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Vegetation series: a tool for the assessment of grassland ecosystem services in Mediterranean large-scale grazing systems.

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Abstract
Large-scale grazing systems (LSGS) are areas in which land-based livestock farming is the dominant productive activity and where grasslands, mainly of secondary origin, represent the main resource. To assess and make comparable the ecosystem services (ESS) of secondary grasslands, a clear space-time reference is needed. In this context, the concept of vegetation series may support the modeling of the dynamic succession trajectories of vegetation in relation to grazing and land use intensity and the identification of ESS benchmarks (e.g. the potential vegetation). While relating ESS to different dynamical stages within a vegetation series it will be possible to identify which land use types should be more useful to improve the effectiveness of one or more ESS. The paper illustrates 3 case studies in which the vegetation series model supported the assessment of grassland ESS in Mediterranean LSGS.

Key words: abandonment, carbon sink, grazing value, Habitats Directive, microhabitat conservation, plant biodiversity.

Riassunto
I sistemi pastorali estensivi (LSGS) sono caratteristici delle aree in cui le attività produttive si basano prevalentemente sull'allevamento del bestiame e nelle quali i pascoli, prevalentemente di origine secondaria, rappresentano la risorsa principale. Per quantificare e rendere confrontabili i servizi ecosistemici (ESS) offerti dai pascoli con quelli relativi ad altre tipologie di vegetazione è necessario avere dei riferimenti spazio-temporali. Il concetto di serie di vegetazione, che consente di interpretare e modellizzare le successione dinamiche della vegetazione e le loro relazioni con l'uso del territorio, può essere di supporto nell'identificazione delle comunità vegetali più efficaci in relazione agli ESS desiderati. Il lavoro illustra 3 casi di studio nei quali il modello di serie di vegetazione supporta la valutazione degli ESS dei pascoli nell'ambito di sistemi di pastorali estensivi mediterranei.

Parole chiave: abbandono, biodiversità vegetale, conservazione di microhabitat, Direttiva habitat, stock di carbonio nel suolo.

Introduction

Large-scale grazing systems (LSGS) are areas in which land-based livestock farming is the dominant productive activity (Caballero *et al*., 2009). Historically, they were characterized by strong cultural traditions maintaining throughout traditional practices based on the exploitation of land resources and the breeding of indigenous species (Riseth, 2006; Hopkins & Holz, 2006). On the other hand they are considered systems of High Nature Value (Dax, 2005), because can be expected to support high levels of biodiversity of species and habitats of conservation concern (Baldock *et al*., 1993; Beaufoy *et al*., 1994; Bignal & McCracken, 2000).

LSGS are mainly located in the Less Favored Areas (LFAs) characterized by harsh environmental and sometimes difficult social conditions, where the co-evolution of man and nature was so profound that in many cases human impacts can hardly be distinguished from natural ones (e.g. Grove & Rackham, 2001).

Grasslands, mainly of secondary origin, represent the main resource inside LSGS. Site-specific farming strategies, developed to feed a growing population in difficult and often unreliable environments, were focused to ensure a continuity of production and avoidance of risks by taking maximum profit from the interannual climatic fluctuations while maintaining the multifunctionality at field, farm and landscape levels (Pinto-Correia & Vos, 2004). The multifunctionality refers to *non-trade benefits of agriculture*, other than commerce and food production. It includes several ecosystem services (ESS) such as dynamic nutrient equilibriums, complete use of natural resources, closing of mineral and water cycles and thus low inputs at field, (Vos *et al*., 1993; Vos & Klijn, 2000) and conservation of high biodiversity and rich historical and cultural traditions (Caballero *et al*., 2007; Caballero *et al*., 2009; Pinto-Correia & Vos, 2004).

At European scale, secondary grasslands are threatened by two contrasting forces: intensification and abandonment. The first one is mainly due to an increasing demand for competitive land uses (e.g. bio-fuel production), which is causing their transformation into other agricultural systems; the second one to the most extreme form of extensification of land use, the abandonment, which particularly affects marginal areas (Caballero, 2007). The effects of these threats are similar: disappearance of potential economic, environmental, and social values (Donald *et al*., 2002; Angelstan *et al*., 2003; Biondi, 2003; Krohmer & Deil, 2003; Waldhardt *et al*., 2004).

