GRASSLAND USE AND PLANT DIVERSITY IN GRAZED ECOSYSTEMS

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Introduction

Earth biomes are being **deconstructed**, through unprecedented rates of species disappearance or invasion (McCann 2000). This, added to the threat of global environmental change and changes in values of a developed society, caused that biodiversity became a topic that has captured the attention of the public as well as the scientific community. Such concern on the importance of biodiversity is based in four basic reasons clearly described by West (1993): (i) morality, that aims for the protection of species; (ii) aesthetics, as people desire to see and appreciate the living parts of nature; (iii) economics and, (iv) the array of "services" provided by the natural ecosystems. It is vital to know how badly is affecting ecosystem function human alarming rate of destroying the original diversity.

Plant Diversity

The broadest concept of biological diversity is that of a variety of organisms, life and its processes (West 1993). Bio-diversity has also been considered as the total sum of all biotic variation from the level of genes to ecosystems (Purvis and Hector 2000). Some of the first ideas of how biodiversity could affect the way ecosystems function are attributable to Darwin and Wallace (1858), who believed that (i) exist a niche diversification of the co-occurring species and, (ii) greater community productivity will sprout from a more effective resource exploitation. However, the central assertion of a relationship between biodiversity and ecosystem function is that greater diversity is associated with higher ecosystem stability. Mac Arthur (1977) suggested that with increases of alternative pathways for energy flow in an ecosystem, less likely that pathway destruction or disruption would unsettle the system. It is peculiar to visualise that this way of thinking is similar to the ideas and objectives that gave life to Internet (!).

Although during decades the functional consequences of species-level biodiversity at the ecosystem level had been highly debated (Chapin *et al* 1992, Walker 1992), recent advances indicate that diversity can be expected to give rise to ecosystem stability (McCann 2000). The evidence also indicates that diversity is not the driver of this relationship; rather, ecosystem stability depends on the ability for communities to contain species or functional groups that are capable of differential response. Decreasing biodiversity will be accompanied by less but stronger interactions within ecosystems and, a concomitant decrease in ecosystem stability. Ecosystem stability does not necessarily extend to population level stability and, because species removal or addition can invoke major shifts in community structure and dynamics, if we wish to preserve an ecosystem and its component species, the best is to proceed as if each species is sacred (McCann 2000).

Most ecosystems exhibit species richness higher than that required for efficient biogeochemical and trophic functions (di Castri 1991). The existence of such great amount of relationship and some redundancy, is also expected to be related with ecosystem function (e.g. productivity) as assures a better resource exploitation. However, rank abundance diagrams demonstrate how asymmetry in the abundance of species is a common feature across many ecosystems (Whittaker 1965), accounting a small number of abundant species for a large fraction of ecosystem function (Golluscio and Sala 1993). Many other communications express there is no direct association between diversity and productivity. Such evidence is dramatically synthesised by Schwartz *et al.* (2000) expression that "solid evidence in support of a linear dependence of ecosystem function on diversity such that even rare species contribute to function is practically non-existent".

Grazed ecosystems

Grazinglands are dynamic ecosystems, highly adapted to several types of disturbance events and, because of this, with a high need of such perturbations. Being disturbance such an intrinsic property of grassland ecosystem, it could be argued that the true disturbance is a lack of disturbance. Because of this, disturbance events added to environmental fluctuations intrinsic to the grassland climate and the co-existing biota are fundamental and have disparate effects to grassland biodiversity, generating the existing spatial or temporal variability (Sala *et al.*. 1996). Disturbance will release directly or indirectly, the limiting influences of species interactions (such as competition) required for species coexistence (McCann 2000).

Drought, fire and grazing by large ungulate herbivores are the three disturbing factors of grassland environment that distinguish them from other ecosystem types (Milchunas 1988). All three provide selection pressures for high turnover of aboveground plant organs, location of perennating organs near the soil surface, and a large fraction of biomass and activity belowground. Drought is a more frequent influence on dry grasslands than it is on those of humid regions while, conversely, fire is a more frequent force in shaping grasslands in humid regions that it is in dry regions (Sala *et al.*. 1996). Moderate intensities and periodicities of grazing and trampling usually increase plant diversity at a community level by decreasing the ability of dominants to competitively exclude other species (Quinn and Robinson 1987) and by creating physical gaps and freeing resources such as light, moisture and nutrients (Archer and Smeins 1991). Naveh and Whittaker (1979) communication add to many others that reported greater plant diversity on moderately grazed areas rather than either ungrazed or heavily grazed areas. This situation feeds back as more diverse vegetation resist grazing due to avoidance (lack of consumption) of a greater portion of the species pool Mc Naughton (1993).

Livestock grazing of any kind may affect grazed ecosystems by varying the abundance of keystone or critical link species that are valuable for maintenance of essential ecosystem states and functions. Keystone species may be regarded as a functional group with no redundant representation, that will excerpt a disproportional control within an ecosystem because they may cause massive changes in the community structure and ecosystem function when removed (Schulze and Mooney 1993). In a similar way, we may acquire the concept of functional groups as a basis for organising our thoughts about biotic diversity implies that species within a functional group are equivalent or "redundant" in their impact on ecosystem processes (Lawton and Brown 1993). These critical species should be identified and its vital role on the ecosystem function understood (Westman 1990) to recognise, impede and ameliorate its presence whenever possible.

The above concepts stress that is not the species number, but the quality of species in the concert of the functioning of the whole community which makes the species important. It will be useful to find the means of describing the range of genetic information present, as new species added to a community adds to diversity by the extent to which it adds new genetic information (Schulze and Mooney 1993). Similarly, as there is not universal classification of functional groups and as any grouping of species will depend on the objectives, it would be helpful to have a coherent picture of their detailed functional roles in ecosystems. Organisms should be classified according to their functional role in a given ecosystem process, as occurs with microbes, and not according to their morphology and anatomy as indicators of their phylogeny, as higher organisms have been classified (Schulze and Mooney 1993).

