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FUNCTIONAL DIFFERENTIATION OF CENTRAL APENNINE GRASSLANDS UNDER MOWING AND GRAZING DISTURBANCE REGIMES

ABSTRACT: This research dealt to two grasslands potentially developing the same vegetation type because sited in the same environmental contest (bioclimate, substratum, soil, slope, altitude) but under diverse management regimes (grazing and mowing) for many decades. The evidenced differentiation between the two pastoral vegetations can be attributed to disturbance type and the statistical functional analysis performed through seven plant traits (prostrate form, early flowering, storage organs, clonal ability, basal meristems, chemical defences and hairs), revealed the distinguishing patterns.

Discriminant analysis pointed out typical biological attributes for each disturbance conditions, while from correlation analysis emerged different possible traits combinations which do not follow the previous traits separation. Such outcomes are explainable because both grazing and mowing provoke aboveground phytomass removal, although grazing is a selective pressure, while mowing gives to all the species the same development chances. It is reasonable to conclude that convergent strategies within the two systems are possible and frequent.

KEY WORDS: disturbance type, grazing, floristic differentiation, functional traits, mowing

1. INTRODUCTION

In the whole Europe, semi-natural calcareous grasslands are in strong decline in extension and are threatened by abandonment (Riecken *et al.* 2002). These managed pastures, being very rich-species ecosystems and representing priority habitat for European Union (92/43/EEC Directive) are noteworthy of conservation (Pärtel *et al.* 1999, Norderhaug *et al.* 2000, Myklestad and Sætersdal 2004, Klimek *et al.* 2006, Sebastià *et al.* 2008). The importance of regular grazing (Milchunas and Lauenroth 1993, Biondini *et al.* 1998, Collins *et al.* 1998, Adler *et al.* 2001, Bullock *et al.* 2001, Frank 2005, Altesor *et al.* 2006, de Bello *et al.* 2006, 2007) and mowing (Hansson and Fogelfors 2000, Moog *et al.* 2002, Kohler *et al.* 2005) and the consequences of variations in land-use and grassland management (Wilson *et al.* 2003, de Bello *et al.* 2006, Kaligarić *et al.* 2006) for species composition maintenance is well demonstrated.

The role of disturbance in the dynamics of ecological systems is currently assumed to be one of the basic ideas in modern ecology (Pickett and White 1985, Lavorel *et al.*

1999a, b, Grime 2001, 2006) and the understanding of disturbance effects has high priority (Walker *et al.* 1999). Lavorel *et al.* (1997) proposed to use plant functional classifications as a tool to achieve this aim. There is considerable and growing interest in the response of functional groups of plants (Simms 1992, Sternberg *et al.* 2000) to grazing as well as the link with plant traits (Watkinson and Ormerod 2001). Plant functional traits are defined as biological characteristics of plant species responding to the dominant processes in an ecosystem (Keddy 1992, Kelly 1996, Gitay and Noble 1997, Lavorel *et al.* 1997, Kahmen and Poschlod 2008). The advantage of dealing with traits instead of species is that different vegetation types or even floras may be compared and general trends may be exposed (Díaz *et al.* 2001). Therefore, functional trait responses give information about the mechanisms of processes like management treatments (Thompson *et al.* 1996, Gillison and Carpenter 1997, Díaz *et al.* 1999, Bullock *et al.* 2001), allowing the assessment of functional differences and shifts acting in complex ecosystems. The comprehension of these mechanisms enables to predict vegetation changes induced by different management types (Bakker *et al.* 1996, Noble and Gitay 1996, Roberts 1996, Campbell *et al.* 1999, Kleyer 1999, Pausas 1999). Several previous studies had already addressed functional responses to management, most of them to grazing pressure (Briemle and Schreiber 1994, Lavorel *et al.* 1999b, Bullock *et al.* 2001, Dupré and Diekmann 2001), but also to mowing practice (Kramberger and Kaligaric 2008). There are some general findings in trait responses to grazing from temperate (Díaz *et al.* 1992, McIntyre *et al.* 1995, Bullock *et al.* 2001, Dupré and Diekmann 2001), Mediterranean (Noy-Meir *et al.* 1989, Perevolotsky and Seligman 1998, Hadar *et al.* 1999, Lavorel *et al.* 1999a, b, Sternberg *et al.* 2000) and arid grasslands (Landsberg *et al.* 1999), suggesting that differential defoliation and soil disturbances are the main processes conditioning trait responses, but few studies refer to the transitional landscape between the Mediterranean and the boreo-alpine biographical regions (de Bello *et al.* 2006, 2007). Small number of works concern functional responses of grassland vegetation to mowing (Lepš 1999), proving how mowing favours tall species, promoting species coexistence.

As a general ecological processes inherent plant community dynamics, in both the disturbance and management type the interspecific competition strongly affects plant growth and phenology (Lemaire and Chapman 1996).

The aim of this work was to understand if and how different disturbance types affect floristic compositions and plant functional traits set, thus the ecological functions, in central Apennine grasslands. The research goals were: i/ to identify the discriminant species leading the ecosystem processes in the two communities; ii/ to verify if there are some differential functional traits between the plant communities, and iii/ how plants can be organized into functional groups based on the relative expression of grazing/mowing resistance mechanisms. A further objective was to understand how these attributes are correlated each other, recognizing functional pattern through their correlations and providing a functional integrated vision.

2. MATERIAL AND METHODS

2.1. Study area

The study site is located along the mountain ridge of Umbria-Marches Apennine (central Italy), at about 1500 m a.s.l., inside Sibillini Mountains National Park (mown system is sited at 43°01’16”N, 13°13’36”E and grazed grassland is located at 42°59’05”N, 13°08’40”E). The two grasslands analyzed develop in two different sites, having same altitude, slope (5–10°), aspect (Northern), limestone substratum and encompassed in the lower supratemperate bioclimatic belt (Biondi and Baldoni 1995, Catorci *et al.* 2009) within temperate region (Rivas-Martinez 2004). In such conditions the length of growing season is 150–180 days per year.

Traditional pastoral activities start on June and last until the end of October. The pastures surveyed undergo different management and from about thirty years one grassland is grazed by sheep while the other is mown once a year in July, representing a late hay cutting.

