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Research Article

Detecting trends in the quality and productivity of grasslands by analyzing the historical vegetation relevés: A case study from Southeastern Carpathians, Vlădeasa Mountains (Romania)

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Abstract

Grassland ecosystems are essential for biomass production but are prone to degradation if management practices are inappropriate. Thus, it is necessary to optimize grazing management since the grazing practices and grassland status are interconnected. Herbage mass production and forage quality of the plant species are among the most important factors for grazing livestock performance, grassland carrying capacity, and their sustainable management. We employed optimized methods for the analysis of two historical vegetation datasets (from 1970 and 2008), along with the statistical data on livestock numbers and types from three administrative units within the Vlădeasa Mountains area, in the Romanian Carpathians. We looked for trends in grassland quality and productivity and explored their connections to grazing management descriptors and practices. We identified a small but statistically significant decreasing trend between the two periods in both pastoral value (from 63.80 to 61.43) and productivity (from 10.80 t ha^{-1} to 9.18 t ha^{-1}). The decline in grassland quality and productivity may be associated with the sharp decrease in livestock numbers (from 9,688 LU to 5,085 LU) and the replacement of cattle by sheep as the dominant livestock type. The abandonment of grasslands and traditional practices also increased the deviation from the optimum of the actual stocking rate. This approach can be used as a model for other areas where time-series vegetation data are available from phytosociological literature and/or databases. These insights can be used to design adaptive grazing management plans to optimize grazing management according to the carrying capacity of the grassland ecosystems.

Keywords: forage quality; grazing livestock; herbage mass production; optimum stocking rate; pastoral value; vegetation relevés

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Introduction

Grasslands are semi-natural ecosystems that are essential for biomass production, providing the basis for farming and grazing, but they are prone to degradation if management practices are inappropriate (White *et al.*, 2000; Hopkins and Holz, 2006; Wick *et al.*, 2016; Török *et al.*, 2018a; Roman *et al.*, 2019). To maintain the grassland ecosystem services, it is necessary to optimize grazing management since the grazing practices and grassland features are interconnected (Angerer, 2012; Török *et al.*, 2016a, 2018b).

This requires the analysis of the effects that different grazing practices have on grassland attributes and monitoring the changes that appear through time. Herbage mass production (HMP) and forage quality of the plant species are the most important factors for grazing livestock performance and grassland carrying capacity and respectively for their sustainable management (White *et al.*, 2000; Novák, 2004; Carlier *et al.*, 2009; Soder *et al.*, 2007).

Several studies have been carried out in areas where pastoralism is the main socio-economic activity. They focused on the livestock's preferences regarding forage vegetation characteristics (Reyneri *et al.*, 1994; Meisser *et al.*, 2014) but also on the effects of grazing intensity and livestock type on grassland parameters such as forage value and plant diversity (Liu *et al.*, 2015; Török *et al.*, 2016b; Schmitz and Isselstein, 2020). However, the results are very diverse, depending on the ecological context and grazing parameters. A similar variability can be observed when studying the effects of grazing cessation on grassland parameters. Some studies conclude that it decreases species richness (Janišová *et al.*, 2020), while others (Ford *et al.*, 2012) noticed significantly greater plant richness in grazed *vs* not grazed grasslands while the primary productivity did not differ. Moreover, a recent study (Bohner *et al.*, 2019) concluded that long-term grazing cessation increased above ground phytomass but decreased species richness. Since these influences are so intricate, more case studies are necessary to clarify the effects of grazing practices on grassland parameters. The area of the Vlădeasa Massif from the Romanian Carpathians, where livestock grazing is the main socio-economic activity is very well suited for analyzing such interrelations.

The evaluation of grassland attributes and their changes under the influence of grazing livestock involves long term monitoring, which most often implies a trade-off between accuracy and efficiency. While temporal data series on livestock numbers and types can be compiled from agricultural censuses, data on the spatio-temporal dynamics of grassland quality and productivity for a particular area are seldom available, as part of long-term studies (Käding *et al.*, 2005; Gillet *et al.*, 2016). The analytical methods that involve cutting and weighing of phytomass for the evaluation of the productivity and respectively the chemical analyses for estimation of nutrient content, are accurate but very time and cost demanding (Catchpole and Wheeler, 1992; Angerer, 2012; Peratoner and Pötsch, 2019). As an alternative, in agronomical practice, visual estimation methods (vegetation surveys) are considered comparable with the analytical ones under certain conditions and accurate enough for the evaluation of grassland biomass and forage quality (Catchpole and Wheeler, 1992; Novák, 2004; Angerer, 2012; Marușca, 2019; Peratoner and Pötsch, 2019).

The most frequently used method for visual evaluation of vegetation characteristics, both in agronomy and vegetation science, is the vegetation (floristic) relevé, which assesses the cover of plant species by assigning each species an estimated percentage or an abundance-dominance class (Catchpole and Wheeler, 1992; Cristea *et al.*, 2004; Marușca, 2019; Peratoner and Pötsch, 2019). In the last century, as part of describing and mapping vegetation types, phytosociology experts gathered a huge amount of semi-quantitative data, as vegetation relevés, available either in literature or centralized in databases (Vassilev *et al.*, 2018; Bruelheide *et al.*, 2019), that are valuable resources for estimating the potential productivity of a grassland or for grazing planning. However, most of these relevés estimate species cover-abundance using the seven-grade scale of Braun-Blanquet (1964), which has an inter-class variation range of 20% (class 2) respectively 25% (class 3, 4 and 5). Usually, these classes are transformed into quantitative data for analyses by using the central value of the interval (Cristea *et al.*, 2004), but this practice results in a raw estimation that may be unsuitable for biomass assessment (Marușca, 2019; Peratoner and Pötsch, 2019) since the central value approximates a very large interval, e.g. 25%

(37.5%-62.5%) between the classes 3 and 4. Adjustments of the method have recently been published (Marușca, 2019; Marușca *et al.*, 2019, 2020) that increase the accuracy of the estimation and makes them comparable for the integration of plant agronomical indexes (based on vegetation plot datasets) with statistical livestock data. Thus, the extensive historical phytosociological datasets can be filtered for time series and be efficiently employed to reveal the dynamic interconnection of grazing livestock and grasslands.