To assess ESS of secondary grasslands and make it comparable, a clear space-time reference is needed. In this context, the concept of vegetation series (Géhu & Rivas-Martínez, 1981; Biondi, 1994) may support the modeling of the dynamic succession trajectories of vegetation in relation to grazing and land use intensity, and the identification of ESS benchmarks (e.g. the potential vegetation). While relating ESS to different dynamical phases within a vegetation series, it will be possible to identify which land use types should be more useful to improve the effectiveness of one or more ESS.

The aim of this paper is to illustrate some case studies in which the vegetation series model supported the assessment of grassland ESS in Mediterranean LSGS.

Case study 1: grasslands as resource

Grasslands in LSGS are a primary resource for livestock but they need livestock and/or an adequate management to preserve them. The integration of agronomic and vegetation data (e.g. phytosociological) can be effective in the assessment of sustainable stocking rate (Catorci *et al*., 2001; Bagella & Roggero, 2004; Gatti *et al*., 2005). The agronomic approach is often based on the assessment of the grazing value (GV), according to Daget & Poissonet (1969) and Daget & Godron (1995). Phytosociological data provide information on the floristic composition, ecology, and dynamic and spatial distribution of plant communities (Géhu & Rivas-Martínez, 1981). GV is calculated on the basis of the floristic composition, the specific contribution and the agronomic value of each species, or specific index (Is). GV have to be assigned to a pastoral *facies*, a spatial unit that can be considered homogeneous from a floristic and agronomic perspective.

On the basis of GV, it is possible to extrapolate useful parameters to support decisions on grassland management (Daget & Godron, 1995). For instance, a linear relationship has been found between GV and the potential annual mean stocking rate of herbivores, under balanced conditions and a pressure of incessant grazing (Daget & Poissonet, 1969; Daget & Godron, 1995).

The objective of this case study was to identify models of management compatible with conservation and regeneration of grasslands in an area of central Apennines where traditional livestock activities were still practiced. The area was included in three vegetation series: *Cytiso sessilifolieae-Querco pubescentis* Σ *Scutellario columnae-Ostryo carpinifoliae* Σ and *Lathyro veneti-Fago sylvaticae* Σ (Ballelli & Biondi, 1982; Bagella, 2001a; Biondi *et al*., 2002; Biondi *et al*., 2010). Livestock were represented by sarda dairy sheep (600 heads), marchigiana cattle (76 heads) and crossbred horses (47 heads). Grasslands, the main feed resource, were referred to the associations *Brizo mediae-Brometum erecti* Bruno in Bruno and Covarelli 1968 corr. Biondi and Ballelli 1982 and *Asperulo purpureae-Brometum erecti* Biondi and Ballelli ex Biondi, Ballelli, Allegrezza and Zuccarello 1995 (Bagella, 2001b; Biondi *et al*., 2005a), which represent successional phases in both vegetation series (Tab.1) both included in the priority habitat 6210(*) – Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (*important orchid sites) – (Biondi *et al*., 2009).

The first one was differentiated in 4 pastoral *facies*: from the xeric rangelands of the top of the mountains, showing the lowest GV (24), to the mesophilous cut grasslands of the high-hilly belt, on deep soils and protected from the wind, showing the highest one (GV = 37). The second one included discontinuous xeric communities with a very low GV (8-9), pioneer in respect to the first. Ten grassland sectors (Bagella, 2001a) including areas with similar vegetation, GV and management type were identified. For each sector the actual stocking rate, based on information provided by the farmers, and the potential and minimal carrying capacity, based on GV and extension of the sector, were evaluated. Stocking rate was expressed in terms of adult bovine equivalent units (UBA) and referred to the length of the growing season (180 dd). The ratio actual/potential stocking rate is an indicator of grazing pressure: an area is considered overgrazed if it is greater than 100% and undergrazed if it is lower than 100% (Tab. 1). In *Scutellario columnae-Ostryo carpinifoliae* Σ, in the hilly belt, grasslands belonging to both associations were overgrazed, with a stocking rate 6 times greater than the potential one (sector 9). In *Lathyro veneti-Fago sylvaticae* Σ the stocking rate rarely exceeded the potential one and, if not very heavily (sector 10), whereas in some sectors the stocking rate was too low (sectors 4, 7, 8).

