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BIODIVERSITY CONSERVATION: GEOSYNPHYTOSOCIOLOGY AS A TOOL OF ANALYSIS AND MODELLING OF GRASSLAND SYSTEMS

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Abstract

The study site is located along the Umbria-Marches Apennine (central Italy). Following a series of research topics, the aims and objectives of this paper are to present the tested process of forage resources modelling at a large scale in a pastoral system in order to define essential management and decision making aimed on biodiversity conservation.

The analytical process is based on correlation between phytosociological and agro-zootechnical analysis. This approach allows one to extend any type of heterogeneous data, provided this is in any way correlated to the intrinsic characteristics of the plant community, can be interpolated to the whole polygon and therefore to all polygons referring to the same phytosociological unit. In terms of planning and application, the results of phytosociological modelling are much more useful when integrated in a database (GIS), in which the different information levels, based on hierarchical criteria, are simulated in multiple polygon segmentations.

In particular, this method allows one to obtain a first general overview of the forage resource using the theoretical data linked to the phytosociological interpretation of the territory. Subsequently, this overview can be enhanced with actual quantitative data, offering also a qualitative dimension coming from the phytosociological aspects.

Key words: Geosynphytosociological modelling, plant community, forage resource, carrying capacity, grazing management, biodiversity conservation.

Izvleček

Raziskovano območje se nahaja vzdolž Apeninov v območju Umbria-Marke (osrednja Italija). V članku so testirali modeliranje krmne vrednosti na velikem območju v travniškem sistemu in določitli ključne načine gospodarjenja in odločanja zaradi ohranjanja biodiverzitete.

Analitični proces temelji na korelaciji med fitocenološko in agro-zootehniško analizo. Ta pristop omogoča uporabo katerihkoli heterogenih podatkov, če so ti v povezavi z bistvenimi lastnostmi rastlinske združbe in jih lahko posplošimo na celoten poligon združbe oziroma na vse poligone iste fitocenološke enote. S stališča načrtovanja in uporabnosti so rezultati fitocenološkega modeliranja uporabnejši, kadar jih vključimo v podatkovno bazo (GIS). V njej lahko simuliramo različne členitve v poligone s pomočjo različnih informacijskih nivojev, ki temeljijo na različnih hierarhičnih merilih.

Metoda omogoča prvi splošni pregled krmnih vrednosti s pomočjo teoretičnih podatkov, povezanih s fitocenološko interpretacijo območja. Dodatno lahko ta pregled izboljšamo z dejanskimi kvantitativnimi podatki, s pritegnitvijo fitocenološkega vidika pa pridobimo tudi kvalitativno dimenzijo.

Ključne besede: Geosinfitosociološko modeliranje, rastlinske združbe, krmna vrednost, nosilna kapaciteta, paša, ohranjanje biodiverzitete.

1. INTRODUCTION

Grassland ecosystems represent a fundamental resource of plant species richness. For example, the Umbria-Marches Apennine (central Italy) occupy only 8 % of the Marches Region but contain 35 % of the total flora (Tardella et al. 2007).

The need to conserve such plant biodiversity in these ecosystems is confronted with socio-economic issues and animal breeding systems which,

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as is the case of most European grassland systems, have experienced a significant decline in productive activities, as well as a substantial reduction of grazing.

The result of this situation is a modification of plant communities, whether in terms of composition of the various phytocenoses or the landscape mosaic, by activation of the dynamic processes of substitution (Persson 1984, Francalancia et al. 1995, Bakker 1998, Pott 1998, Biondi 2001, Bonanomi & Allegrezza 2004, Foglia et al. 2007).

For this reason it is absolutely necessary to prepare an investigative framework aimed at planning biodiversity grazing management. However, this objective is difficult to achieve because within a certain bio-geographical area the composition and plant species richness of a pastoral landscape are correlated to multiple factors: a) the pattern of plant communities connected to a mosaic of environmental factors which act on a landscape scale, such as climate and geology (Ercole et al. 2005, Biondi et al. 2006, Cutini et al. 2007); b) the pattern of seasonal conditions, which are interrupted by topographic (exposure and slope) and pedological variations (Miles 1985, Grime 2001, Miles 2004, Agnelli et al. 2008), which define the ecological space of each plant community; c) the micro pattern created by localised variations, mainly soil chemical and physical properties (differences in AWC, Nitrogen content, pH, etc.), which interfere with the differentiation of plants within the plant community (Filesi et al. 2004); d) the intensity of grazing, which acts on the plant population scale and in this case corresponds to the so-called intermediate disturbance level, which guarantees maximum plant species richness (Grime 1973) with regard to the site's environmental characteristics and its biogeographical history.

Therefore, grasslands are complex ecosystems, which constitute numerous abiotic and biotic elements whose interactions vary in space and time (Tainton et al. 1996). In order to be fully understood, the multidimensional complexity of ecological grassland systems must be divided into organisational levels, each containing a few interacting unities. With this method the reciprocal relationships and the connectivity between the highest and the lowest organisational levels can be modelled (Tainton et al. 1996). This analytical process can only result from a hierarchical interpretation of the interacting factors of a territory in varying spatial-temporal intervals (King 1977, Allen & Starr 1982, O'Neill & King 1998, Blasi et al. 2000, Blasi et al. 2003). Furthermore, once the scale of analysis is changed, each element becomes part of a superior element, thus containing multiple systems of inferior rank (Farina 2001).

In order to obtain applicable documents, the hierarchical levels that constitute an "ecological landscape" of a territory must be defined, both conceptually and spatially. In this regard, using the methods and concepts of dynamic-catenal phytosociology (Ozenda 1982, Géhu et al. 1991, Rivas-Martinez 2005) can be a useful basis, particularly if these data are expressed by means of phytosociological maps (Pedrotti 2004).