2.2. Data collection

Soil characteristics were measured in both disturbance type, collecting soil samples in the field and then analyzing them. The considered soil parameters are: texture, sand, silt, clay, pH, total and active calcium carbonate, organic matter, total nitrogen (N), available phosphorus (P), exchangeable potassium (K), cation exchange capacity (CEC) and carbon/nitrogen rate (C/N) made by Marche Region agrochemical analysis and research laboratories (following the methodological standard predicted by Italian Ministerial Decree 13/09/99) and depth (measured directly in the field through graduate pole). Thermo-pluviometric data were collected since 30 years and are caught in a station located close the study area at the same altitude (Biondi *et al.* 1995). Grassland vegetation survey was carried out using 1m^2 point quadrat transect method (Bullock *et al.* 2001) and for each plant community 30 relevés have been made in June 2009, maintaining a constant distance of 10 m between each relevé, assessing the cover percentage for each species. Furthermore, phytosociological relevés (Braun-Blanquet 1964) have been carried out for each grassland, used then for the calculation of pastoral values. Floristic nomenclature follows Pignatti (1982) and Conti *et al.* (2005). Life form, mean and maximum height, families and four bioindication values (light request – L; nutrients need – N; humidity demand – U; pH request – R) (Ellenberg 1974, Pignatti 2005) have been assigned to all the species collected. Moreover, for the plant species seven functional traits have been attributed (occurrence of the character in the species): prostrate form, early flowering, storage organs, clonal ability, basal meristems, chemical defences and hairs. The consulted bibliography is referred to Pignatti (1982), Grime *et al.* (1988), Klotz *et al.* (2002), Ballelli and Bellomaria (2005), Klimešová and Klimeš (2006).

2.3. Data elaboration and statistical analysis

Soil parameters have been compared through t-test of means, in order to understand if there were statistical differences of pedological conditions.

To evaluate if the floristic composition of grasslands developing in grazed and mown conditions are statistically differentiated principal coordinates analysis (PCoA, binary Euclidean distance) is performed using the whole data set of species cover obtained from point quadrat survey, through Syntax 2000 software (Podani 2001). Then, Sørensen index of community similarity (CC) (Magurran 1988) have been assessed to quantify the plant community similarity between the two communities evidenced by the ordination procedure. To evaluate the pasture quality, pastoral value of both the grasslands has been assessed starting from the phytosociological relevés. The pastoral value (PV) was calculated after determining the specific quality index (IS) (Tomaselli 1956, Daget and Poissonet 1972) for each species. The specific index ranges from 0 (species that have null forage interest) to 5 (excellent forage) and is carried out by Bagella (2001), Roggero *et al.* (2002) and Gatti *et al.* (2007b).

T-test for mean and standard error have been calculated for bioindication values and for mean and maximum plants height. Life form and species families percentage have been carried out for each disturbance condition in order to underline possible variations.

One-way ANOVA is carried out for the identification of species which statistically explain the grassland-systems diversification, using weighted presence/absence data (integrated with cover percentage values).

To the species overcoming the significant level of ANOVA ($P \leq 0.01$) the selected plant traits have been attributed (weighted with species cover percentage) and then processed with discriminant function multivariate analysis (DFA), in order to identify which functional shifts occur, and which traits and species are discriminant (Wilks' Lambda $P \leq 0.000$) within the two communities. Finally, Pearson correlation coefficient has been performed for all the considered traits. One-way ANOVA, DFA and correlation analysis are performed using SPSS 13.0 software package (2005).

Table 1. The analyzed soil parameters for each disturbance condition (1 – corresponds to grazing disturbance; 2 – refers to mowing management). In bold significant differences between the two disturbances are indicated (*P* ≤0.05).

Parameter	Disturbance condition	Mean ± SE
Sand (g kg^{-1})	1	608.6 ± 28.47
	2	633.4 ± 12.45
Silt (g kg^{-1})	1	230.4 ± 16.6
	2	228.8 ± 16.19
Clay (g kg^{-1})	1	161 ± 13.7
	2	137.8 ± 6.66
pH	1	5.558 ± 0.09
	2	5.51 ± 0.08
Total $CaCO_3$ (g kg^{-1})	1	1.6 ± 0.75
	2	1.6 ± 0.75
Active $CaCO_3$ (g kg^{-1})	1	0.8 ± 0.37
	2	0.8 ± 0.37
Organic matter (g kg^{-1})	1	119.14 ± 5.87
	2	139.54 ± 10.43
Total N (g kg^{-1})	1	8.46 ± 0.07
	2	8.78 ± 0.21
Assimilable P (mg kg^{-1})	1	2.2 ± 0.49
	2	1.6 ± 0.60
Exchangeable K (mg kg^{-1})	**1**	**150.8 ± 25.66**
	2	**51.8 ± 12.01**
CEC (meq $100g^{-1}$)	1	74.14 ± 1.01
	2	74.1 ± 1.04
C/N	1	8.16 ± 0.34
	2	9.22 ± 0.55
Depth (cm)	1	30.00 ± 1.00
	2	27.6 ± 1.25

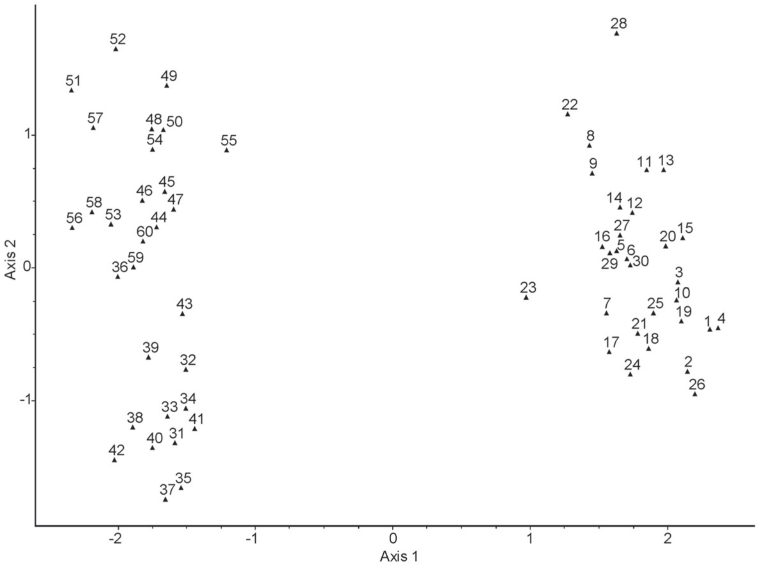

Fig. 1. PCoA outcome showing a clear separation between the two grasslands: relevés 1–30 are referred to grazed system, while relevés 31–60 are related to mown pasture.

3. RESULTS

T-test outcome for mean differences of the considered soil parameters within the two different management type are reported in Table 1. It is worth of notice that only the exchangeable potassium (K) is statistically recognized at the significance level of *P* ≤0.05.

Principal Coordinates Analysis (Fig. 1) highlighted that relevés referring to plant communities developing under different management are separated. The left side of the graph identifies the mowing condition, while in the right part it is recognizable the grazed grassland.