We employed these recent adjustments for the analysis of two vegetation datasets acquired cca. 38 years apart from the same area and grassland type and addressed the following questions:

1. Which were the main changes in grassland quality and productivity from the 1970s to 2008 across this region?

2. Can we associate the observed changes in the grasslands quality and productivity descriptors (pastoral value, herbage mass production, optimum stocking rate) to grazing management descriptors and practices (actual stocking rate, deviation from optimum stocking rate, livestock types)?

Materials and Methods

Study site

The evaluation of the changes between 1970 and 2008 regarding the grassland quality and production was carried out in the Romanian Southeastern Carpathians, in the eastern part of the Vlădeasa Mountains, (Figure 1). The analyzed grasslands were located in Poieni, Măргău, and Săcuieu Administrative Territorial Units (ATUs) from Cluj County. These permanent grasslands had covered 11,160 ha in 1970 and until 2010 extended to 12,340 ha. The terrain elevation varies from 600 to 1836 m.a.s.l. (Vlădeasa Peak). The climate of the region is temperate-continental, with high annual precipitation (900 mm to 1,100 mm) and an average temperature of - 3.5 °C during winter and 14.3 °C during the summer. The dominant grassland type in this area is *Festuco rubrae-Agrostietum capillaris* Horvat 1951, that represents more than 85% of the grasslands from the Vlădeasa Mountains (Resmeriță, 1970; Coldea *et al.*, 2008). These grasslands are used mostly as pastures, having a medium plant diversity. Similarly, to most mountain regions from Romania, the predominant socio-economic activities are centered around livestock (mainly cattle and sheep) raising and breeding (Rușdea *et al.*, 2005; Janišová *et al.*, 2020).

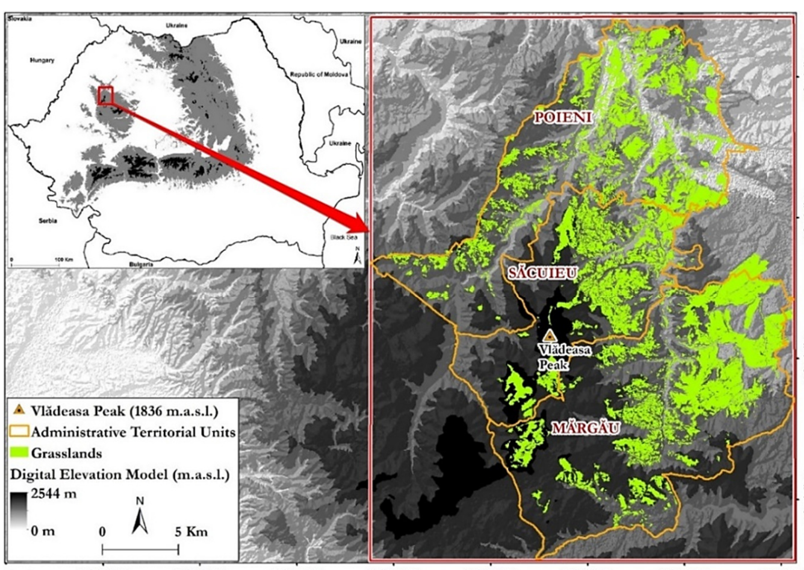

Figure 1. The analysed grasslands within the Administrative Territorial Units from the Vlădeasa Mountains area

Data and analysis

Trends regarding the grassland quality and production were assessed using historical vegetation relevés compiled from literature, from the *Festuco rubrae-Agrostietum capillaris* plant community. The relevés were carried out in two different time periods: the synoptic table A1970, comprises 50 phytosociological relevés performed between 1959-1969 (Resmeriță, 1970) while the synoptic table B2008, comprises 46 relevés from 2004-2008 (Coldea *et al.*, 2008). The relevés included in both datasets were carried out according to the phytosociological method by using the seven-grade cover-abundance scale of Braun-Blanquet (1964). The sampling plots were square, each having a 25 m^2 area.

For each of the two datasets, at first, we transformed the cover-abundance interval and absolute frequency provided in the synoptic tables into the cover proportion for each species (CP) as percentage, according to the method proposed by Marușca (2019) as presented in Supplementary material - Table S1. In order to compare the two datasets having different overall vegetation covers, the CP of each species was standardized, using the formula presented in Peratoner and Pötsch (2019).

$$SCP = \frac{CP}{CV} \times 100 \qquad (1)$$

Where:
SCP = Standardized Cover Proportion of a species (%)
CP = Cover Proportion of a species (%)
CV = Total Cover of Vegetation (%)

$$CV = \sum_{i=1}^{n} CP_i \qquad (2)$$

Subsequently, the grassland quality was estimated through its forage value for the grazing livestock according to the categories presented in Supplementary Material - Table S3. For calculating the pastoral value (PV) we assigned the agronomic Forage Index (FI) and calculated the forage value for each plant species according to Păcurar and Rotar (2014), who adopted the specific forage indices of plant taxa from Central and Western Europe and adjusted them for the ecological conditions of Romania. Details regarding the FI categories are provided in the Supplementary Material - Table S2. The PV of the grassland was determined by the equation of Daget and Poissonet (1971), adapted to the specific FI used, whose maximum value is 9.

$$PV = \frac{\sum_{i=1}^{n}(SCP_i \times FI_i)}{9} \qquad (3)$$

Where:
PV - Pastoral Value (0-100)
SCP - Standardized Cover Proportion of a species (%)
FI - Forage Index

For the indirect estimation of the grassland's Herbage Mass Production (HMP), we employed a recently validated method (Marușca, 2019). It is based on the Herbage Index (HI) of each forage species (Marușca, 2016) and it involves the calculation of a Productivity Index (PI) for the entire grassland plot. According to the PI value, different conversion factors were used to finally obtain the HMP in tones/hectare (t ha^{-1}) of the grasslands. For the values of HI, PI and the conversion factors see the Supplementary Material - Table S4 and Table S5. The equation for determining PI for a grassland is:

$$PI = \frac{\sum_{i=1}^{n}(SCP \times HI_i)}{100} \quad (4)$$

Where:
PI - Productivity Index
SCP - Standardized Cover Proportion of a species (%)
HI - Herbage Index

This workflow for HMP evaluation was previously validated against analytical methods of cutting and weighing in the permanent grasslands from Măcinului Mountains National Park (Marușca *et al.*, 2019) and other grasslands from Dobruja (Marușca, 2019; Marușca *et al.*, 2019, 2020).