This opportunity is inherent to the fact that the phytosociological modelling of the landscape of a territory is based on floristic, ecological, statistical and hierarchical criteria (Rivas Martinez 2005). This assumption makes it possible to map families of polygons within which physiognomic, floristic, dynamic and ecological characteristics are most likely to present a reduced variability. For this reason any data carried out from an experimental plot (e.g. productivity), provided this is in any way correlated to the intrinsic characteristics of the plant community (plant composition, architectonic structure, dynamic tendencies, bioclimatic properties, phenological rhythms, etc.), can be applied to the whole polygon and therefore to all polygons referring to the same phytosociological unit.

In addition, the syndynamic and geo-syndynamic characterization of a territory indirectly allows the geographic defining of varying bioclimatic indices, i.e. stresses induced by cold and aridity (Cano et al. 1997), which have a considerable influence on certain important parameters of forage resources in a grassland system.

This approach can therefore allow for the design of models aimed at representing pastures and their respective functions also in very large territories. Models have become powerful tools for translating the complexity of reality into meaningful concepts. They have the potential to supply substantial management support in the form of decision support models and expert systems (WallisDe Vries & Van de Koppel 1998).

Different types of models may be put to different uses: explanatory models unravel the mechanism processes; predictive models yield quantitative predictions of future development after thorough validation; integrated functional models ease the difficult task of finding an optimal trade-off between generality and specificity in response to the manager's questions and under constraints of available knowledge and funding. The choice to review models is prompted by their capacity to synthesize the knowledge and experience, and to reach new insights.

In terms of planning and application, the results of phytosociological modelling are much more useful when integrated in a Geographic Information System (GIS) database, in which the different information levels, based on hierarchical criteria, are simulated in multiple polygon segmentations (Blaschke 2001).

Based on these scientific-cultural assumptions, the aims and objectives of this paper are to present the modelling process of forage resources in a large scale pastoral system in order to define essential management efforts aimed at biodiversity conservation.

2. MATERIALS AND METHODS

2.1 Conceptual Logics

In order to carry out the management plan it is necessary to perform in-depth forage resource characterization and modelling (Hodgson & Hillius 1998). This entails a complex cognitive process, which is impossible to complete in one season. This process requires several years and thorough planning on deciding which data to collect and when. Therefore, a research plan must be created including the input of results into a database.

The research presented here aims at underlining the path followed for the establishment of an exclusive database, as well as the various evaluated botanical-agronomical and ecological parameters.

2.2 Study Area

The study site is located along the Apennine ridge that characterizes the interior of central Italy; the Umbria-Marches Apennine constitutes two parallel ridges with a NW-SE trend. Among these ridges, the western peaks reach altitudes of 1200 to 1500 metres, whereas most of the eastern peaks reach altitudes of 800 to 1200 metres. Towards the south, the two ridges merge with the Sibillini Mountain chain, not included in this study, whose peaks generally exceed 2000 metres in altitude.

In terms of geology the Umbria-Marches Apennine is characterised by predominantly calcareous lithotypes (Regione Marche 1991). The morphology of this mountain chain is characterised by steep slopes, cut by deep valleys, whereas the summits present weak slopes.

In terms of pedology, the aforementioned geomorphological areas are differentiated by the presence of soil catenas (Cremaschi & Rodolfi 1991). These are characterised by the presence of less evolved and shallow soils found gradually moving from more conservative morphologies (flat surfaces) toward steeper morphologies or from northern to southern exposure (Pieruccini 2007).

With regard to the bioclimatic area, the study is comprised within the following bioclimatic belts (Biondi et al. 1995, Orsomando et al. 1999, Catorci et al. 2007a): Upper Mesotemperate, Lower Supratemperate and Upper Supratemperate. The principal bioclimatic characteristics of the aforementioned levels are summarised in Table 1.

Table 1: Main bioclimatic characteristics of the study area
Tabela 1: Glavne bioklimatske značilnosti preučevanega območja.

Bioclimatic belt	Altitudinal range m a.s.l.	Average annual T °C	Average Annual P mm	N° of months with annual T<10 ° C	N° of months with tmin <0 ° C	Thermo-type	Ombro-type	Drought stress N° months	Cold stress N° months	Length of growing period (N° days with tmin >6 °C)
Upper Mesotemperate	450–1000	11–13	850–1100	5–6	1–2	Upper Mesotemperate	Lower Humid	0	6–7	180–210
Lower Supratemperate	1000–1450	9–11	1100–1300	6–7	2–3	Lower Supratemperate	Upper Humid	0	7–8	150–180
Upper Supratemperate	1450–1900	7–9	1300–1500	7–8	3–4	Upper Supratemperate	Lower Iperhumid	0	8–9	120–150

2.3 Data collection

For the purposes described in the introduction, the first step in the research plan was to characterise grassland vegetation using the phytosociological method (Braun-Blanquet 1931) combined with the most recent information on synphytosociology and geosynphtosociology (Géhu & Rivas-Martinez 1981, Theurillat 1992, Biondi 1996, Biondi et al. 2004a). Geobotanical maps were used as guidelines (Pedrotti 2004).

Subsequently, the distributions of the various *syntaxa* were modelled using numerous transects in the field and multivariate analyses (Podani 2001), Principle Component Analysis (PCA) in particular.

Using ARCGIS 9.0, the Vegetation Map of grassland communities was created, which also allowed activation of the database.

Following the guidelines of dynamic phytosociology, *sigmeta* (vegetation series) as well as *geosigmeta* (geoseries) (Rivas-Martinez 2005) (belonging to the different *syntaxa*) were identified and thus the management levels defined (isofunctional landscape cells) as described by Géhu (1988).