The mean species number for each 1m^2 point quadrat relevé is 18 and 26 respectively for grazed and mown conditions (differences statistically confirmed *P* ≤0.000) and also the total number of species collected in all the

Table 2. Mean bioindication (Ellenberg's) values (light request – L; humidity demand – U; pH request – R; nutrients need – N) with standard error. T-test of means did not highlight significant shifts between the two disturbance conditions.

Bioindication values	Grazing	Mowing
L	7.87 ± 0.21	7.54 ± 0.15
U	3.44 ± 0.18	3.64 ± 0.15
R	5.32 ± 0.36	5.16 ± 0.32
N	2.77 ± 0.20	2.75 ± 0.18

Table 3. Frequency of different families in the whole data set in each disturbance condition.

Family	Grazing	Mowing
Asteraceae	14	13
Poaceae	14	9
Fabaceae	8	10
Rosaceae	8	4
Ranunculaceae	8	3
Rubiaceae	8	3
Scrophulariaceae	4	6
Cyperaceae	2	3
Lamiaceae	2	6
Plantaginaceae	2	6
other	29	37

Table 4. Function at group centroids (1 correspond to grazing system and 2 to mowing grassland) and discrimant traits by DFA (Wilks' Lambda *P* <0.000). In the lower part of the table, negative values are referred to grazing system (1) and characterized by clonal ability, basal meristems and hairs traits; positive values are referred to mowing system (2) and distinguished by prostrate form, early flowering, storage organs, chemical defences traits.

Functions at group centroids	
Disturbance regime	**Function 1**
1	−0.222
2	0.222
Standardized canonical discriminant function coefficients	
Traits	**Function 1**
Prostrate form	0.283
Early flowering	0.092
Storage organs	5.112
Clonal ability	−2.341
Basal meristems	−2.125
Chemical defences	0.663
Hairs	−0.860

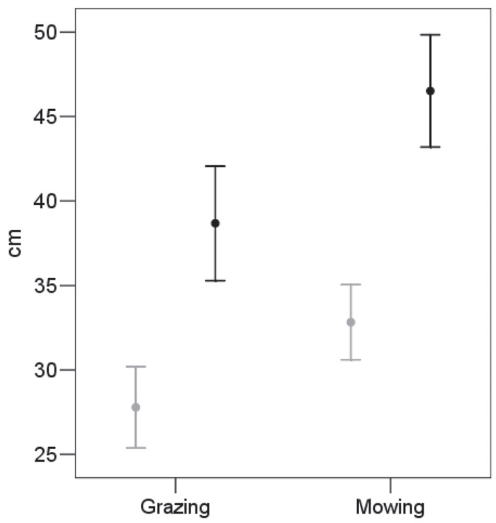

Fig. 2. Mean of average and maximum plant heights of the species in the two disturbance conditions with standard error (statistically not significant $P > 0.05$). Black bars indicate maximum species heights while grey colour shows average heights.

transects confirm this trend (49 in grazed pasture and 68 in mown system). The result of Sørensen index of community similarity (CC) between the two plant communities is 0.56 evidencing that the systems have a floristic similarity of 56%.

The pastoral value increases from 18.52 under mowing system to 23.65 in grazed condition.

Mean and standard error of bioindication values for each management type are shown in Table 2; the selected bioindication values do not show particular changes. Instead, plant height analysis evidences an increasing pattern moving from grazed to mown pastures, both average and maximum species heights (passing from 27.8 cm to 32.8 cm the average height and from 38.7 cm to 46.5 cm the maximum height) (Fig. 2).

Concerning the life forms (Fig. 3), scapose hemicryptophytes and rosulate hemicryptophytes show the same frequency in both the disturbance conditions, while caespitose hemicryptophytes and scapose therophytes decrease in mown pasture. Bulbose geophytes increase in mown condition, and the other life forms are present only in this grassland (reptant hemicryptophytes, reptant, succulent and sufruticose chamaephytes, biennal hemicryptophytes). Overall, mown pasture presents ten life forms, while grazed has five forms.

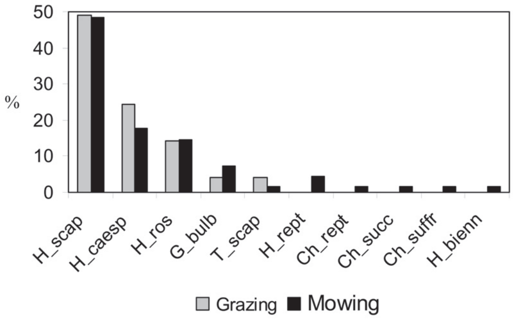

Fig. 3. Life forms percentage distribution in the whole data set for each disturbance situation. (H scap – scapose hemicryptophytes; H caesp – caespitose hemicryptophytes; H ros – rosulate hemicryptophytes; G bulb – bulbose geophytes; T scap – scapose therophytes; H rept – reptant hemicryptophytes; Ch rept – reptant chamaephytes; Ch succ – succulent chamaephytes; Ch suffr – sufruticose chamaephytes; H bienn – biennal hemicryptophytes).

Regarding species families occurrence (Table 3), it is observable that Asteraceae and Cyperaceae have almost the same occurrence percentage; Poaceae, Ranunculaceae and Rosaceae increase under grazed condition while Fabaceae, Scrophulariaceae, Lamiaceae and Plantaginaceae decrease in pasture conditions.

One-way ANOVA ($P \leq 0.01$) shows that there are 40 species that differentiate the two grasslands. To the species highlighted by ANOVA the seven plant traits mentioned above have been attributed, then processed with DFA (Wilks' Lambda $P < 0.000$). The traits which are discriminant within the two communities are reported in Table 4 together with function at group centroids. Along the linear axis, the negative part is occupied by the traits characterizing the grazed system (clonal ability, basal meristems and hairs), while the positive sector distinguishes the mown grassland (prostrate form, early flowering, storage organs and chemical defences). From such analysis it was possible to highlight which species characterize the two disturbance conditions with their presence as well as their absence (Table 5).

It is possible to note that the two systems differentiation is due to species with higher

Table 5. Species evidenced by one-way ANOVA ($P \leq 0.01$) and discriminant species by DFA for presence (p) or absence (a) within the two disturbance conditions. Discriminant species for bigger (p+) or smaller frequency (p–).