To test the statistical significance of the observed differences we used the nonparametric paired Wilcoxon signed-rank tests since the grassland dataset parameters (the relative contribution of species to PV and PI) did not meet the assumption of normally distributed differences between paired observations.

Based on the HMP, we calculated the Optimum Stocking Rate (OSR), measured in Livestock Units/hectare (LU ha^{-1}) according to the formula (Marușca *et al.*, 2014):

$$OSR = \frac{HMP}{Dr \times Gd} \quad (5)$$

Where:
OSR - Optimum Stocking Rate (LU ha^{-1})
Dr - the Daily requirement of green forage, 65 kg for 1 LU
Gd - the total number of the Grazing days/season (140 days for the study area)

The optimum grazing season in the sub-montane and montane area of the Romanian Carpathians encompasses 175 days between 400-600 m altitude and decreases by 7.5 days for each 100 m increase in elevation, down to 100 days between 1600-1800 m (Marușca *et al.*, 2016). The reference unit used for the calculation of Livestock Units (1 LU) is the grazing equivalent of one adult dairy cow producing 3000 kg of milk annually, without additional concentrated foodstuffs.

The Stocking Rate (SR), measured in LU ha^{-1}, was derived from the official reports on the livestock numbers by using the officially recommended livestock unit conversion coefficients (MADR, 2013; Marușca *et al.*, 2014). The livestock numbers and grassland area within the three communes (Poieni, Mărgău, Săcuieu) for the year 1970 were obtained from the Agricultural Direction of the Cluj County. The more recent data for the analyzed period (2008), were extracted from the General Agricultural Census datasets (INS, 2011).

In order to associate the changes regarding grassland quality and productivity to grazing management practices, the OSR, SR and the differences between them were assessed for the two different time periods. These values were subsequently compared with the actual stocking rate (SR) from the area during the two analyzed time periods.

The taxonomic nomenclature for vascular plants follows the Euro+Med Plant Database (*http://www.theplantlist.org/*) and The Plant List (*http://ww2.bgbm.org/EuroPlusMed*).

Results and Discussion

The results regarding the SCP of the plant species, its changes between 1970 and 2008 and the values of the FI and HI are presented in Table 1.

Table 1. The Standardized Cover Proportion (SCP), its changes between the two time periods and the values of the Forage Index (FI) and Herbage Index (HI) for each species. P-*Poaceae*; F-*Fabaceae*: O-Other plant families

Species name	SCP - A1970 (%)	SCP - B2008 (%)	Absolute difference B-A (+/-)	Botanical family	FI	HI
Decreasing cover						
Festuca rubra	29.32	18.21	-11.10	P	7	6
Alchemilla vulgaris	4.34	0.02	-4.32	O	6	4
Trifolium pratense	2.73	1.19	-1.54	F	7	5
Prunella vulgaris	1.67	0.33	-1.34	O	4	2
Trifolium repens	1.96	0.64	-1.32	F	8	7
Carlina acaulis	1.75	0.45	-1.30	O	3	0
Leontodon hispidus	1.31	0.08	-1.23	O	5	3
Campanula serrata	1.07	0.05	-1.02	O	3	0
Arabidopsis halleri	0.78	0.00	-0.78	O	3	0
Agrostis capillaris	27.62	26.94	-0.68	P	7	5
Trifolium montanum	2.14	1.49	-0.65	F	7	4
Rhinanthus minor	2.31	1.87	-0.43	O	3	0
Veronica officinalis	0.47	0.05	-0.42	O	4	4
Scorzoneroides autumnalis	0.55	0.24	-0.31	O	5	3
Achillea distans	0.29	0.02	-0.27	O	6	3
Pilosella officinarum	0.32	0.09	-0.23	O	4	1
Euphrasia rostkoviana	0.22	0.00	-0.22	O	3	0
Hieracium maculatum	0.12	0.00	-0.12	O	4	2
Fragaria vesca	0.14	0.03	-0.11	O	5	1
Veronica chamaedrys	0.29	0.18	-0.10	O	4	2
Leucanthemum vulgare	0.57	0.47	-0.10	O	5	5
Increasing cover						
Nardus stricta	0.78	4.95	4.17	P	3	0
Briza media	0.25	3.90	3.66	P	5	2
Anthoxanthum odoratum	2.94	5.45	2.52	P	5	3
Lotus corniculatus	0.27	1.71	1.44	F	8	6
Plantago lanceolata	0.17	1.48	1.31	O	6	1
Thymus odoratissimus	0.01	1.28	1.27	O	4	2
Trisetum flavescens	0.01	1.22	1.21	P	8	6
Centaurea phrygia	0.00	1.12	1.12	O	3	0
Anthyllis vulneraria	1.48	2.27	0.80	F	6	5
Pimpinella saxifraga	0.07	0.87	0.80	O	5	3
Luzula campestris	0.10	0.88	0.78	O	4	2
Avenella flexuosa	0.04	0.78	0.74	P	4	3
Carex pallescens	0.05	0.77	0.72	O	4	3
Holcus lanatus	0.14	0.81	0.67	P	6	6
Polygala vulgaris	0.20	0.71	0.51	O	4	1
Hypericum maculatum	0.17	0.65	0.48	O	3	0