The agronomical and zootechnical aspects of each studied phytosociological unit were associated with the following parameters, collected throughout a 3 year period: pastoral value (Tomaselli 1956, Delpech 1960, Daget & Poissonet 1969, Corrall & Fenlon 1978, Sarno et al. 1989, Bagella 2001, Cavallero et al. 2002, Roggero et al. 2002, Bagella & Roggero 2004); maximum and seasonal productivity (Floret & Le Floch 1983, Gratani et al. 1999); theoretical utilisation coefficient of phytomass (Gatti & Catorci 2005, Gatti et al. 2005); theoretical carrying capacity (Bittante et al. 1990, 1993); bromatological characterization (Grayson 1999, Sánchez Rodríguez et al. 2006). The required database was obtained partly from Gatti & Catorci (2007) and Gatti et al. (2007b/c), partly by collecting data in the field as an addition to data already published.

The formula used to calculate the pastoral value is:

$$Pv = 0{,}2 \times \sum_{i=1}^{n} CSP_i \times Is_i$$

where Pv is the pastoral value of the community; n is the number of species in the community; CSP_i is the specific contribution of the presence of *i* species and Is_i is its specific index.

The productivity of the studied *syntaxa* was analysed by means of fortnightly grass cutting in permanent plots, excluding pastures for domestic animals; the seasonal productivity of each *syntaxon* was calculated in g/m^2 of dry matter, adding the forage productivity at maximum vegetative development with that of successive re-growth collected with the fortnightly grass cutting within the same plot.

In order to determine the theoretical carrying capacity, the complex dry matter was transformed into theoretical forage units (FU/ha per year). According to Bittante et al. (1993) 1 kg of dry matter of natural polyphyletic grassland has an approximate nutritional value of 0.69 FU. This value is used as a basis to estimate the livestock units (LSU) that the pasture is able to sustain (theoretical carrying capacity, LSU/ha).

The formula used is:

$$LSU / ha = \left(\frac{FU/ha\ anno}{\frac{3000}{365} \times D} \right) \times Cu_t \times \left(1 + \frac{CRS_{tot}}{1000} \right)$$

where D is the number of days of permanent grazing on the pasture (summer pasture), which is generally 150 days in the Apennines and Cu_t is the theoretical utilisation coefficient, calculated using the formula:

$$Cu_t = \frac{\sum_{i=1}^{N} CRS_{i,Is\neq 0}}{CRS_{tot}}$$

where CRS $_{Is \neq 0}$ is the coefficient of specific presence of palatable plants (species with Is ≠ 0) and CRS $_{tot}$ is the coefficient of specific presence of the plant communities, estimated on the basis of phytosociological data.

With the calculated pastoral value, the productivity and theoretical carrying capacity of each plant community, the optimal class number (C) and their relative size were obtained based on N observations, according to the formula described by Sturges (1926).

With the aim of obtaining data for zootechnical purposes, a bromatological analysis was carried out on the main *syntaxa* present in the study area using the method described by Weende and subsequent additions (Bittante et al. 1990).

It is hereby possible to determine the chemical composition (moisture content, ash content, unrefined proteins, unrefined fats, unrefined cellulose, extracts lacking nitrogen), an essential step in nutritional assessment. This allows for characterization of the various nutritional substances as well as accurate definition of the system's carrying capacity.

Finally, modelling of certain characteristics of forage resources was carried out using productivity data and bioclimatic characteristics. These characteristics were correlated to the different seasonal phases, such as determination of the peak in production for each *syntaxon*, presence and duration of a potential summer productivity stasis (senescence); duration of vegetative phase.

3. RESULTS

3.1 Geosynphytosociological characterization

In this study, the grassland ecosystems represent a well defined phytosociological system. Geoformations, exposures and altitudinal gradients play an important role in defining the characteristics of the pastoral landscape.

In particular, 14 *syntaxa* contained mainly within the alliances *Phleo ambigui-Bromion erecti*, *Ranunculo-Nardion strictae* and *Seslerion apenninae* have been detected (Biondi & Ballelli 1995, Baldoni et al. 1996, Allegrezza 2003, Biondi et al. 2004b, Biondi et al. 2005, Catorci et al. 2007b). The main ecological-spatial characteristics of these *syntaxa* are summarised in Table 3, whereas Table 2 shows their subdivision in the respective *sigmeta* and *geosigmeta*.

Table 2: Subdivisions of the analysed *syntaxa* in their respective *sigmeta* and *geosigmeta*
Tabela 2: Členitev obravnavanih sintaksonov ter njihovih sigmetov in geosigmetov.

UPPER MESOTEMPERATE BELT GEOSIGMETUM
Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum
Brizo mediae-Brometum erecti cynosuretosum cristati (Northern slopes)
Colchico lusitani-Cynosuretum cristati (Flat valleys)
Cytiso sessilifolii-Querco pubescentis sigmetum
Asperulo purpureae-Brometum erecti asperuletosum purpureae (Southern slopes)
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae (Southern slopes)
Stipo apenninicolae-Seslerio juncifoliae seslerio juncifoliae sigmetosum
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae (Watershed)
Carici sylvaticae-Quercetum cerridis
Brizo mediae-Brometum erecti danthonietosum alpinae (Top)
LOWER SUPRATEMPERATE BELT GEOSIGMETUM
Lathyro veneti-Fago sylvaticae lathyro veneti sigmetosum
Brizo mediae-Brometum erecti brizetosum mediae (Northern slopes)
Brizo mediae-Brometum erecti pöetosum alpinae (Top)
Brizo mediae-Brometum erecti festucetosum commutatae (Northern slopes)
Colchico lusitani-Cynosuretum cristati (Flat valleys)
Scutellario columnae-Ostryo carpinifoliae seslerio nitidae sigmetosum
Potentillo cinereae-Brometum erecti potentilletosum cinereae (Southern slopes)
Potentillo cinereae-Brometum erecti caricetosum humilis (Southern slopes)
Seslerio nitidae-Brometum erecti (Southern slopes)
Carici humilis-Seslerio apenninae sigmetum
Carici humilis-Seslerietum apenninae (Watershed)
HIGHER SUPRATEMPERATE BELT GEOSIGMETUM
Cardamino kitaibelii-Fago sylvaticae sigmetum
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae (Northern slopes)
Carici humilis-Seslerio apenninae sigmetum
Carici humilis-Seslerietum apenninae (Watershed)

Table 3: Main ecological-spatial characteristics of the named *syntaxa* **Tabela 3:** Glavne ekološko-prostorske značilnosti obravnavanih sintaksonov.