Species	*P*	Grazing	Mowing
Achillea millefolium L. ssp. *millefolium*	0.00	p	a
Ajuga reptans L.	0.01	a	p
Arabis hirsuta (L.) Scop.	0.00	a	p
Armeria canescens (Host) Boiss.	0.00	p	
Brachypodium genuense (DC.) Roem. *et* Schult.	0.00	a	p
Bromus erectus Huds. ssp. *erectus*	0.00	p	
Campanula glomerata L.	0.01	a	
Carex macrolepis DC.	0.00	a	p
Crocus vernus (L.) Hill ssp. *vernus*	0.00	p–	p+
Cyanus triumfetti (All.) Dostál *ex* Á. Löve *et* D. Löve	0.00	a	p
Dactylorhiza sambucina (L.) Soó	0.00	a	p
Dianthus monspessulanus L.	0.00	a	p
Festuca circummediterranea Patzke	0.00	p	
Filipendula vulgaris Moench	0.00	p–	p+
Knautia purpurea (Vill.) Borbas	0.00	a	p
Koeleria cristata Pers.	0.00	p	a
Leontodon cichoraceous (Ten.) Sanguin.	0.00	p	
Leucanthemum adustum (Koch) Gremli	0.00	a	p
Linum alpinum Jacq.	0.01	a	p
Luzula campestris (L.) DC.	0.00	p	
Myosotis alpestris F. W. Schmidt	0.00	p	a
Narcissus poëticus L.	0.00	a	p
Pedicularis tuberosa L.	0.00	a	p
Plantago lanceolata L.	0.00	a	
Poa alpina L. ssp. *alpina*	0.00	p–	p+
Potentilla rigoana Th. Wolf	0.00	p	
Ranunculus milllefoliatus Vahl	0.00	p	a
Ranunculus pollinensis (Terr.) Chiov.	0.00	p	
Rhinanthus minor L.	0.00	a	p
Saxifraga bulbifera L.	0.00	p	a
Saxifraga granulata L.	0.00	p	a
Sedum rupestre L.	0.00	a	p
Senecio scopolii Hoppe *et* Hornsch. ssp. *flocculosus* (Bertol.) Greuter	0.00		p
Thesium linophyllon L.	0.00	a	p
Thymus longicaulis Presl ssp. *longicaulis*	0.00	p	
Tragopogon pratensis L.	0.00	a	p
Trifolium montanum L. ssp. *rupestre* (Ten.) Nyman	0.00	p–	p+
Trifolium ochroleucum Huds.	0.00	p	
Valeriana tuberosa L.	0.00	p+	p–
Viola eugeniae Parl. ssp. *eugeniae*	0.01	a	p

cover in one condition and smaller presence or absence in the other.

Some graminoids appear to be discriminant for strong occurrence in grazed grassland (*Bromus erectus* Huds. ssp. *erectus*, *Festuca circummediterranea* Patzke, *Koeleria cristata* Pers., *Luzula campestris* (L.) DC.) even if there are also grasses which distinguish for their abundant presence the mown condition (*Brachypodium genuense* (DC.) Roem. et Schult., *Carex macrolepis* DC., *Poa alpina* L. ssp. *alpina*). Other species increase in abundance or are exclusively present with grazing; they are toxic (e.g. *Ranunculus* sp.)

and/or are characterized by early flowering (*Saxifraga* sp.) and rosette and semi-rosette and prostrate form (*Leontodon cichoraceous* (Ten.) Sanguin., *Potentilla rigoana* Th. Wolf, *Thymus longicaulis* Presl ssp. *longicaulis*). On the other hand, species having storage organs, early flowering and high palatability increase or appear when mowing practices are applied (*Arabis irsuta* (L.) Scop., *Crocus vernus* (L.) Hill ssp. *vernus, Dactylorhiza sambucina* (L.) Soó, *Knautia purpurea* (Vill.) Borbas, *Narcissus poeticus* L., *Tragopogon pratensis* L., *Trifolium montanum* L. ssp. *rupestre* (Ten.) Nyman*, Viola eugeniae* Parl. ssp. *eugeniae*).

Pearson correlation analysis reveals that some functional traits are correlated in different ways within the two disturbed grasslands (Tables 6 and 7).

This correlation analysis points out how many functional traits are correlated each other, even if in grazed condition about 39% (19/49) are not significantly correlated, while under mowing practice about 26% (13/49) are not correlated. It is interesting to consider the differential combinations (correlations) between the two management situations: under grazing pressure the combination among prostrate form, early flowering and chemical defences results to be the distinguishing integrated functional traits strategy. In mowing condition three peculiar traits combinations are highlighted: prostrate form, storage organs and basal meristems; early flowering, storage organs and basal meristems; storage organs, chemical defences and basal meristems. It does not mean that the other significant correlations are not relevant (e.g. clonal ability is correlated with all the other traits in both the conditions); in fact all the evidenced correlations are positively selected by the systems. This step allows to understand which combinations mostly characterize the two disturbance conditions.

It is possible to observe from the traits table elaborated and utilised for such functional analysis that some species have the following differential traits set: in grazing grassland *Potentilla rigoana* Th. Wolf shows the differential combination (prostrate form, early flowering and chemical defences). In mowing condition *Ajuga reptans* L., *Plantago lanceolata* L. and *Trifolium montanum* L. ssp. *rupestre* (Ten.) Nyman have prostrate form, storage organs and basal meristems combination; *Ajuga reptans* L., *Carex macrolepis* DC. and *Plantago lanceolata* L. have early flowering, storage organs and basal meristems combination; *Ajuga reptans* L., *Brachypodium*

Table 6. Pearson coefficient of correlation between the functional traits under grazing disturbance. *Correlation is significant at the 0.01 level.

Traits	Prostrate form	Early flowering	Storage organs	Clonal ability	Basal meristems	Chemical defences	Hairs
Prostrate form	1	0.760*	–0.019	0.146*	–0.019	0.949*	0.165*
Early flowering	0.760*	1	–0.018	0.116*	–0.03	0.806*	0.123*
Storage organs	–0.019	–0.018	1	0.985*	0.990*	–0.026	0.928*
Clonal ability	0.146*	0.116*	0.985*	1	0.975*	0.145*	0.946*
Basal meristems	–0.019	–0.03	0.990*	0.975*	1	–0.03	0.920*
Chemical defences	0.949*	0.806*	–0.026	0.145*	–0.03	1	0.156*
Hairs	0.165*	0.123*	0.928*	0.946*	0.920*	0.156*	1

Table 7. Pearson coefficient of correlation between the functional traits under mowing disturbance. *Correlation is significant at the 0.01 level.