Thymus pulegioides subsp. *pannonicus*	0.00	0.44	0.44	O	4	2
Cynosurus cristatus	0.12	0.53	0.41	P	7	4
Cytisus albus	0.00	0.37	0.37	F	3	0
Pteridium aquilinum	0.00	0.35	0.35	O	1	0
Filipendula vulgaris	0.00	0.33	0.33	O	5	4
Genista sagittalis	0.11	0.44	0.33	F	3	0
Hypochoeris maculata	0.06	0.39	0.33	O	3	0
Achillea millefolium	0.46	0.76	0.30	O	6	4
Genista tinctoria	0.10	0.39	0.29	F	3	0
Medicago lupulina	0.00	0.28	0.28	F	8	3
Securigera varia	0.01	0.29	0.28	F	1	0
Cruciata glabra	0.00	0.27	0.27	O	3	0
Potentilla erecta	0.10	0.33	0.23	O	5	2
Linum catharticum	0.12	0.35	0.23	O	3	0
Galium verum	0.16	0.38	0.22	O	5	4
Ranunculus polyanthemos	0.11	0.33	0.22	O	4	4
Deschampsia caespitosa	0.02	0.24	0.22	P	3	0
Thymus bihorensis	0.00	0.21	0.21	O	4	2
Vicia cracca	0.00	0.20	0.20	F	7	6
Dactylis glomerata	0.00	0.19	0.19	P	9	8
Ochlopoa annua	0.04	0.21	0.17	P	7	2
Helianthemum nummularium	0.01	0.18	0.17	O	4	2
Stachys officinalis	0.09	0.23	0.14	O	4	5
Trifolium alpestre	0.06	0.20	0.14	F	6	3
Arnica montana	0.07	0.20	0.13	O	4	3
Potentilla incana	0.00	0.12	0.12	O	3	0
Danthonia decumbens	0.16	0.28	0.12	P	4	3
Campanula patula	0.10	0.21	0.11	O	3	0
Lembotropis nigricans	0.00	0.11	0.11	F	3	0
Symphytum officinale	0.00	0.11	0.11	O	5	5
Knautia arvensis	0.11	0.22	0.11	O	4	4
Centaurea arenaria	0.00	0.10	0.10	O	3	0
Galium valdepilosum	0.00	0.10	0.10	O	3	0
Indifferent species						
Dorycnium pentaphyllum subsp. *herbaceum*	0.01	0.10	0.09	F	3	0
Dianthus carthusianorum	0.12	0.21	0.09	O	3	0
Scabiosa ochroleuca	0.04	0.12	0.08	O	4	4
Taraxacum officinale	0.11	0.19	0.08	O	6	1
Trifolium pannonicum	0.07	0.14	0.07	F	7	5
Silene nutans	0.10	0.16	0.06	O	3	0
Crepis biennis	0.01	0.07	0.06	O	4	5
Stellaria graminea	0.19	0.24	0.05	O	1	0

Plantago media	0.15	0.20	0.05	O	6	2
Calamagrostis arundinacea	0.06	0.10	0.04	P	3	0
Sanguisorba minor	0.01	0.05	0.04	O	6	3
Ajuga genevensis	0.01	0.04	0.03	O	4	2
Fragaria viridis	0.01	0.03	0.02	O	4	1
Luzula luzuloides	0.17	0.18	0.01	O	3	0
Poa pratensis	0.05	0.05	0.00	P	8	6
Potentilla argentea	0.02	0.02	0.00	O	4	2
Thymus pulegioides	0.11	0.11	0.00	O	4	2
Hypochoeris radicata	0.17	0.17	0.00	O	3	0
Trifolium campestre	0.06	0.05	-0.01	F	7	2
Carex sempervirens	0.01	0.00	-0.01	O	4	2
Polygonum aviculare	0.01	0.00	-0.01	O	5	3
Pilosella aurantiaca	0.07	0.06	-0.01	O	4	2
Crataegus monogyna	0.02	0.01	-0.01	O	3	0
Cytisus hirsutus	0.02	0.00	-0.02	F	3	0
Rumex acetosa	0.45	0.42	-0.03	O	4	5
Trifolium dubium	0.04	0.00	-0.04	F	6	2
Achillea collina	0.04	0.00	-0.04	O	6	5
Schedonorus pratensis	0.05	0.01	-0.04	P	9	8
Plantago major	0.05	0.01	-0.04	O	5	3
Achillea distans subsp. stricta	0.05	0.00	-0.05	O	6	6
Carex leporina	0.09	0.03	-0.06	O	3	0
Carum carvi	0.11	0.04	-0.07	O	6	3
Trifolium medium	0.07	0.00	-0.07	F	6	4
Trifolium aureum	0.07	0.00	-0.07	F	6	4
Antennaria dioica	0.09	0.01	-0.08	O	4	2
Potentilla aurea	0.10	0.01	-0.09	O	4	1
Infrequent species						
Gentianella lutescens	0.00	0.06	0.06	O	3	0
Tragopogon pratensis	0.00	0.05	0.05	O	5	5
Daucus carota	0.00	0.04	0.04	O	6	5
Vicia sepium	0.00	0.03	0.03	F	7	5
Salvia pratensis	0.00	0.02	0.02	O	4	4
Brachypodium pinnatum	0.00	0.01	0.01	P	5	7
Elytrigia intermedia	0.00	0.01	0.01	P	5	7
Brachypodium sylvaticum	0.00	0.01	0.01	P	5	7
Bromus hordeaceus	0.00	0.01	0.01	P	3	0
Lathyrus pratensis	0.00	0.01	0.01	F	7	6
Trifolium arvense	0.00	0.01	0.01	F	4	2
Convolvulus arvensis	0.00	0.01	0.01	O	7	6
Lysimachia vulgaris	0.00	0.01	0.01	O	4	7
Origanum vulgare	0.00	0.01	0.01	O	4	4

The differences in grassland quality and productivity between 1970 and 2008 are presented in Table 2. Both the PV and the PI show a relatively small but statistically significant decrease. The PV decreases from 63.80 in the 1970s to 61.43 in the period around 2008 (Table 2, the paired Wilcoxon signed-rank test, $p < 0.05$).

Table 2. The results regarding the grasslands quality and productivity descriptors between old (1970) and more recent relevés (2008)

Grassland's quality and productivity descriptors	A1970	B2008	P- values
Standardized total vegetation cover (%)	91.92	94.84	
PV - Pastoral Value	63.80	61.43	**0.018***
PI - Productivity Index	4.15	3.67	**0.021***
HMP - herbage mass production (t/ha)	10.80	9.18	
Grassland quality class**	Good	Good	
Grassland productivity class***	Average-Good	Average	

P-values are given for paired two-tailed Wilcoxon signed-rank test. *p < 0.05, Significant results in bold. **for the grassland quality classes see Supplementary Material - Table S3. **for the grassland productivity classes see Supplementary Material - Table S5.

