. (2003). Effects of manure/sawdust fertilisation on *Festuca rubra* type meadows at Gheţari (Apuseni Mountains). In *Optimal Forage Systems for*

Animal Production and the Environment (EGF Proceedings, Vol. 8, pp. 192–194).

58. Rotar, I., Păcurar, F., Vidican, R., & Sima, N. (2005). Impact of the agricultural use on the biodiversity of a *Festuca rubra* meadow. In *XX International Grassland Conference: Offered Papers* (p. 616). https://doi.org/10.3920/978-90-8686-552-9_520
59. Rotar, I., Păcurar, F., Vidican, R., & Sima, N. (2005). The influence of organic and organo-mineral fertilization on biodiversity of the *Festuca rubra* meadows in Apuseni Mountains. *Lucrări Ştiinţifice – Seria Agronomie, 48*, 355–359.
60. Rotar, I., Toth, G., Vaida, I., Mălinaș, A., Stoian, V., & Deac, V. (2016). Ecological and agronomical value of *Festuca rupicola–Bromus erectus* grasslands. *Romanian Journal of Grasslands and Forage Crops, 19*, 81–87.
61. Rotar, I., Vaida, I., & Păcurar, F. (2020). Species with indicative values for the management of mountain grasslands. *Romanian Agricultural Research, 37*, 2067–5720.
62. Rotar, I., Vidican, R., Ciure, A., Păcurar, F., Gliga, A., & Balázsi, A. (2014). The behavior of the mixture formed by *Trifolium pratense, Medicago sativa, Lolium perenne, Festulolium, Phleum pratense* and *Dactylis glomerata* under the influence of mineral fertilization. *Romanian Journal of Grasslands and Forage Crops, 9*, 87.
63. Rotar, I., Vidican, R., Păcurar, F., Mălinaș, A., & Vaida, I. (2016). A forage mixture with red clover in the fourth experimental year. *Bulletin UASVM Agriculture, 73*(2).
64. Rușdea, E., Reif, A., Höchtl, F., Păcurar, F., Rotar, I., Stoie, A., Dahlström, A., Svensson, R., & Aronsson, M. (2011). Grassland vegetation and management—On the interface between science and education. *Bulletin UASVM Agriculture, 68*(1).
65. Samuil, C., Nazare, A.-I., Sîrbu, C., Grigoraș, B., & Vîntu, V. (2025). The impact of fertilizer gradient on high nature value mountain grassland. *Plants, 14*, 3397.
66. Sângeorzan, D. D., Păcurar, F., Reif, A., Weinacker, H., Rușdea, E., Vaida, I., & Rotar, I. (2024). Detection and quantification of *Arnica montana* inflorescences in grassland ecosystems using convolutional neural networks and drone-based remote sensing. *Remote Sensing, 16*, 2012.
67. Sângeorzan, D. D., Rotar, I., Vidican, R., & Păcurar, F. (2018). Romania's diet footprints: Minimum arable land and ecological footprint of consumption (1961–2013). *Romanian Journal of Grasslands and Forage Crops, 20*, 65–74.
68. Sângeorzan, D., Rotar, I., Păcurar, F., Vaida, I., Šuteu, A., & Deac, V. (2018). The definition of oligotrophic grasslands. *Romanian Journal of Grasslands and Forage Crops, 20*, 17.
69. Sima, N., & Păcurar, F. (2002). Quality of forage obtained from a mountain pasture as influenced by harvesting phenophase and management. In *Multi-function Grasslands: Quality Forages,*

Animal Products and Landscapes (EGF Proceedings, Vol. 7, pp. 160–161).

70. Stoian, V., Vidican, R., Crișan, I., Puia, C., Șandor, M., Stoian, V. A., Păcurar, F., & Vaida, I. (2019). Sensitive approach and future perspectives in microscopic patterns of mycorrhizal roots. *Scientific Reports, 9*, 10233.
71. Stoian, V., Vidican, R., Rotar, I., Păcurar, F., & Morea, A. (2014). The development of mycorrhizal fungi in the roots of *Festuca rubra* under the influence of fertilization and maintenance of a constant climate. *Romanian Journal of Grasslands and Forage Crops, 10*, 85.
72. Stoian, V., Vidican, R., Rotar, I., Păcurar, F., & Niște, M. (2014). Analysis of disturbing impact of management on the stability of mycorrhizal colonization in mountain meadow ecosystems. *Romanian Journal of Grasslands and Forage Crops, 9*, 11.
73. Vaida, I., Păcurar, F., Rotar, I., Tomoș, L., & Stoian, V. (2021). Changes in diversity due to long-term management in a high nature value grassland. *Plants, 10*, 739.
74. Vaida, I., Rotar, I., & Păcurar, F. (2017). The cumulative effect of manure on a *Festuca rubra* grassland for 15 years. *Bulletin UASVM Agriculture, 74*(2).
75. Vaida, I., Rotar, I., Păcurar, F., Vidican, R., Pleșa, A., Mălinaș, A., & Stoian, V. (2016). Impact of the abandonment of semi-natural grasslands from Apuseni Mountains. *Bulletin UASVM Agriculture, 73*(2).
76. Vârban, D., Păcurar, F., Vârban, R., & Odagiu, A. (2011). Research concerning the study of germination in *Arnica montana* L. species. *ProEnvironment/ProMediu, 4*, 8.