Traits	Prostrate form	Early flowering	Storage organs	Clonal ability	Basal meristems	Chemical defences	Hairs
Prostrate form	1	0.018	0.275*	0.337*	0.301*	0.033	0.382*
Early flowering	0.018	1	0.492*	0.372*	0.361*	–0.012	0.123*
Storage organs	0.275*	0.492*	1	0.943*	0.938*	0.567*	0.838*
Clonal ability	0.337*	0.372*	0.943*	1	0.974*	0.615*	0.787*
Basal meristems	0.301*	0.361*	0.938*	0.974*	1	0.600*	0.766*
Chemical defences	0.033	–0.012	0.567*	0.615*	0.600*	1	0.661*
Hairs	0.382*	0.123*	0.838*	0.787*	0.766*	0.661*	1

genuense (DC.) Roem. et Schult., *Filipendula vulgaris* Moench and *Knautia purpurea* (Vill.) Borbas have storage organs, chemical defences and basal meristems combination.

4. DISCUSSION

The plant communities analyzed are located in the same bioclimatic contest, bioindication values and soil analysis do not show significant differences, except for exchangeable potassium (K), that is relevant in grazing condition due to livestock urine contribution (Di and Cameron 2004). From these considerations it is assumable that the two grasslands potentially can develop the same plant community and the management type is the main environmental driver. Such scenario is coherent with other studies concerning the effects of management regime on plant communities (Liira and Zobel 2000, Wilson *et al.* 2003, de Bello *et al.* 2006, Kaligarić *et al.* 2006). This study has confirmed that the different plant community and floristic composition, as evidenced by PCoA, correspond to different disturbance types (mowing and grazing). This pattern is supported by the Sørensen index output, showing that two plant communities are similar only in 56%. Species richness significantly increases under mowing condition and such result is in accordance with Wells and Cox (1993). The different grassland management influences the species stem heights. This study demonstrated that its average and maximum value decreases under grazing pressure, accordingly with many other authors (Noy-Meir *et al.* 1989, Fernández-Alès *et al.* 1993, Hadar *et al.* 1999) asserting that grazing favours small statured species. Moreover species having photosynthetic tissues under the cut level but reproductive structures extended over canopy top appear to be winner species (e.g. *Leucanthemum adustum* (Koch) Gremli, *Senecio scopolii* Hoppe et Hornsch. ssp. *flocculosus* (Bertol.) Greuter), probably because they can be more visible to pollinators. Furthermore several studies have shown that mowing at moderate cutting intensity maintained plant species richness in grasslands (Hansson and Fogelfors 2000, Fischer and Wipf 2002) and it is proved that grassland management plays a fundamental role for the maintenance of plant diversity by reducing the competitive ability of dominant species (Collins *et al.* 1998, Olff and Ritchie 1998). Such size analysis supports the findings of Lemaire and Chapman (1996) and Kahmen and Poschlod (2008) on the plastic response of grasses species to frequent and severe defoliation leading to a reduction in individual tillers dimension.

Life forms number increases under mowing condition, showing a double number of forms than in grazed pasture; about species richness a similar pattern is observed. Bulbose geophytes are more abundant in mowing grasslands, because they are suppressed by grazing (Skarpe 2001). The similar occurrence percentage of rosulate forms can be explained like by Kahmen and Poschlod (2008), who proved that species with leaves located closely to the ground level are favoured under condition of vertical defoliation which in this case is present in both disturbance regimes. Moreover, therophytes species are jointed to trampling phenomenon, thus to grazing. The chamaephytes forms occupy a temporal niche as they are characterized by later flowering period (when a drought stress occurs) (Gatti *et al.* 2007a), when they do not have other competitors and can get the reproductive success.

There is a relationship between caespitose hemicryptophytes life forms and Poaceae species. In fact many grasses belonging to this family show a remarkable increase in grazing disturbance, in which they contribute to the enhancement of the pastoral value (Sebastià *et al.* 2008) and consequently to the grassland quality. Regarding other families, the most notable trend is inherent Fabaceae species favoured by mowing management, as mentioned by Lavorel *et al.* (1999a) and Ilmarinen and Mykola (2009). In this study emerged that *Trifolium montanum* L. ssp. *rupestre* (Ten.) Nyman is favoured by mowing, because in such condition is not disturbed by grazing; in fact grazers limit its development being highly palatable species (Curll and Wilkins 1982, Armstrong *et al.* 1993) and furthermore sheep urine scorches clover leaves, while grass leaves are more resistant to this damage (Davies 2001), coherent with K trend in grazed situation (Di and Cameron 2004). On the other hand, *Trifolium ochro-*

leucum Huds. undergoes the urine injury, although being very pubescent and low palatable is advantaged in grazing system.

The functional study allowed to identify the plant traits distinguishing the two disturbance conditions. In fact, from statistical analysis emerged a clear separation between discriminant attributes favoured within both communities. The biological traits characterizing grazing condition are hairs that allow the species to be low palatable and together with clonal ability represent avoidance strategies. This evidence is coherent with Lavorel *et al.* (1999a) that demonstrated how lateral spread is induced by grazing. Other attribute having importance in this condition is the occurrence of basal meristems, representing a tolerance mechanism that promotes re-growth following defoliation conferring a further chance to survive and resistance to the pressure (Briske 1996). This attribute is typical of graminoids, growing in rich environmental condition (McNaughton and Chapin 1985) evidenced also by the enhancement of Poaceae species in grazed grassland. The mowing condition is distinguished by traits representing avoidance and tolerance strategies. According to Lack (1982), early flowering is a winner adaptation to hay grasslands and a reduction or elimination of species was observed with this attributes through the conversion of meadows to permanent pastures (Baker 1937, Rodwell 1992, Jefferson 1999). Species equipped with such trait can reach fruiting phenological phase before the sward cut, thus having a reproduction advantage regards the other species. Moreover this represents a further adaptation against late-flowering tall grasses in the competition for light, useful in early spring before being shaded by big-statured plants (Givnish 1982, Grubb *et al.* 1982, Grime 2001). Another attribute which consents to escape from the hay cutting is the prostrate form, because plant showing this feature remain under the cut level. Otherwise, the occurrence of storage organs is a tolerance mechanism, in fact after the mowing practice, species owning this trait can develop new photosynthetic tissue as well as reproductive structures (e.g. *Tragopogon pratensis* L.). Therefore this feature represents a re-growth capacity allowing to overcome this kind of disturbance. Surprisingly, chemical defences are associated to mowing grassland, but typically this trait is considered to be an avoidance response to grazing (Bergström 1992, Skarpe 2001).