The detected trend is mainly caused by the 11.1% decrease in the cover of *Festuca rubra*, a grass species with both high coverage and good forage value. The cover of *Agrostis capillaris*, the other co-dominant grass species remains relatively unchanged. Although two other grass species, *Anthoxanthum odoratum* and *Briza media* increased their added cover with cca. 6%, their forage value is mediocre. Also, *Nardus stricta*, a species that depreciates the forage quality, has increased its coverage by more than 4% (Table 1). The *Fabaceae*, important for soil trophicity as they fix atmospheric nitrogen, followed the same trend of decreasing PV, since the cover of three most widespread species (*Trifolium pratense*, *T. montanum* and *T. repens*) with good/very good forage value decreased by half. *Lotus corniculatus*, with very good forage value and *Anthyllis vulneraria*, with average forage value increased their cover (Table 1) but without being able to compensate the PV. We have noticed that the species *Alchemilla vulgaris,* an important forage species for these grasslands both as PV and PI, was relatively well represented in 1970 (over 4% SCP) and almost disappeared until 2008. Also, the toxic species (*Securigera varia* and *Stellaria graminea*) have increased their cover and a new expansive species, *Pteridium aquilinum* (which is also toxic for humans and livestock), has appeared in the last period (Table 1). However, their presence (as total cover) is not yet substantial in these grasslands.

Overall, the cover of species with good and average forage value decreased by almost 15% while the species with mediocre and poor forage value doubled their cover. The cover of species that depreciate the grassland value almost doubled while the toxic species expanded to more than three times their original coverage (Supplementary Material - Table S6). There is a small but significant decreasing trend in the coverage of the species with good forage value, but in 2008 the grasslands remain in the same grazing quality class as in 1970, of good pastoral value, although very close to the lower limit of this class (Table 2; Supplementary Material - Table S3).

In what regards the HMP of the forage species, it decreased by 15%, from 10.80 t ha^{-1} in the 1970s to 9.18 t ha^{-1} around 2008 (Table 2, paired Wilcoxon signed-rank test, $p < 0.05$). A large part of it is explained by the decrease in the cover of *Festuca rubra*, the only grass species with high cover and good biomass production. The green biomass of *Agrostis capillaris* decreased only slightly while the expansion of *Anthoxanthum odoratum* and *Briza media* brought only a small increase in the HMP of the grasslands. Also, the increase in cover of *Nardus stricta* has not contributed to the HMP since it is not a forage species. For the *Fabaceae*, the decrease in biomass production was not so important because the decline of *Trifolium pratense*, *T. montanum* and *T. repens* was partially compensated by the expansion of *Lotus corniculatus* and *Anthyllis vulneraria*.

Following the decrease in biomass production, the grasslands that were included, in 1970, in the average-good productivity class, have dropped, around 2008, to the average productivity class.

Along with grassland productivity, the OSR has also changed between the two analyzed datasets. In 1970, the grassland's productivity had indicated an OSR of 1.19 LU ha^{-1}, while around 2008 it decreased to 1.01 LU ha^{-1} (Table 3).

Since the analyzed grassland type (*Festuco rubrae-Agrostietum capillaris*) covers only about 85% of the grassland area of the three ATUs, the remaining 15% of the total grassland area, considered unsuitable for grazing (comprising mainly matgrass-*Nardus stricta*), was excluded from the actual productivity calculation. Therefore, the grassland areas considered suitable for grazing are 9,486 ha for 1970 and 10,489 ha for 2008 (Table 3). The obtained OSR and the corrected areas were used to estimate the optimum number of LU for the available grassland area in the three ATU's. For 1970 the optimum LU number was 11,288 and decreased to 10,594 LU until 2008, although the available grassland area increased with 1,003 ha, mainly because of arable land abandonment but possibly also from forest or shrub clearings. Therefore, the deviation from optimum increased between the two observation periods. Thus, in 1970, the livestock number in the area of the 3 ATU's was 9,688 LU, resulting in an understocking of 1,600 LU while in 2008 the livestock number dropped to 5,085 LU, resulting in an understocking of 5,509 LU (Table 3). We need to note that the understocking might be even more severe since although we excluded the area of *Nardus stricta* dominated grasslands from the productivity calculation, livestock grazing still occurs, to some extent, on this vegetation type. Also, since the original relevés were focused on the qualitative evaluation of plant species composition and not on the quantitative assessment of biomass, the sampling design might induce some biases from the biomass point of view. However, although these issues may, to some extent, decrease accuracy, this method is efficient and makes use of the great wealth of historical vegetation data.

The understocking mentioned above was caused by both the sharp decrease in livestock numbers in the studied period (from 24,684 to 18,619) and the increase in grassland area. Such grazing abandonment is known to strongly impact floristic composition and biomass (Peco *et al.*, 2006; Steinshamn *et al.*, 2018). This abandonment trend, accompanied by life-style changes of the local farmers, is consistent with that observed in other rural regions in Romania (Rușdea *et al.*, 2005; Dahlström *et al.*, 2013; Janišová *et al.*, 2020) and several other European countries (Meisser *et al.*, 2014; Török *et al.*, 2016a, 2018a).

Temperature increases and a lengthening of dry spells was reported for the 1961-2010 period, that may also intensify these changes. An increase of about 2 °C of average temperature during summer, winter and spring was found (Busuioc *et al.*, 2015). Similar results were shown for several temperature extremes such as maximum and minimum daily temperatures and a significant increase was found in the maximum duration of dry spells during summer in the above-mentioned period (MEF, 2010).

Table 3. Changes of the grazing management descriptors between 1970 and 2008

Grazing management descriptor	A1970	B2008	B-A difference	B-A %
Total grassland area (ha)	11,160	12,340	1,180	11
Festuco rubrae-Agrostietum capillaris grassland area (ha)	9,486	10,489	1,003	11
*Livestock (LU)	9,688	5,085	-4,603	-48
Optimum livestock (LU)	11,288	10,594	-694	-6
Stocking rate (LU ha^{-1})	1.02	0.48	-0.54	-53
Optimum stocking rate (LU ha^{-1})	1.19	1.01	-0.18	-15
Deviation from the optimum livestock (LU)	-1,600	-5,509	-3,909	244

*Actual livestock for the area of the three ATU's

Regarding livestock types, only the number of sheep and goats remained relatively similar for the two periods (2,213 vs. 2,227 LU's), while the other livestock types reduced their numbers, resulting in an overall decrease of 4,603 LU's and an important change in the predominant livestock type. In 1970, 70% of the LU's were cattle, while sheep and goats added together to about 23%. Around 2008, cattle numbers were much lower, accounting for only 44% of the LU's, while sheep and goat percentages in the LU's almost doubled, also reaching 44%. Although the proportion of *Equidae* relative to the other livestock types increased with time, their absolute numbers dropped from 897 to 790 (Table 4).