Plant community	Description of ecological characteristics	Environmental data			Floristic composition %					
		Exp.	Slope (°)	Altitude (a.s.l.)	*Festuco-Brometea*	*Nardetea strictae*	*Molinio-Arrhenatheretea*	*Elyno-Seslerietea*	*Rosmarinetea officinalis, Thero-Brachypodietea*	Others
Asperulo purpureae-Brometum erecti Biondi *et* Ballelli, 1981 *asperuletosum purpureae* Allegrezza 2003 corr.	Open turf community of southern and little steep slopes covered by lithosoils into Higher Mesotemperate Belt	SE-SW	20–45	550–900	87	0	2	2	4	5
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae Catorci, Gatti *et* Ballelli 2007	Open turf community of southern and little steep slopes covered by lithosoils into Higher Mesotemperate Belt	SE-SW	20–45	550–900	84	0	4	1	8	3
Seslerio nitidae-Brometum erecti Bruno in Bruno *et* Covarelli 1968	Open turf community of southern and very steep slopes covered by lithosoils into Higher Mesotemperate and Lower Supratemperate Belt	S	30–50	800–1200	88	0	0	4	2	6
Brizo mediae-Brometum erecti brizetosum mediae Biondi, Allegrezza *et* Zuccarello 2005	Firm turf community of northern and little steep slopes or tops with soils deep into Higher Mesotemperate and Lower Supratemperate Belt	NE-NW	10–40	800–1200	65	16	12	4	0	3
Brizo mediae-Brometum erecti cynosuretosum cristati Catorci, Gatti *et* Ballelli 2007	Firm turf community of northern and little steep slopes or tops with deep soils into Higher Mesotemperate and Lower Supratemperate Belt	Pl-N	0–10	800–1200	58	15	19	4	0	4
Brizo mediae-Brometum erecti poetosum alpinae Catorci, Gatti *et* Ballelli 2007	Firm turf community of northern and little steep slopes or tops with deep soils into Higher Mesotemperate and Lower Supratemperate Belt	N	0–10	1200–1400	68	6	21	1	1	3
Brizo mediae-Brometum erecti festucetosum commutatae Catorci, Gatti *et* Ballelli 2007	Firm turf community of northern and little steep slopes or tops with deep soils into Higher Mesotemperate and Lower Supratemperate Belt	Pl-N	10–20	1200–1400	62	6	25	2	2	3
Brizo mediae- Brometum erecti danthonietosum alpinae Ballelli, Castagnari, Catorci *et* Fortunati 2002 em.	Firm turf community of northern and little steep slopes or tops with deep soils into Higher Mesotemperate and Lower Supratemperate Belt	N	0–10	800–1200	56	2	35	1	3	3
Colchico lusitani-Cynosuretum cristati Biondi, Ballelli, Allegrezza, Guitian *et* Taffetani 1986	Meadows of the flat bottom of small valleys with deep and devoid of carbonate soils into Higher Mesotemperate and Lower Supratemperate Belt	N	0–10	800–1300	69	2	20	1	3	5

Potentillo cinereae-Brometum erecti potentilletosum cinereae Biondi, Pinzi *et* Gubellini 2004	Open turf community of southern and very steep slopes covered by lithosoils into Lower Supratemperate Belt	S	40–55	1000–1300	75	0	1	5	12	7
Potentillo cinereae- Brometum erecti caricetosum humilis Catorci, Gatti *et* Ballelli 2007	Open turf community of southern and very steep slopes covered by lithosoils into Lower Supratemperate Belt	S	40–55	1000–1300	84	0	4	2	5	5
Carici humilis-Seslerietum apenninae Biondi, Ballelli, Guitian *et* Allegrezza 1988	Open turf community with "large step" structure of southern and very steep slopes with outcrop substratum of rock into Lower and Higher Supratemperate Belt	S-SE-SW	56-70	1000–1700	54	1	1	42	1	1
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae Catorci, Gatti *et* Ballelli 2007	Open turf community with "large step" structure of southern and very steep slopes with outcrop substratum of rock into Lower and Higher Supratemperate Belt	S-SE-SW	40–55	700–1000	67	0	1	22	4	6
Filipendulo vulgaris-Trifolietum montani ranunculetosum oreophylii Catorci, Gatti *et* Ballelli 2007	Firm turf community of northern and little steep slopes with soils deep into Higher Supratemperate Belt	N	25–39	1300–1600	33	1	60	0	2	4

3.2 Agro-zootechnical characterization

3.2.1 Pastoral value

The pastoral value results are presented in Table 4. It is shown that the pastoral values of the xeric plant communities found in summit areas are lower than those found on Southern slopes, as are the values of Northern mesophilic plant communities. These show lower pastoral values than the *syntaxa* typically found in flat areas of valleys or summits.

Table 4: Pastoral values (means) and relative reference classes for each *syntaxon*

Tabela 4: Krmne vrednosti (povprečne) in relativni referenčni razred za posamezni sintakson.