Interesting considerations can be developed from traits correlation analysis (Pearson coefficient), which at a first approach could appear divergent regards the other functional analysis derived from DFA. Indeed, while DFA assigns different traits to mowing and to grazing condition, the correlation analysis shows that if they are combined together the net borders are deleted. It has been demonstrated that there are many possible traits combinations, some of which are differential for each disturbance and obviously, there are common correlations between the two different plant communities. Moreover, grazing system is distinguished by one differential traits combination with one species (*Potentilla rigoana* Th. Wolf), while mowing disturbance showed three differential traits set and seven species equipped with such characters (*Ajuga reptans* L., *Brachypodium genuense* (DC.) Roem. et Schult., *Carex macrolepis* DC., *Filipendula vulgaris* Moench, *Knautia purpurea* (Vill.) Borbas, *Plantago lanceolata* L., *Trifolium montanum* L. ssp. *rupestre* (Ten.) Nyman). Particularly, *Ajuga reptans* L. is furnished of all the three combinations and *Plantago lanceolata* L. has two of them so having further competitive ability. Thus, it is assumable that mowing allows to plants to have larger functional chances and it is consistent with how it is observed from floristic richness, in accordance with Navas and Violle (2009).

5. CONCLUSIONS

This research demonstrated how different disturbance types lead the separation of floristic composition and that late-mowing favours a higher species richness, life forms and functional strategies; grazing is a more selective disturbance regime than mowing. Species having different functional adaptations, as represented by traits combinations, are advantaged by the system. Grazing favours grasses (especially Poaceae species) while mowing advantages tall species. Mowing favours the affirmation of species equipped with dominant strategies

(*B. genuense* and *C. macrolepis*) that probably are not under control in late mowing managed grassland, having involvement for species richness and distribution responding to Grime's hump-back model (2001). This could highlight that probably in central Apennine grasslands only mowing cannot ensure the long-term maintenance of the floristic peculiarities, thus it should be suitable an integrated management strategy, planning a late mowing followed by a moderate grazing. Both grazing and mowing provoke aboveground phytomass remove but act in different ways on plant community: grazing is a selective pressure, while late-mowing gives to all the species the same development chances. Hence, it is understandable that convergent strategies within the two systems are possible and frequent.

Finally this study has confirmed how disturbance represents the main environmental driver for plant community differentiation, either at floristic and functional traits level, in central Apennine landscape too.

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6. REFERENCES

Adler P., Raff R., Lauenroth W.K. 2001 – The effect of grazing on the spatial heterogeneity of vegetation – Oecologia, 128: 465–479.

Altesor A., Piñero G., Lezama F., Jackson R.B., Sarasola M., Paruelo J.M. 2006 – Ecosystem changes associated with grazing in sub-humid South American grasslands – J. Veg. Sci. 17: 323–332.

Armstrong R.H., Robertson E., Lamb C.S., Gordon I.J., Elston D.A. 1993 – Diet selection by lambs in ryegrass-white clover swards differing in the horizontal distribution of clover (In: Proceeding of the XVII$^{\text{th}}$ International Grassland Congress) – New Zealand, pp. 715–716.

Bagella S. 2001 – Valore pastorale delle associazioni vegetali: un esempio di applicazione nell'Appennino Umbro-Marchigiano (Italia) – Fitosociologia, 38: 153–165.

Baker H. 1937 – Alluvional meadows: A comparative study of grazed and mown meadows – J. Ecol. 25: 408–420.

Bakker J.P., Olff H., Willems J.H., Zobel M. 1996 – Why do we need permanent plots in the study of long-term vegetation dynamics? – J. Veg. Sci. 7:147–156.

Ballelli S., Bellomaria B. 2005 – La flora officinale delle Marche – Arte Lito, Camerino, 997 pp.

Bergström R. 1992 – Browse characteristics and impact of browsing on trees and shrubs in African savannas – J. Veg. Sci. 3: 315–324.

Biondi E., Baldoni M.A. 1995 – The climate and vegetation of peninsular Italy – Colloq. Phytosociol. 23: 675–721.

Biondi E., Baldoni M.A., Talamonti M.C. 1995 – Il fitoclima delle Marche (In: Salvaguardia e gestione dei beni ambientali nelle Marche), Tipolit Trifogli, Ancona, pp. 21–70.

Biondini M.E., Patton B.D., Nyren P.E. 1998 – Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA – Ecol. Appl. 8: 469–479.

Braun-Blanquet J. 1964 – Pflanzensoziologie (Third Edition) – Springer, Wien, New York.

Briemle G., Schreiber K.F. 1994 – Zur Frage der Beeinflussung pflanzlicher Lebensund Wuchsformen durch unterschiedliche Landschaftspflegemaßnahmen – Tuexenia, 14: 229–244.

Briske D.D. 1996 – Strategies of plant survival in grazed systems: a functional interpretation (In: The Ecology and Management of Grazing Systems, Eds: J. Hodgson, A.W. Illius) – CAB International, Wallingford, pp. 37–68.

Bullock J.M., Franklin J., Stevenson M.J., Silvertown J., Coulson S.J., Gregory S.J., Tofts R. 2001 – A plant trait analysis of responses to grazing in a long-term experiment – J. Appl. Ecol. 38: 253–267.

Campbell B.D., Stafford Smith D.M., Ash A.J. 1999 – A rule-based model for the functional analysis of vegetation change in Australasian grasslands – J. Veg. Sci. 10: 723–730.

Catorci A., Cesaretti S., Gatti R. 2009 – Biodiversity conservation: geosynphytosociology as a tool of analysis and modelling of grassland systems – Hacquetia, 8: 129–146.

Collins S.L., Knapp A.K., Briggs J.M., Blairs J.M., Steinauer E.M. 1998 – Modulation of diversity by grazing and mowing in native tallgrass prairie – Science, 280: 745–747.

Conti F., Abbate G., Alessandrini A., Blasi C. 2005 – An annotated checklist of the Italian vascular flora – Palombi Editori, Roma, 420 pp.

Curll M.L., Wilkins R.J. 1982 – Frequency and severity of defoliation of grass and clover by sheep at different stocking rates – Grass and Forage Science 37: 291–297.

Daget P.H., Poissonet J. 1972 – Un procédé d'estimation de la valeur pastorale des pâturages – Fourrages 49: 31–40.

Davies A. 2001 – Competition between grasses and legumes in established pastures – (In: Competition and succession in pastures, Eds: P.G. Tow, A. Lazenby) – CABI Publishing, Wallingford, pp. 63–83.

de Bello F., Lepš J., Sebastià M.T. 2006 – Variations in species and functional plant diversity along climatic and grazing gradients – Ecography, 29: 801–810.

de Bello F., Lepš J., Sebastià M.T. 2007 – Grazing effect on species and functional diversity along a climatic gradient – J. Veg. Sci. 18: 25–34.

Di H.J., Cameron K.C. 2004 – Effects of the nitrification inhibitor dicyandiamide on potassium, magnesium and calcium leaching in grazed grassland – Soil Use and Management, 20: 2–7.

Díaz S., Acosta A., Cabido M. 1992 – Morphological analysis of herbaceous communities under different grazing regimes – J. Veg. Sci. 3: 689–696.