Table 4. Changes in livestock types and predominance between 1970 and 2008

Livestock	A1970			B2008			B-A Difference		B-A %
	Number of livestock		%	Number of livestock		%	Number of livestock		%
	Heads	LU*		Heads	LU		Heads	LU	
Cattle	9,035	6,776	70	2,985	2,239	44	-6,050	-4,538	-26
Sheep	14,082	2,112	22	13,313	1,997	39	-769	-115	17
Goats	670	101	1	1,531	230	5	861	129	3
Equidae-horses	804	643	7	729	583	11	-75	-60	5
Equidae-donkeys	93	56	1	61	37	1	-32	-19	0
TOTAL	24,684	9,688		18,619	5,085		-6,065	-4,603	

*Coefficients used for conversion of livestock numbers into livestock units, were: 0.75 for cattle, 0.15 for sheep and goats, 0.8 for horses and 0.6 for donkeys (MADR, 2013; Marușca *et al.*, 2014).

The decrease in cattle numbers by more than half (in this traditional cattle raising and breeding area) and the subsequent predominance of sheep meant that some grasslands that had been grazed by cattle in 1970, were, until 2008, either grazed by sheep or abandoned. Several studies indicate that sheep grazing decreases grassland taxonomic and functional diversity, together with forb cover far more than cattle grazing does (Soder *et al.*, 2007; Liu *et al.*, 2015; Tóth *et al.*, 2016; Schmitz and Isselstein, 2020). However, in the analyzed datasets, among the forbs, only the steep decrease of *Alchemilla vulgaris* is noticeable. This trend might be explained by the change in the predominant livestock type, in agreement with the patterns described elsewhere for increasing sheep impact (Tóth *et al.*, 2016; Schmitz and Isselstein, 2020), this forb being poorly tolerant to grazing and intolerant to trampling. Also, another contributing factor may have been the dry and hot summers from the last decades, the Lady's mantle preferring mesophilic ecological conditions. On the other hand, *Pteridium aquilinium,* a forb that has good tolerance to grazing but it is intolerant to trampling, has appeared and expanded. However, in this case, it might be that cattle are better at controlling the large ferns than sheep (Reyneri *et al.*, 1994), which are too small to trample it effectively. Nevertheless, the fact that data on the effects of grazing livestock types on the various plant species are scarce and that many of the observed changes in species cover are not yet explainable, indicates the need for more studies to unveil these hidden connections.

Studies performed on sheep-grazed *vs* abandoned grasslands showed that abandonment (for 12 years) strongly reduced total annual biomass production while not affecting botanical composition (Steinshamn *et al.*, 2018). However, Ford *et al.* (2012) noticed that grasslands grazed extensively by cattle, ponies and rabbits had significantly greater plant species (including forb) richness than those abandoned for 6 years, while the primary productivity did not differ. A recent study (Bohner *et al.*, 2019) concluded that long-term abandonment changed floristic composition by replacing short or shade intolerant species with medium or tall-sized grasses. Also, it increased above-ground phytomass but decreased species richness. Unlike our results where decreasing livestock density was paralleled by an increase in *Anthoxanthum* and *Nardus stricta*, other studies (Pakeman *et al.*, 2019) found that these species benefited from increased grazing. Nevertheless, the increase of *Pteridium aquilinium* cover that we witnessed along decreased grazing intensity agrees with their conclusion that this species benefits from abandonment. Studies of simulated grazing (Ónodi *et al.*, 2006) showed that heavy clipping (corresponding to overgrazing) has a strong negative impact on grassland canopy cover and biomass production while low and moderate clipping supported species richness compared to no clipping (abandonment). The risk of widespread grazing abandonment, along with its negative effects (decreased ecosystem productivity, quality and stability) and the need for agri-environmental policies designed for maintaining diverse livestock types and grazing regimes is also widely acknowledged (Peco *et al.*, 2006; Pakeman *et al.*, 2019).

While studies that compare time series of vegetation parameters from long-term observation plots are ideal, they are scarce since they involve high costs and time involvement (Käding *et al.*, 2005; Gillet *et al.*, 2016). We show that the use of phytosociological data analyzed through the adjusted methods proposed by Marușca (2019) are a valuable proxy to explore the dynamics of grassland parameters on extensive areas, under the influence of grazing livestock, either as an independent tool or complementary to the small-scale analytical studies.

Conclusions

A small but statistically significant decreasing trend was identified in the studied grasslands from the Vlădeasa Mountains between 1970 and 2008, in both pastoral value (from 63.80 to 61.43) and productivity (from 10.80 t ha^{-1} to 9.18 t ha^{-1}). The decline in grassland quality and productivity may be associated with the sharp decrease in livestock numbers (from 9,688 LU to 5,085 LU) and with the replacement of cattle by sheep as dominant livestock type. These changes, which are caused by land abandonment and dwindling of traditional practices, and possibly intensified by climatic influences, also increased the deviation of the actual stocking rate from optimum. This approach can be used as a model for other areas where time series vegetation data can be extracted from phytosociological literature and/or databases. The extensive historical vegetation datasets can be filtered for time series and employed to reveal the dynamic interconnection of grazing livestock and grasslands status. Also, new livestock data that become available can be associated with novel vegetation data to continue and complement the existing time series. These insights can be used to design adaptive grazing management plans in order to optimize grazing management according to the carrying capacity of the grassland ecosystems.