PLANT COMMUNITY	PASTORAL VALUE	PASTORAL VALUE CLASSES
Carici humilis-Seslerietum apenninae	12,45	1
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	12,70	1
Seslerio nitidae-Brometum erecti	12,86	1
Potentillo cinereae-Brometum erecti caricetosum humilis	12,88	1
Potentillo cinereae-Brometum erecti potentilletosum cinereae	15,42	1
Brizo mediae-Brometum erecti festucetosum commutatae	18,46	2
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	18,52	2
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	20,69	2
Brizo mediae-Brometum erecti cynosuretosum cristati	21,07	3
Brizo mediae-Brometum erecti brizetosum mediae	21,32	3
Asperulo purpureae-Brometum erecti asperuletosum purpureae	21,70	3
Brizo mediae-Brometum erecti poetosum alpinae	21,74	3
Brizo mediae-Brometum erecti danthonietosum alpinae	26,66	4
Colchico lusitani-Cynosuretum cristati	33,04	5

Table 5: Productivity and relative reference classes for each *syntaxon*
Tabela 5: Produktivnost in relativni referenčni razred za posamezni sintakson.

PLANT COMMUNITY	AVERAGE PRODUCTIVITY (dry matter) g/m^2					AVERAGE REGROWTH (dry matter) g/m^2	TOTAL AVERAGE PRODUCTIVITY (dry matter) g/m^2	PRODUCTIVITY CLASSES
	year 2003	year 2004	year 2005	year 2006	Total average			
Potentillo cinereae-Brometum erecti potentilletosum cinereae	–	–	–	42	42	10	52	1
Potentillo cinereae-Brometum erecti caricetosum humilis	–	–	–	67	67	20	87	1
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	107	65	–	–	86	20	106	1
Asperulo purpureae-Brometum erecti asperuletosum purpureae	85	79	85	58	77	30	107	1
Brizo mediae-Brometum erecti poetosum alpinae	130	68	–	–	99	10	109	1
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	98	86	87	107	94	20	114	1
Carici humilis-Seslerietum apenninae	137	69	99	47	88	30	118	1
Seslerio nitidae-Brometum erecti	–	–	116	–	116	30	146	2
Brizo mediae-Brometum erecti brizetosum mediae	138	128	123	125	128	50	178	2
Brizo mediae-Brometum erecti festucetosum commutatae	183	174	150	200	177	40	217	3
Brizo mediae-Brometum erecti cynosuretosum cristati	178	223	205	196	200	40	240	3
Brizo mediae-Brometum erecti danthonietosum alpinae	247	182	243	275	236	50	286	4
Colchico lusitani-Cynosuretum cristati	274	313	–	316	301	60	361	5
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	370	280	–	–	325	50	375	5

3.2.2 Productivity

The productivity results are shown in Table 5. Also here it is shown that productivity levels of the xeric plant communities found in summit areas are lower than those found on Southern slopes, as are the values of Northern mesophilic plant communities. These show lower productivity levels than the *syntaxa* typically found in flat areas of valleys or summits.

3.2.3 Theoretical utilisation coefficient

The results obtained from the calculation of the theoretical utilisation coefficient (Cu_t) of each *syntaxon* are shown in Table 6.

Table 6: Theoretical utilisation coefficient (means) for each *syntaxon*

Tabela 6: Teoretični uporabni koeficient (povprečni) za posamezni sintakson.

PLANT COMMUNITY	Cu_t
Potentillo cinereae-Brometum erecti caricetosum humilis	0,40
Brizo mediae-Brometum erecti poetosum alpinae	0,42
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	0,48
Seslerio nitidae-Brometum erecti	0,50
Potentillo cinereae-Brometum erecti potentilletosum cinereae	0,51
Asperulo purpureae-Brometum erecti asperuletosum purpureae	0,52
Carici humilis-Seslerietum apenninae	0,53
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	0,56
Brizo mediae-Brometum erecti festucetosum commutatae	0,56
Brizo mediae-Brometum erecti cynosuretosum cristati	0,64
Brizo mediae-Brometum erecti brizetosum mediae	0,65
Brizo mediae-Brometum erecti danthonietosum alpinae	0,66
Colchico lusitani-Cynosuretum cristati	0,71
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	0,76

3.2.4 Bromatological composition

Table 7 shows data from the bromatological analysis (chemical composition) of the main plant communities found in the study area.

Table 7: Bromatological characterization

Tabela 7: Bromatološke značilnosti (kemijska sestava).

PLANT COMMUNITY	Proteins %	Lipides %	ADF %	NDF %	Ashes %
Brizo mediae-Brometum erecti cynosuretosum cristati	10,0	1,75	30,2	53,75	6,8
Brizo mediae-Brometum erecti brizetosum mediae	11,8	3,70	37,0	49,3	6,50
Brizo mediae-Brometum erecti danthonietosum alpinae	11,6	1,73	33,0	55,6	6,67
Filipendulo vulgaris-Trifolietum montani	10,76	1,46	36,0	42,5	7,16
Asperulo purpurea-Brometum erecti onobrychidetosum viciifoliae	9,66	1,6	25,96	49,26	7,4
Brizo mediae-Brometum erecti festucetosum commutatate	10,3	1,5	–	–	6,7
Colchico lusitani-Cynosuretum cristati	10,2	0,95	31,3	51,7	6,7
Carici humilis-Seslerietum apenninae	9,5	1,9	34,05	62,6	4,65
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	9,0	1,73	39,8	59,63	5,4
Asperulo purpurea-Brometum erecti asperuletosum purpureae	6,9	1,95	65,0	34,7	6,2

3.2.5 Carrying capacity

The results for the carrying capacity (LSU/ha) of the studied plant communities are presented in Table 8. In general, these results maintain the same pattern of differentiation between the summit communities, slopes and plains, as previously described.

Table 8: Carrying capacity and relative reference classes for each *syntaxon*

Tabela 8: Nosilna kapaciteta in relativni referenčni razred za posamezni sintakson.