Díaz S., Cabido M., Zak M., Martinez Carretero E., Araníbar J. 1999 – Plant functional traits, ecosystem structure and land-use history along a climatic gradient in central-western Argentina – J. Veg. Sci. 10: 651–660.

Díaz S., Noy-Meir I., Cabido M. 2001 – Can grazing response of herbaceous plants be predicted from simple vegetative traits? – J. Appl. Ecol. 38: 497–508.

Dupré C., Diekmann M. 2001 – Differences in species richness and life-history traits between grazed and abandoned grasslands in southern Sweden – Ecography, 24: 275–286.

Ellenberg H. 1974 – Zeigerwerte der Gefässpflanzen Mitteleuropas – Scripta Geobotanica, 9. Göttingen

Fernández-Alès R., Laffarga J.M., Ortega F. 1993 – Strategies in Mediterranean grassland annuals in relation to stress and disturbance – J. Veg. Sci. 4: 313–322.

Fischer M., Wipf S. 2002 – Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadows – Biol. Conserv. 104: 1–11.

Frank D.A. 2005 – The interactive effects of grazing ungulates and aboveground production on grassland diversity – Oecologia, 143: 629–634.

Gatti R., Carotenuto L., Catorci A. 2007a – Sinfenologia di alcuni syntaxa prativi dell'Appennino Umbro-Marchigiano (Italia centrale) (In: Le praterie montane dell'Appennino maceratese, Eds: A. Catorci, R. Gatti) – Braun-Blanquetia, 42: 179–202.

Gatti R., Galliano A., Catorci A. 2007b – Valore pastorale delle praterie montane dell'Appennino maceratese (In: Le praterie montane dell'Appennino maceratese, Eds: A. Catorci, R. Gatti) – Braun-Blanquetia, 42: 247–253.

Gillison A.N., Carpenter G 1997 – A generic plant functional attribute set and grammar for dynamic vegetation description and analysis – Funct. Ecol. 11: 775–783.

Gitay H., Noble I.R. 1997 – What are functional types and how should we seek them? (In Plant Functional Types – Their Relevance to Ecosystem Properties and Global Change, Eds: T.M. Smith, H.H. Shugart, F.I. Woodward) – Cambridge University Press, Cambridge, pp 3–19.

Givnish T.J. 1982 – On the adaptive significance of leaf height in forest herbs – Am. Nat. 120: 353–381.

Grime J.P. 2001 – Plant Strategies, Vegetation Processes and Ecosystem Properties (Second Edition) – John Wiley and Sons, Chichester, 417 pp.

Grime J.P. 2006 – Trait convergence and trait divergence in herbaceous plant communities: Mechanisms and consequences – J. Veg. Sci. 17: 255–260.

Grime J.P., Hodgson J.G., Hunt R. 1988 – Comparative plant ecology A functional approach to common British species – Unwin Hyman, London, 742 pp.

Grubb P.J., Kelly D., Mitchley J. 1982 – The control of relative abundance in communities of herbaceous plants (In: The Plant Community as a Working Mechanism, Ed: E. Newman) – British Ecological Society No.1, Blackwell, Oxford, pp. 77–97.

Hadar L., Noy-Meir I., Perevolotsky A. 1999 – The effect of shrub clearing and grazing on the composition of a Mediterranean plant community: functional groups versus species – J. Veg. Sci. 10: 673–683.

Hansson M., Fogelfors H. 2000 – Management of a seminatural grassland; results from a 15–year old experiment in southern Sweden – J. Veg. Sci. 11: 31–38.

Ilmarinen K., Mikola J. 2009 – Soil feedback does not explain mowing effects on vegetation structure in a semi-natural grassland – Acta Oecol. 35: 838–848.

Jefferson R.G. 1999 – Mowing and cutting (In: The lowland grassland management handbook, Eds: A. Crofts, R.G. Jefferson) – English nature/ The wildlife trusts of the Royal society for nature conservation, London, chapter 6: 1–27.

Kahmen S., Poschlod P. 2008 – Effects of grassland management on plant functional trait composition – Agric. Ecosyst. Environ. 128: 137–145.

Kaligarič M., Culiberg M., Kramberger B. 2006 – Recent vegetation history of the North Adriatic grasslands – expansion and decay of an anthropogenic habitat – Folia Geobot. 41: 241–258.

Keddy P.A. 1992 – A pragmatic approach to functional ecology – Funct. Ecol. 6: 621–626.

Kelly C.K. 1996 – Identifying plant functional types using floristic data bases: Ecological correlates of plant size – J. Veg. Sci. 7: 417–424.

Kleyer M. 1999 – The distribution of plant functional types on gradients of disturbance intensity and resource supply in an agricultural landscape – J. Veg. Sci. 10: 697–708.

Klimek S., Richter Kemmermann A., Hofmann M., Isselstein J. 2006 – Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors – Biol. Conserv. 134: 559–570.

Klimešová J., Klimeš L. 2006 – Clo-Pla3: A database of clonal growth architecture of Central-European plants – http://clopla.butbn.cas.cz/

Klotz S., Kühn I., Durka W. 2002 – Biolflor: Eine Datenbank zu biologisch-ökologischen Merkmalen der Gefäßpflanzen in Deutschland – Schriftenreihe für Vegetationskunde 38, Bonn, Bundesamt für Naturschutz – http://www.ufz.de/biolflor/index.jsp

Köhler B., Gigon A., Edwards P.J., Krusi B., Langenauer R., Luscher A., Ryser P. 2005 – Changes in the species composition and conservation value of limestone grasslands in Northern Switzerland after 22 years of contrasting managements – Perspect. Plant Ecol. Evol. Syst. 7: 51–67.

Kramberger B., Kaligaric M. 2008 – Semi-natural grasslands: the effects of cutting frequency on long-term changes of floristic composition – Pol. J. Ecol. 56: 33–43.

Lack A.J. 1982 – Competition for pollinators in the ecology of *Centaurea scabiosa* L. and *Centaurea nigra* L. I. Variation in flowering time – New Phytol. 91: 297–308.

Landsberg J., Lavorel S., Stol J. 1999 – Grazing response groups among understorey plants in arid rangelands – J. Veg. Sci. 10: 683–696.

Lavorel S., McIntyre S., Landsberg J., Forbes T.D.A. 1997 – Plant functional classifications: from general groups to specific groups based on response to disturbance – Trends Ecol. Evol. 12: 474–478.

Lavorel S., McIntyre S., Grigulis K. 1999a – Plant response to disturbance in a Mediterranean grassland: How many functional groups? – J. Veg. Sci. 10: 661–672.

Lavorel S., Rochette C., Lebreton J.D. 1999b – Functional groups for response to disturbance in Mediterranean old fields – Oikos 84: 480–498.