Authors' Contributions

Conceptualization and methodology: TM, AR and RDP; Data curation and Formal analysis ET, TMU and RDP; Writing - original draft: TM and AR; Writing - review and editing: TM, AR, ET, RDP and TMU. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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Supplementary files

Table S1. The correspondence table used for transformation of the species Cover-Abundance interval and Absolute frequency data from the synoptic table into the Cover Proportion percentage (adapted from Marușca, 2019)

Cover- Abundance interval*	CP-Cover Proportion (%)				
	V** (81 – 100)	IV** (61 – 80)	III** (41 – 60)	II** (21 – 40)	I** (<20)
5	**87.5**	**61.3**	**43.8**	**26.3**	**8.8**
4 - 5	75.0	52.5	37.5	22.5	7.5
3 - 5	62.5	43.8	31.3	18.8	6.3
2 - 5	52.5	36.8	26.3	15.8	5.3
1 - 5	46.3	32.4	23.2	13.9	4.6
+ - 5	44.0	30.8	22.0	13.2	4.4
4	**62.5**	**43.8**	**31.3**	**18.8**	**6.3**
3 – 4	50.0	35.0	25.0	15.0	5.0
2 – 4	40.0	28.0	20.0	12.0	4.0
1 – 4	33.8	23.7	16.9	10.1	3.4
+ - 4	31.5	22.1	15.8	9.5	3.2
3	**37.5**	**26.3**	**18.9**	**11.3**	**3.8**
2 – 3	27.5	19.3	13.8	8.3	2.8
1 – 3	21.3	14.9	10.7	6.4	2.1
+ - 3	19.0	13.3	9.5	5.7	1.9
2	**17.5**	**12.3**	**8.8**	**5.3**	**1.8**
1 – 2	11.3	7.9	5.7	3.4	1.1
+ - 2	9.0	6.3	4.5	2.7	0.9
1	**5.0**	**3.5**	**2.5**	**1.5**	**0.5**
+ - 1	2.8	2.0	1.4	0.8	0.3
+	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**

*The Cover-Abundance interval (Cristea *et al.*, 2004).

**The Absolute frequency as classes (Roman numerals) or percentage interval (Arabic numerals).

Table S2. The Forage Index (FI) scale (Păcurar and Rotar, 2014; Marușca, 2016)

FI-Forage index	Categories of plant species
1	Toxic for livestock or humans
2	Depreciate the quality of the livestock products
3	Depreciate the grassland forage value
4	Poor forage
5	Mediocre forage
6	Average forage
7	Good forage
8	Very good forage
9	Excellent forage

Table S3. The grassland quality classes according to its pastoral value (MADR, 2013; Marușca, 2016)

PV-Pastoral Value	Grassland Quality Class
0 – 5	Degraded
5 - 15	Very poor
15 - 25	Poor
25 - 40	Mediocre
40 - 60	Average
60 - 80	Good
80 - 100	Very good

Table S4. The green Herbage Index (HI) scale according to Marușca (2016)

HI- Herbage Index	Categories of green herbage mass production
0	Not evaluated species, without forage value
1	Very poor (1 – 3 t/ha)
2 and 3	Poor (3 – 6 t/ha)
4 and 5	Mediocre (6 – 10 t/ha)
6 and 7	Good (10 – 15 t/ha)
8	Very good (15 – 25 t/ha)
9	Excellent (over 25 t/ha)

Table S5. Conversion factors from Productivity index (PI) to Herbage Mass Production (HMP) for unfertilized permanent grasslands (Marușca, 2019)

Productivity index	Conversion factors	Herbage mass production (t/ha)	Grassland productivity class
0.1 – 0.5 0.5 – 1.0	x 1.8 x 1.9	0.2 – 0.9 1.0 – 1.9	Very poor
1.0 – 1.5 1.5 – 2.0	x 2.0 x 2.1	2.0 – 3.0 3.2 – 4.2	Poor
2.0 – 2.5 2.5 – 3.0	x 2.2 x 2.3	4.4 – 5.5 5.8 – 6.9	Poor – Average
3.0 – 3.5 3.5 – 4.0	x 2.4 x 2.5	7.2 – 8.4 8.8 – 10.0	Average
4.0 – 4.5 4.5 – 5.0	x 2.6 x 2.7	10.4 – 11.7 12.2 – 13.5	Average – Good
5.0 – 5.5 5.5 – 6.0	x 2.8 x 2.9	14.0 – 15.4 16.0 – 17.4	Good
6.0 – 6.5 6.5 – 7.0	x 3.0 x 3.1	18.0 – 19.5 20.2 – 21.7	Good – Very good
7.0 – 7.5 7.5 – 8.0	x 3.2 x 3.3	22.4 – 24.0 24.8 – 26.4	Very good
8.0 – 8.5 8.5 – 9.0	x 3.4 x 3.5	27.2 – 28.9 29.8 – 31.5	Excellent

Table S6. The changes in cover (SCP), between the two time periods for the plant species from different forage value categories (SCP-Standardized Cover Proportion; FI-Forage Index)

Species name	SCP - A1970 (%)	SCP - B2008 (%)	Absolute difference B-A (+/-)	Percent (%) difference	FI
Excellent and very good forage value			**1.76**		
Schedonorus pratensis	0.05	0.01	-0.04	79.82	9
Dactylis glomerata	0.00	0.19	0.19	>500	9
Trifolium repens	1.96	0.64	-1.32	67.30	8
Poa pratensis	0.05	0.05	0.00	0.00	8
Medicago lupulina	0.00	0.28	0.28	>500	8
Trisetum flavescens	0.01	1.22	1.21	>500	8
Lotus corniculatus	0.27	1.71	1.44	>500	8
Good and average forage value			**-14.68**		
Festuca rubra	29.32	18.21	-11.10	37.87	7
Trifolium pratense	2.73	1.19	-1.54	56.33	7
Agrostis capillaris	27.62	26.94	-0.68	2.45	7
Trifolium montanum	2.14	1.49	-0.65	30.47	7
Trifolium campestre	0.06	0.05	-0.01	19.27	7