PLANT COMMUNITY	LSU /ha (Gatti & al. 2005)	CARRYING CAPACITY CLASSES
Potentillo cinereae-Brometum erecti potentilletosum cinereae	0,18	1
Potentillo cinereae-Brometum erecti caricetosum humilis	0,24	1
Brizo mediae-Brometum erecti poetosum alpinae	0,27	1
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	0,37	1
Carici humilis-Seslerietum apenninae	0,40	1
Asperulo purpureae-Brometum erecti asperuletosum purpureae	0,41	1
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	0,42	1
Seslerio nitidae-Brometum erecti	0,48	1
Brizo mediae-Brometum erecti festucetosum commutatae	0,77	2
Brizo mediae-Brometum erecti brizetosum mediae	0,79	2
Brizo mediae-Brometum erecti cynosuretosum cristati	1,12	3
Brizo mediae-Brometum erecti danthonietosum alpinae	1,29	3
Colchico lusitani-Cynosuretum cristati	1,71	4
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	1,95	5

3.2.6 Total carrying capacity of the pastoral system

The database associated with the polygons of the phytosociological vegetation map allows for the combination of all data related to the agro-zootechnical characteristics of the polygons with the total surface of each polygon family (vegetation association or group of vegetation associations). As an example, relevant data for management purposes are shown in Table 9. This represents the total carrying capacity of the pastoral system of the Umbria-Marches Apennine (Macerata province only) subdivided into bioclimatic belts. Of course this process can be replicated for any territorial fraction within the pastoral system.

Table 9: Total carrying capacity of the studied pastoral system (The total carrying capacity of the pastoral system of the Apennines in the Macerata province is between 84,200 and 135,450 sheep, according to the conversion of 1 LSU/ha into 6 adult ovines – Ronchi 1988).

Tabela 9: Celotna nosilna kapaciteta obravnavanega pašnega sistema (celotna nosilna kapaciteta pašnega sistema Apeninov v provinci Macerata je glede na pretvorbo 1 LSU/ha v 6 odraslih ovc od 84,200 do 135,450 ovc; Ronchi, 1988).

BIO-CLMATIC BELTS	LSU/ha SOUTH-ERN SLOPES	LSU/ha NORTH-ERN SLOPES	LSU/ha FLAT AREAS	TOTAL LSU/ha
Upper	149	787	1840	2776
Meso-temperate	479	131	2576	4376
Lower	721	2893	3130	6744
Supra-temperate	2323	4855	4382	11560
Upper	537	1989	1287	4515
Supra-temperate	1731	3338	1570	6639
			Minimum	14035
			Maximum	22575

3.3 Characterization of the seasonal productivity trends

The ability to correlate a *syntaxon* with a certain bioclimatic belt, and thus its particular thermo-pluviometric characteristics, allows for the modelling of a series of temporal attributes linked to the forage resource, which is essential in managing the system.

Table 10: Seasonal characteristics of annual productivity

Tabela 10: Sezonske značilnosti letne produktivnosti.

PLANT COMMUNITY	VEGETATIVE PHASE START	PRODUCTIVITY PEAK Period Productivity	INSTANT CARRYING CAPACITY OF THE VEGETATION MAXIMUM LSU/ha	SUMMER VEGETATIVE STASIS PERIOD Days	INSTANT CARRYING CAPACITY OF SUMMER VEGETATION MINIMUM LSU/ha	AVERAGE CARRYING CAPACITY OF SUMMER VEGETATIVE STASIS LSU/ha
Potentillo cinereae-Brometum erecti potentilletosum cinereae	1–15 may	01–15 june 42 g/m^2	22,28	40–60	3,71	0,06
Potentillo cinereae-Brometum erecti caricetosum humilis	1–15 may	01–15 june 67 g/m^2	28,21	40–60	5,90	0,10
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	15–30 april	15–30 june 86 g/m^2	43,49	> 60	7,08	0,08
Asperulo purpureae-Brometum erecti asperuletosum purpureae	15–30 april	15–30 may 77 g/m^2	42,10	> 60	11,48	0,13
Brizo mediae-Brometum erecti poetosum alpinae	15–30 may	01–15 july 99 g/m^2	39,53	40–60	2,80	0,05
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	15–30 april	15–30 may 94 g/m^2	54,49	40–60	8,12	0,09
Carici humilis-Seslerietum apenninae	1–15 may	15–30 june 88 g/m^2	47,31	40–60	11,29	0,19
Seslerio nitidae-Brometum erecti	1–15 may	01–15 june 116 g/m^2	57,21	40–60	10,36	0,17
Brizo mediae-Brometum erecti brizetosum mediae	1–15 may	15–30 june 128 g/m^2	92,90	< 30	25,40	0,85
Brizo mediae-Brometum erecti festucetosum commutatae	15–30 may	01–15 july 177 g/m^2	113,17	< 30	17,90	0,60
Brizo mediae-Brometum erecti cynosuretosum cristati	1–15 may	15–30 may 200 g/m^2	143,99	30–45	20,16	0,45
Brizo mediae-Brometum erecti danthonietosum alpinae	1–15 may	15–30 june 236 g/m^2	175,22	30–45	25,99	0,58
Colchico lusitani-Cynosuretum cristati	1–15 may	15–30 june 301 g/m^2	263,73	< 30	36,80	1,23
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	15–30 may	01–15 july 325 g/m^2	256,19	< 30	27,59	0,92

3.3.1 Vegetative phase

The vegetative phase, or rather the period in which phytomass is produced, represents a central element in determining the optimal duration for seasonal grazing. There are many direct and indirect methods to obtain these data. Indirect methods lead to preliminary estimates that can subsequently be optimised by using direct data.

In the first case agronomical criteria can be used, which specify the onset of bacterial activity and of the subsequent capacity of the plants to fix nitrogen from the soil. A requirement for this is the existence of mean daily temperature > 10 °C or, alternatively, minimum daily temperatures > 6 °C (Conrad & Pollak 1950, Blasi 1994). The direct methods allow for the creation of productivity curves (Fig. 1), ideally integrating these studies with synphenological data. The start of the vegetative phase can be induced by anthesis of geophytes, immediately preceding or parallel to the vegetative phase of *Poaceae* and other taxonomic components of grassland (Catorci et al. 2006, Gatti et al. 2007a). Table 10 shows the mean onset of the grassland vegetative phase of the *syntaxa* within the study area.