The uneven spatial distribution of the stocking rates was recognized to be one of the most important factors of grassland degradation and shrub encroachment.

Sector	Association	Σ	Area	GV	Stocking rate (180 dd)				Carrying capacity	
			ha		*UBA ha⁻¹*		*UBA tot*			*UBA tot*
					potential	*actual*	*potential*	*actual*	*actual/potential*	*minimal*
1	Bri-Bro	Scu-Ost	11	37	0.9	1.6	10	17	174%	2
2	Bri-Bro	Lat-Fag	75	23	0.6	0.5	44	40	92%	11
3	Bri-Bro	Lat-Fag	50	23	0.6	0.5	26	24	92%	7
4	Bri-Bro	Lat-Fag	27	24	0.6	0.2	15	7	42%	4
5	Bri-Bro	Lat-Fag	5	24	0.6	0.8	3	3	101%	1
6	Bri-Bro	Lat-Fag	22	24	0.6	0.8	16	22	133%	4
7	Bri-Bro	Lat-Fag	10	24	0.6	0.2	3	1	38%	1
8	Bri-Bro	Lat-Fag	4	36	1.1	0.3	4	3	24%	1
9	Asp-Br	Scu-Ost	39	8	0.2	1.3	8	51	616%	2
10	Asp-Br	Lat-Fag	70	9	0.2	0.3	13	18	137%	3

Tab. 1 - Stocking rate and carrying capacity relative to the 10 sectors identified in the studied area (after Bagella, 2001b modified). Bri-Bro=*Brizo mediae-Brometum erecti;* Asp-Br=*Asperulo purpureae-Brometum erecti;* Scu-Ost=*Scutellario columnae-Ostryo carpinifoliae* ∑; Lat-Fag *Lathyro veneti-Fago sylvaticae* ∑.

The reduction of stocking rate or the abandonment of *Brizo mediae-Brometum erecti* grasslands encouraged the spread of *Brachypodium rupestre* (Host) R. *et* S. and subsequently of shrub and woody species. The competitive ability of this species in Apennine grasslands, in the absence of grazing and mowing, which rapidly result in loss of species diversity, is well known (Biondi *et al*., 2000; Bagella, 2001a; Biondi *et al*., 2005b; Bonanomi *et al*., 2006; Biondi *et al*., 2006). The overexploitation on the other side causes the degradation of the grasslands by favoring, for instance the increase of spiny or poisonous species in the case of *Brizo mediae-Brometum erecti* and a degradation of vegetation cover and impoverishment of soil in the case of *Asperulo purpureae-Brometum erecti*.

Therefore, to promote grassland renovation and conservation, it would be desirable to improve the grazing management by exploiting the grazing behavior of different animal species and introducing some devices (water points, small fences, etc.) to redistribute the stocking rate according to the carrying capacity of the different sectors.

Case study 2: grazing and microhabitat conservation

The effects of grazing on biodiversity should be direct or indirect. Direct effects concern grasslands or other types of grazed vegetation: in the European Union among 198 habitats of community interest (EC, 1992), 28 are threatened by the cessation of pastoral activities (Ostermann, 1998). Indirect effects are well documented relatively to some faunal groups, such as avian, the diversity of which is decreasing as a consequence of large-scale grazing abandonment (Laiolo *et al*., 2004).

Less known are the consequences of changing in stocking rate on microhabitats even if it has been supposed that any change had a profound influence on small-scale grassland heterogeneity by creating disturbances in the soil and in the sward structure, thereby enabling species establishment through niches (Olff & Ritchie, 1998; Adler *et al*., 2001). This case study points out the linkage between an emblematic microhabitat type, such as temporary wetlands (TWs) and grazing (Bagella *et al*., 2009a, Bagella *et al*., 2010a).

The presence of TWs is often neglected at least partly because of their intrinsic characteristics and the traits of the plants that they host. In fact, they cover very limited surface areas, are ephemeral and present high variability in the flooding period. Furthermore, the species that colonize them are often inconspicuous (e.g. dwarf annuals or dwarf geophytes), exhibit a very short life cycle and are often not well known. Then their disappearance goes often unobserved (Bagella *et al*., 2007). TWs are spread particularly across some landscapes. Even if they are not part of the successional trajectories of the main vegetation series, the surrounding woody vegetation, if not controlled by grazing, is able to encroach them.