Lemaire G., Chapman D. 1996 – Tissue flows in grazed plant communities (In: The Ecology and Management of Grazing Systems, Eds: J. Hodgson, A.W. Illius) – CAB International, Wallingford, pp. 3–36.

Lepš J. 1999 – Nutrient status disturbance and competition: an experimental test of relationships in a wet meadow – J. Veg. Sci.10: 219–230.

Liira J., Zobel K. 2000 – Vertical structure of a species-rich grassland canopy, treated with additional illumination, fertilization and mowing – Plant Ecol. 146: 185–195.

Magurran A.E. 1988 – Ecological diversity and its measurement – Chapman and Hall, London, 197 pp.

McIntyre S., Lavorel S., Tremont R.M. 1995 – Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation – J. Ecol. 83: 31–44.

McNaughton S.J., Chapin F.S. 1985 – Effects of phosphorus nutrition and defoliation on C_4 graminoids from the Serengeti plains – Ecology, 66: 1671–1629.

Milchunas D.G., Lauenroth W.K. 1993 – Quantitative effects of grazing on vegetation and soils over a global range of environments – Ecol. Monogr. 63: 327–366.

Moog D., Poschlod P., Kahmen S., Schreiber K.F. 2002 – Comparison of species composition between different grassland management treatments after 25 years – Appl. Veg. Sci. 5: 99–106.

Myklestad Å., Sætersdal M. 2004 – The importance of traditional meadow management techniques for conservation of vascular plant species richness in Norway – Biol. Conserv. 118: 133–139.

Navas M.L., Violle C. 2009 – Plant traits related to competition: how do they shape the functional diversity of communities? – Community Ecol. 10: 131–137.

Noble I., Gitay H. 1996 – A functional classification for predicting the dynamics of landscapes – J. Veg. Sci. 7: 329–336.

Norderhaug A., Ihse M., Pedersen O. 2000 – Biotope patterns and abundance of meadow plant species in a Norwegian rural landscape – Landsc. Ecol. 15: 201–218

Noy-Meir I., Gutman M., Kaplan Y. 1989 – Responses of Mediterranean grassland plants to grazing and protection – J. Ecol. 77: 290–310.

Olff H., Ritchie M.E. 1998 – Effects of herbivores on grassland plant diversity – Trends Ecol. Evol. 13: 261–265.

Pärtel M., Mändla R., Zobel M. 1999 – Landscape history of a calcareous (alvar) grassland in Hanila, western Estonia during the last three hundred years – Landsc. Ecol. 14: 187–196.

Pausas J.G. 1999 – Response of plant functional types to changes in the fire regime in Mediterranean ecosystems: a simulation approach – J. Veg. Sci. 10: 717–722.

Perevolotsky A., Seligman N.G. 1998 – Role of grazing in Mediterranean rangeland ecosystems – inversion of a paradigm – BioScience, 48: 1007–1017.

Pickett S.T.A., White P.S. 1985 – Patch dynamics: A synthesis (In: The ecology of natural disturbance and patch dynamics, Eds: S.T.A. Pickett, P.S. White) – Academic Press, New York, NY, pp. 371–384.

Pignatti S. 1982 – Flora d'Italia, 1–3 – Edagricole, Bologna, 2302 pp.

Pignatti S 2005 – Valori di bioindicazione delle piante vascolari della flora d'Italia – Braun-Blanquetia 39: 1–97.

Podani J. 2001 – Syn-tax 2000 Computer program for data analysis in ecology and systematics – Budapest.

Riecken U., Finck P., Schröder E. 2002 – Significance of pasture landscape for nature conservation and extensive agriculture (In: Pasture landscape and nature conservation, Eds: B. Redecker, P. Finck, W. Härdtle, U. Riecken, E. Schröder) – Springer, Verlag, Berlin, Heidelberg, pp. 423–435.

Rivas-Martinez S. 2004 – Global bioclimatics – http://www.globalbioclimatics.org

Rodwell J.S. 1992 – British plant communities Volume 3 – Grassland and montane communities – Cambridge, Cambridge University Press, 523 pp.

Roberts D.W. 1996 – Landscape vegetation modelling with vital attributes and fuzzy system theory – Ecol. Model. 90: 175–184.

Roggero P.P., Bagella S., Farina R. 2002 – Un archivio dati di Indici specifici per la valutazione integrata del valore pastorale – Rivista di Agronomia, 36: 149–156.

Sebastià M.T., de Bello F., Puig L., Taull M. 2008 – Grazing as a factor structuring grasslands in the Pyrenees – Appl. Veg. Sci. 11: 215–222.

Skarpe C. 2001 – Effects of Large Herbivores on Competition and Succession in Natural Savannah Rangelands (In: Competition and succession in pastures, Eds: P.G. Tow, A. Lazenby) – CABI Publishing, Wallingford, pp. 175–192.

Simms E.L. 1992 – Costs of plant resistance to herbivory (In: Plant resistance to herbivory and pathogens, Eds: R.S. Fritz, E.L. Simms) – University of Chicago Press, Chicago, pp 392–425.

SPSS Inc. 2005 – SPSS for Windows – Version 13.0, Chicago, Illinois, NJ, USA.

Sternberg M., Gutman M., Perevolotsky A., Ungar E.D., Kigel J. 2000 – Vegetation response to grazing management in a Mediterranean community: a functional group approach – J. Appl. Ecol. 37: 224–237.

Thompson K., Hillier S.H., Grime J.P., Bossard C.C., Brand S.R. 1996 – A functional analysis of a limestone grassland community – J. Veg. Sci. 7: 371–380.

Tomaselli R. 1956 – Introduzione allo studio della fitosociologia – Industria Poligrafica Lombarda, Milano, 319 pp.

Walker B.H., Steffen W.L., Canadell J., Ingram J.S.I. 1999 – Implications of global change for natural and managed ecosystems: a synthesis of GCTE and related research – IGBP Book Series 4, Cambridge University Press, Cambridge.

Watkinson A.R., Ormerod S.J. 2001 – Grasslands, grazing and biodiversity: editors' introduction – J. Appl. Ecol. 38: 233–237.

Wells T.C.E., Cox R. 1993 – The long-term effects of cutting on the yield, floristic composition and soil nutrient status of chalk grassland – Peterborough, English Nature Research Report, No. 71.

Wilson W.L., Abernethy V.J., Murphy K.J., Adam A., McCracken D.I., Downie I.S., Foster G.N., Furness R.W., Waterhouse A., Ribera I. 2003 – Prediction of plant diversity response to land-use change on Scottish agricultural land – Agric. Ecosyst. Environ. 94: 249–263.

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