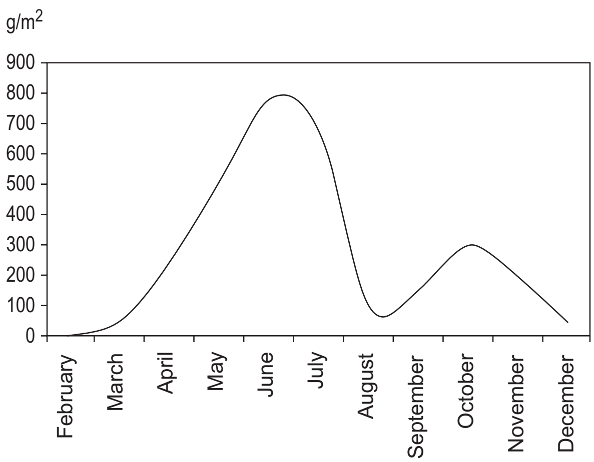

Figure 1: Examples of productivity curves of the northern slopes (*Brizo mediae-Brometum erecti brizetosum mediae*)

Slika 1: Primeri produktivnostnih krivulj na severnih pobočjih (*Brizo mediae-Brometum erecti brizetosum mediae*).

3.3.2 Period of maximum productivity and summer vegetative stasis

The integration of the climatic analyses with the geo-synphytosociological aspects of the vegetation allows one to relate the relative data to space both at the seasonal peak of productivity (with the relative theoretical carrying capacity) and during the phase of minimum productivity, or even the vegetative stasis due to a period of summer aridity stress. As before, it is also possible to evaluate the relative theoretical carrying capacity. The availability of these two sets of data represents an important element (together with the mean theoretical carrying capacity of the summer grazing period), for example in defining rotational stocking rates in a pastoral system.

Also in this case it is possible to use indirect and direct methods. In the first case, for example, by verifying whether there is a period of summer aridity or not using the SDS index by Mitrakos (1980, 1982). In the second case, by using data from syn-ecological studies or productivity curves.

Table 10, cited above, shows these parameters for all *syntaxa* studied.

3.4 Other characteristics of pastoral systems

3.4.1 Combining productivity and pastoral values (phyto-pastoral value)

The phytosociological pastoral value and agronomical productivity of a *syntaxon* express parameters that are not necessarily related to each other. In fact, a *syntaxon* with high productivity could consist mainly of unpalatable species, whereas a *syntaxon* with a high pastoral value could be characterised by low productivity. The combination of the two parameters (phyto-pastoral value) is important because it allows one to obtain a comprehensive picture to be used in the design of maps (Cavallero et al. 2002). As shown in Table 11, the productivity classes and pastoral values were compared for each plant community. Using the mean of these values, the sizes of the corresponding intervals were calculated according to Sturges (1926), and each phytocenosis was attributed to its respective reference class with regard to the phyto-pastoral value. This method allows for a fast comparison of the various plant communities and is important especially in evaluation and management of large territories.

Table 11: Phyto-pastoral values of the studied *syntaxa*
Tabela 11: Fito-pašne vrednosti obravnavanih sintaksonov.

PLANT COMMUNITY	PRODUCTIVITY CLASSES	PASTORAL VALUE CLASSES	PHYTO-PASTORAL CLASSES
Potentillo cinereae-Brometum erecti potentilletosum cinereae	1	1	1
Potentillo cinereae-Brometum erecti caricetosum humilis	1	1	1
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	1	1	1
Carici humilis-Seslerietum apenninae	1	1	1
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	1	2	1
Seslerio nitidae-Brometum erecti	2	1	1
Asperulo purpureae-Brometum erecti asperuletosum purpureae	1	3	2
Brizo mediae-Brometum erecti poetosum alpinae	1	3	2
Brizo mediae-Brometum erecti brizetosum mediae	2	3	2
Brizo mediae-Brometum erecti festucetosum commutatae	3	2	2
Brizo mediae-Brometum erecti cynosuretosum cristati	3	3	3
Brizo mediae-Brometum erecti danthonietosum alpinae	4	4	4
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	5	2	4
Colchico lusitani-Cynosuretum cristati	5	5	5

3.4.2 Combining phyto-pastoral values with floristic values

Knowledge of particular diversity present in a habitat or a certain territory is now considered a basic necessity in describing environmental systems (Ferrari, 2001). The adoption of appropriate strategies aimed at conserving this diversity must include knowledge and quantification of biodiversity. It is important to remember that there are several indices used to reach such a result. Using the phytosociological database from the Apennines in the Macerata province, a conservation and a rarity index were created, allowing comparison of different plant communities within a territory (Tardella et al. 2007). The results obtained from these analyses are shown in Table 12, in which it can be seen that certain xeric communities, such as *Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae*, *Asperulo purpureae-Brometum erecti asperuletosum purpureae*, *Brizo mediae-Brometum erecti festucetosum commutatae*, *Brizo mediae-Brometum erecti danthonietosum alpinae* have a high rarity index, i.e. contain numerous species within their floristic composition exclusive of the *syntaxon*. In contrast, another group consisting of *Brizo mediae-Brometum erecti brizetosum mediae*, *Brizo mediae-Brometum erecti poetosum alpinae*, *Brizo mediae-Brometum erecti festucetosum commutatae*, *Brizo mediae-Brometum erecti cynosuretosum cristati* and *Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae* is characterised by a high conservation index value.

Given that biodiversity conservation implies conservation of the entire mosaic of plant communities that characterise a territory, comparison of the aforementioned results combined with the phyto-pastoral value allows for the definition of certain priorities and critical points.