Trifolium pannonicum	0.07	0.14	0.07	88.38	7
Ochlopoa annua	0.04	0.21	0.17	465.14	7
Vicia cracca	0.00	0.20	0.20	>500	7
Cynosurus cristatus	0.12	0.53	0.41	327.89	7
Alchemilla vulgaris	4.34	0.02	-4.32	99.54	6
Achillea distans	0.29	0.02	-0.27	92.98	6
Trifolium medium	0.07	0.00	-0.07	100.00	6
Trifolium aureum	0.07	0.00	-0.07	100.00	6
Carum carvi	0.11	0.04	-0.07	64.12	6
Achillea distans subsp. *stricta*	0.05	0.00	-0.05	100.00	6
Trifolium dubium	0.04	0.00	-0.04	100.00	6
Achillea collina	0.04	0.00	-0.04	100.00	6
Sanguisorba minor	0.01	0.05	0.04	303.67	6
Plantago media	0.15	0.20	0.05	34.56	6
Taraxacum officinale	0.11	0.19	0.08	70.44	6
Trifolium alpestre	0.06	0.20	0.14	222.93	6
Achillea millefolium	0.46	0.76	0.30	65.83	6
Holcus lanatus	0.14	0.81	0.67	494.49	6
Anthyllis vulneraria	1.48	2.27	0.80	54.00	6
Plantago lanceolata	0.17	1.48	1.31	>500	6
Mediocre and poor forage value			**9.36**		
Leontodon hispidus	1.31	0.08	-1.23	93.91	5
Scorzoneroides autumnalis	0.55	0.24	-0.31	55.96	5
Fragaria vesca	0.14	0.03	-0.11	77.98	5
Leucanthemum vulgare	0.57	0.47	-0.10	17.51	5
Plantago major	0.05	0.01	-0.04	79.82	5
Polygonum aviculare	0.01	0.00	-0.01	100.00	5
Symphytum officinale	0.00	0.11	0.11	>500	5
Galium verum	0.16	0.38	0.22	135.99	5
Potentilla erecta	0.10	0.33	0.23	233.03	5
Filipendula vulgaris	0.00	0.33	0.33	>500	5
Pimpinella saxifraga	0.07	0.87	0.80	>500	5
Anthoxanthum odoratum	2.94	5.45	2.52	85.65	5
Briza media	0.25	3.90	3.66	>500	5
Prunella vulgaris	1.67	0.33	-1.34	80.27	4
Veronica officinalis	0.47	0.05	-0.42	89.38	4
Pilosella officinarum	0.32	0.09	-0.23	72.05	4
Hieracium maculatum	0.12	0.00	-0.12	100.00	4
Veronica chamaedrys	0.29	0.18	-0.10	36.82	4
Potentilla aurea	0.10	0.01	-0.09	89.91	4
Antennaria dioica	0.09	0.01	-0.08	88.47	4

Rumex acetosa	0.45	0.42	-0.03	5.81	4
Pilosella aurantiaca	0.07	0.06	-0.01	19.27	4
Carex sempervirens	0.01	0.00	-0.01	100.00	4
Thymus pulegioides	0.11	0.11	0.00	1.33	4
Potentilla argentea	0.02	0.02	0.00	0.00	4
Fragaria viridis	0.01	0.03	0.02	142.20	4
Ajuga genevensis	0.01	0.04	0.03	222.93	4
Crepis biennis	0.01	0.07	0.06	465.14	4
Scabiosa ochroleuca	0.04	0.12	0.08	222.93	4
Knautia arvensis	0.11	0.22	0.11	97.35	4
Danthonia decumbens	0.16	0.28	0.12	73.89	4
Arnica montana	0.07	0.20	0.13	169.11	4
Stachys officinalis	0.09	0.23	0.14	165.27	4
Helianthemum nummularium	0.01	0.18	0.17	>500	4
Thymus bihorensis	0.00	0.21	0.21	>500	4
Ranunculus polyanthemos	0.11	0.33	0.22	196.02	4
Thymus pulegioides subsp. *pannonicus*	0.00	0.44	0.44	>500	4
Polygala vulgaris	0.20	0.71	0.51	258.26	4
Carex pallescens	0.05	0.77	0.72	>500	4
Avenella flexuosa	0.04	0.78	0.74	>500	4
Luzula campestris	0.10	0.88	0.78	>500	4
Thymus odoratissimus	0.01	1.28	1.27	>500	4
Depreciative and toxic species			**5.45**		
Carlina acaulis	1.75	0.45	-1.30	74.23	3
Campanula serrata	1.07	0.05	-1.02	95.31	3
Arabidopsis halleri	0.78	0.00	-0.78	100.00	3
Rhinanthus minor	2.31	1.87	-0.43	18.83	3
Euphrasia rostkoviana	0.22	0.00	-0.22	100.00	3
Carex leporina	0.09	0.03	-0.06	65.40	3
Cytisus hirsutus	0.02	0.00	-0.02	100.00	3
Crataegus monogyna	0.02	0.01	-0.01	59.63	3
Hypochoeris radicata	0.17	0.17	0.00	1.97	3
Luzula luzuloides	0.17	0.18	0.01	3.80	3
Calamagrostis arundinacea	0.06	0.10	0.04	61.47	3
Silene nutans	0.10	0.16	0.06	61.47	3
Dianthus carthusianorum	0.12	0.21	0.09	69.54	3
Dorycnium pentaphyllum subsp. *herbaceum*	0.01	0.10	0.09	>500	3
Centaurea arenaria	0.00	0.10	0.10	>500	3
Galium valdepilosum	0.00	0.10	0.10	>500	3
Lembotropis nigricans	0.00	0.11	0.11	>500	3

Campanula patula	0.10	0.21	0.11	111.93	3
Potentilla incana	0.00	0.12	0.12	>500	3
Deschampsia caespitosa	0.02	0.24	0.22	>500	3
Linum catharticum	0.12	0.35	0.23	182.57	3
Cruciata glabra	0.00	0.27	0.27	>500	3
Genista tinctoria	0.10	0.39	0.29	293.58	3
Hypochoeris maculata	0.06	0.39	0.33	>500	3
Genista sagittalis	0.11	0.44	0.33	294.70	3
Cytisus albus	0.00	0.37	0.37	>500	3
Hypericum maculatum	0.17	0.65	0.48	274.83	3
Centaurea phrygia	0.00	1.12	1.12	>500	3
Nardus stricta	0.78	4.95	4.17	>500	3
Stellaria graminea	0.19	0.24	0.05	29.17	1
Securigera varia	0.01	0.29	0.28	>500	1
Pteridium aquilinum	0.00	0.35	0.35	>500	1

*The infrequent species are not represented