In Sardinia the presence of TWs is relevant, especially on the tablelands, on impermeable ignimbritic rocks in the meso-Mediterranean phytoclimatic belt (Bagella *et al*., 2009a, 2009b). In these areas plant landscape is characterized by the neutroacidophilic cork-oak series, *Violo dehnhardtii-Querco suberis myrtetosum communis* ∑ (Bacchetta *et al*., 2004), linked to hydromorphic soils with a clay texture and slow drainage. Land use until 20 years ago was mainly based on traditional livestock activities, which favored the formation of wooded pastures, known in the Mediterranean basin as *dehesa* landscape.

Despite their small size, TWs present a large variability (Bagella *et al*., 2009a, 2010a), which is attributed mainly to their typical trait: a fine-scale zonation of the vegetation, depending on the water depth and the flooding period (Deil, 2005). The typical arrangement of plant communities within TWs is based on concentric belts according to water-depth gradient and flooding period. The belts should be considered homogeneous areas and the targets for conservation actions. The external belt is the more differentiated and well characterized. Vegetation is dominated by terophytes and geophytes with a high proportion of cover of species of *Isoeto-Nanojuncetea* class, which is considered the benchmark class for the identification of temporary wet habitats, according to the Habitats Directive (European Community, 1992). Then was ascribed to the priority habitat 3170*. The *Isoeto-Nanojuncetea* class is well represented also in the intermediate and central belts but they showed a relevant coverage of species from the *Potametea* and *Phragmito-Magnocaricetea* classes, attributable to different hydrological conditions. The external belt is also to be considered more vulnerable in respect to the colonization by terrestrial woody species in undergrazed systems and by ruderal species, belonging to the *Stellateritea mediae* class in overgrazed systems (Bagella *et al*., 2009c). Therefore, the external belt should represent the main conservation target within TWs.

Moreover, a canonical correspondence analysis (CCA) between plant cover and several environmental variables, including water, landscape and pond characteristics and animal disturbances pointed out the relevance of grazing by cattle for plants (Bagella *et al*., 2010b). This observation confirms the importance of land use for the conservation of TWs. In fact, several authors (Rhazi *et al*., 2001; Crosslé & Brock, 2002; Rhazi *et al*., 2006) have documented that plant diversity in these habitats has been maintained over the centuries despite being subjected to extensive human activities; thus changes in land use could lead to changes in plant assemblages.

Case study 3: grasslands and carbon sequestration in soil

Carbon sequestration refers to any activity that removes CO_2 from the atmosphere by 'locking up' carbon in a solid state (Anon, 1998). The two carbon pools most likely to change are woody plant biomass and soil organic matter, the dominant pool of carbon in grasslands (Amundson, 2001). The invasion of woody vegetation into deserts, grasslands and savannas is generally thought to lead to an increase in the amount of carbon stored in those ecosystems. For this reason, shrub and forest expansion (for example, into grasslands) was also suggested to be a substantial, if uncertain, component of the terrestrial carbon sink. Recently a clear negative relationship between precipitation and changes in soil organic carbon (SOC) content was found when grasslands were invaded by woody vegetation, with drier sites gaining and wetter sites losing. Losses of SOC at the wetter sites were substantial enough to offset increases in plant biomass carbon, suggesting that current land-based assessments may overestimate carbon sinks. Assessments relying on carbon stored from woody plant invasions to balance emissions may therefore be incorrect (Robert *et al*., 2002).

Afforestation and forest regeneration clearly increase the amount of carbon stored. New woody biomass stores carbon in quantities that depend on the age, productivity and density of the stand. Less known and still under debate are changes in soil carbon stock. Soil carbon plays a vital role as long-term carbon stocks that they are generally regarded as more stable than carbon stored in organic layers and in vegetation, which can easily be destroyed or harvested (Thuille & Schulze, 2006). Land use change can cause a change in carbon stocks (Bolin & Sukumar, 2000). A new challenge in the context of climate change mitigation is the management of terrestrial ecosystems to conserve existing carbon stocks and to remove carbon from the atmosphere by adding the stock in soil.