Table 12: Conservation value of studied *syntaxa* (from Tardella & al. 2007).
Tabela 12: Ohranitvene vrednosti obravnavanih sintaksonov (iz Tardella & al. 2007).

PLANT COMMUNITY	FLORISTIC RARITY INDEX	FLORISTIC CONSERVATION INDEX VALUE
Seslerio nitidae-Brometum erecti	0,68	3,90
Asperulo purpureae-Brometum erecti onobrychidetosum viciifoliae	0,92	14,30
Stipo apenninicolae-Seslerietum juncifoliae seslerietosum juncifoliae	0,83	19,44
Potentillo cinereae-Brometum erecti potentilletosum cinereae	0,88	26,04
Potentillo cinereae-Brometum erecti caricetosum humilis	0,88	26,04
Carici humilis-Seslerietum apenninae	0,75	29,57
Asperulo purpureae-Brometum erecti asperuletosum purpureae	0,92	14,30
Brizo mediae-Brometum erecti brizetosum mediae	0,89	72,60
Brizo mediae-Brometum erecti poetosum alpinae	0,80	72,60
Brizo mediae-Brometum erecti festucetosum commutatae	0,92	76,20
Brizo mediae-Brometum erecti cynosuretosum cristati	0,80	72,60
Brizo mediae-Brometum erecti danthonietosum alpinae	0,89	72,60
Filipendulo vulgaris-Trifolietum montani gentianelletosum columnae	0,71	42,39
Colchico lusitani-Cynosuretum cristati	0,80	3,75

For example, within the study area, *Asperulo purpureae-Brometum erecti*, has a high rarity index but a low phyto-pastoral value. On the one hand, this shows the importance of conserving these plant communities. On the other hand, given the low density of grazing animals, these plant communities are more likely to be abandoned, as they are less interesting for animal nutrition. With regard to management, it may be necessary to place economic priority on zootechnical development in order to sustain pasture on arid and less productive grasslands. In this way colonisation through shrubs and eliophilic trees can be avoided.

4. DISCUSSION

As seen in the flow chart in Fig. 2, phytosociological analysis can be used to create models aimed at describing pastoral landscapes, their functions and their priorities. Following this procedure, phytosociological maps (basic and derived) can be created. Due to the spatial characterization of collected data this information can be applied to all homogeneous polygons in terms of phytosociology and correlated to the intrinsic floristic-structural characteristics of the studied association. This method allows one to proceed along two main conceptual pathways, defined as indirect and direct, respectively. The indirect method is based on phytosociologically derived

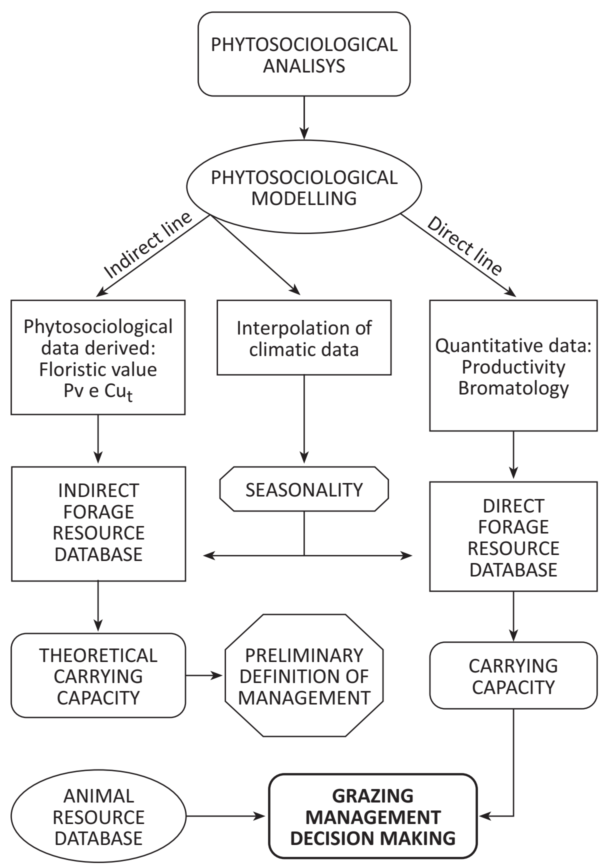

Figure 2: Grazing management decision making on the basis of the phytosociological analysis and modelling
Slika 2: Odločanje o pašnem gospodarjenju na podlagi fitosociološke analize in modeliranja.

data (floristic significance, Vp e Cu_t), thus making it possible to calculate the theoretical carrying capacity and define a preliminary grazing management strategy.

Using the direct procedure, by means of quantitative analysis of productivity parameters and bromatological characterization, a definition of the actual carrying capacity can be obtained.

The correlation of these parameters with seasonality and the qualitative elements that result from the direct analysis enables a first definition of a management strategy for the pastoral system.

Overlapping the results obtained from the analysis of the forage resource with those of the animal population, a first definition of the main strategies for grazing management can be obtained, an essential planning element for the conservation and maintenance of grassland ecosystems.

5. CONCLUSIONS

Modelling of forage resources and pastoral systems through an integrated approach has shown great potential in on-field application by combining landscape ecology, vegetation and agro-zootechnical sciences. These results are important in terms of biodiversity conservation and in defining the main strategies for pastoral systems management.

Furthermore, this process has shown how the hierarchical organisation of a database enables, in such a long and complex process, the progressive gathering of knowledge, both in qualitative and quantitative terms. This process avoids long periods of research prior to making management decisions, followed by a more detailed management strategy based on improved knowledge. In particular, this method makes it posible to obtain a first general overview of the forage resource using the theoretical data linked to the phytosociological interpretation of the territory. Subsequently, this overview can be enhanced with actual quantitative data, offering also a qualitative dimension coming from the phytosociological aspects.

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