A review based on 74 publications concerning the effects of land use changes on soil carbon stock confirmed the effectiveness of grasslands in soil carbon storage (Guo & Gifford, 2002). The meta-analysis indicates that soil carbon stocks decline after land use changes from pasture to plantation (-10%), native forest to plantation (-13%), native forest to crop (-42%) and pasture to crop (-59%). Soil C stocks increase after land use changes from native forest to pasture (+8%), crop to pasture (+19%), crop to plantation (+18%), and crop to secondary forest (+53%) (Guo & Gifford, 2002).

The objective of this case study was to quantify the soil sink capacity under different land uses in a typical agro-forestry Sardinian system (Ledda *et al*., 2008). The study area was located in the northeastern sector of the island (Gallura region) on granite substrate at 300 m a.s.l. and it was included in the same environmental unit defined according to Blasi *et al*.

(2000). The potential vegetation was represented by neutroacidophylous cork-oak meso-woods belonging to the association *Violo dehnhardtii-Quercetum suberis* (Bacchetta *et al*., 2004; Bacchetta *et al*., 2009). Landscape was dominated by grasslands, vineyards and open *Quercus suber* forests. Six sites characterized by use and management with growing human impact were chosen: ploughed vineyard unploughed vineyard, abandoned vineyard, hayland-pasture rotation, seminatural grassland and *Quercus suber* forest. Each site is affected by the current land use at least for the last 15 years. As the sites were located within the same environmental units, the compared land use should be considered a chronosequence in which the space replaced the time. At each site some profiles were open and the soils were classified as *Typic Dystroxerepts*. SOC content was higher in *Quercus suber* forest, in hayland-pasture rotation, and in seminatural grassland. While ploughed and unploughed vineyards had lower SOC content, the abandoned vineyard showed intermediated level of SOC. These preliminary results suggest that in the studied system grasslands are as effective as forest in soil C sink (Ledda *et al*., 2008).

Conclusions

The three case studies illustrate how vegetation series model should support the assessment of grassland ESS in Mediterranean LSGS.

In the first case study we compared grasslands belonging to the associations *Brizo mediae-Brometum erecti* and *Asperulo purpureae-Brometum erecti*, which represent a relevant feed resource in the calcareous central Appennine LSGS. Both associations are included in the 2 vegetation series: *Scutellario columnae-Ostryo carpinifoliae* ∑ in the hilly belt and *Lathyro veneti-Fago sylvaticae* ∑ in the mountain belt. *Asperulo purpureae-Brometum erecti* communities are pioneers and present a lower GV in respect to *Brizo mediae-Brometum erecti* communities. Otherwise, the last one presented a wide range of variability in GV mainly in relation to the elevation and then in the vegetation. *Asperulo purpureae-Brometum erecti* communities, in spite of their low GV, were overgrazed especially in *Scutellario columnae-Ostryo carpinifoliae* ∑ because of the need of a resource during the cold season. For the same reason *Brizo mediae-Brometum erecti* communities were overgrazed mainly in this series, while in *Lathyro veneti-Fago sylvaticae* ∑ they were even undergrazed because grassland availability during the warm season is larger.

In the second case study we presented an example of grassland EES: plant biodiversity conservation. In the illustrated case, the positive effect of grazing was considered to be effective in a microhabitat that was not part of the same vegetation series to which the grassland belonged. Nevertheless, it was observed that in undergrazed or in abandonment conditions shrub vegetation encroached upon the external part of the TWs limiting the development of the vegetation typical of this belt, ascribed to the priority habitat 3170*, because of the shading effect. *Violo dehnhardtii-Querco suberis myrtetosum communis* ∑ should be considered the benchmark vegetation series for this microhabitat type.

Carbon sequestration in soil should be considered another relevant ESS. In the assessment of this service it is essential to consider the vegetation series as reference. In this way it is possible to evaluate the efficiency in this process of each vegetation type or land use within the same environmental unit minimizing the effects due to ecological factors (e.g. climate and substrata). Following this rationale, we compared soil sink sequestration under different vegetation covers in a vegetation series. The results showed that seminatural grasslands were as efficient as cork oak forest. Then we can affirm that in the case of the analyzed vegetation series the role of benchmark for SOC sequestration in soils is not limited to potential vegetation.

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