Following the above criteria, is possible to evaluate variations in grasslands condition in an utilitarian way, describing the presence and vigour of certain key species or plant functional groups, as well as soil cover and signs of erosion. As a linear relationship is assumed between primary and secondary productivity and the presence and vigour of given functional groups, grassland managers procure to orient disturbance events in order to increase desirable functional groups or keystone species for upgrading grazed ecosystem functioning. Any management action or inaction involves a trade-off between species that benefit and those that do not.

Grassland Use

Herbivory affect grazing ecosystems ecological processes such as succession, carbon flow, nutrient dynamics and water infiltration. This effect may be negative or positive depending on moment, intensity and frequency that perturbations occur. Sound grassland management aims to orient those processes and stimulate its dynamics intervening in determining the moment, periodicity and intensity of the grazing disturbance. In this way have experimented scientists and producers, with some good and many bad results.

After evaluating 25 long term grazing management studies Holechek *et al.* (1999) concluded that stocking rate is the major determinant of grassland condition, evaluated through functional groups presence and vigour and some ecological processes symptomatology. These authors also reported that heavy stocking consistently causes a downward trend in ecological condition, while light stocking rate caused an upward trend and moderate stocking showed inconclusive results. Many other authors (Houston and Woodward 1966, Launchbaugh 1967, Smith 1967, Smoliak 1974, Martin and Cable 1974, Skovlin *et al.* 1976) have communicated that, invariably, the most productive and palatable forage species showed a decline in cover under heavy stocking. The longer the time the study involved, the more divergence there was between heavy and light stocking in terms of vegetation composition.

Unlike stocking rate studies, research comparing grazing systems has shown much inconsistency regarding influences on rangeland vegetation. Generally, rotation grazing has been more beneficial to desirable humid types forage species, when given a convenient opportunity for recovery after defoliation. But, this varied with the environment and the presence of species that do benefit. Rotation grazing systems have generally been inferior to continuous grazing in desert areas from both vegetation and livestock standpoints (Hughes 1982, Martin and Severson 1988, Beck and Mc Neely 1993). None of the studies from the semi-arid grasslands have shown that rotation grazing systems to have any definite advantage over continuous or season-long grazing in terms of forage production or vegetation composition (Klipple and Costello 1960, Houston and Woodward 1966, Smoliak 1960 and 1974, Burzlaff and Harris 1969, Skorlin *et al.* 1976, Sims *et al.* 1976, Willms et al. 1986, Hart *et al.* 1988 and Manley *et al.* 1997). Rotation grazing in humid grasslands has, in some cases, given improved vegetation productivity over continuous or season long grazing (Herbel and Anderson 1959, Drawe 1988, Heitschmidt *et al.* 1990, Taylor *et al.* 1993).

Various studies comparing the effects of continuous and rotation grazing systems on rangeland vegetation were reviewed by van Poollen and Lacey (1979). They found that forage production was, on average, about 13% higher under rotation schemes, although a greater increase (35%) occurred when heavy stocking was reduced to a moderate rate.

Generally, those experiments made in the more humid prairie ecosystems show that rotation systems are most advantageous in terms of improving vegetation composition and forage.

Humid Grasslands and the Flooding Pampas

Species persistence within plant communities in humid regions depends as much, or perhaps more, on its ability compete for aboveground resources (light) than for belowground resources (water and nitrogen). In this way tall dominant species overtop and outcompete smaller ones when the areas remain undisturbed, with a consequent reduction of green tissue, plant density (Sala 1988), and dead material is accumulated. When disturbance reduces the height and open the canopy, the selection pressures are antagonistic to the ones analysed before. For that reason, in humid grasslands occurs a shifting competition that alternatively selects for tall plant types and for short ones. The intensity and frequency of this natural perturbation may determine the proportion of different functional groups that co-exist in these plant communities. Fire will occur at different temporal scale than alternate grazing by wildlife or managed herbivores, and the latter from domestic continuous grazing.

High primary productivity, generally associated with grasses of great stature, may be greatly reduced as shorter, more grazing tolerant grasses (Sala *et al.* 1996) replaced the tall species. The effects of grazing on plant community-level diversity depend on grazing intensity, evolutionary history of the site, and climatic regimes (Milchunas *et al.* 1988) In semiarid grasslands with a strong evolutionary history of grazing, herbivore appears to have a relatively small effect on community composition. In contrast, grasslands with a shorter evolutionary history of large mammal grazing (e.g. Pampa), that evolved under light grazing conditions and under mesic conditions are more vulnerable to species invasions.

The Flooding Pampa located in the province of Buenos Aires (Argentina) is an extensive plane plain. The region has a temperate and sub-humid climate (mean temperatures are 8.5 ºC in winter and 21.5 ºC in summer and the annual rainfall ranges from 850 to 1,050 mm). They are common the periods of excesses of water, followed by those of water deficit. The soils remain water saturated in winter. In years with excessive rains, the soils are flooded from July to November (spring). In summer, severe droughts are caused by the high evapotranspiration that produces when the rainfall is low. Because of the flat relief and the occurrence of a high water table, soils belong to the halohydromorphic complex and associations (INTA 1977).

In the Flooding Pampa, the influence of grazing and flooding perturbations upon community diversity was distinctly perceived according to the spatial scales and levels of the species hierarchy defined by Chaneton and Facelli (1991). High plant species richness was the salient feature of the grassland under continuous grazing, having the grazed community a lower stand diversity and a higher patch diversity than the ungrazed one. This suggest that large herbivores may drastically alter dominance hierarchies by selectively feeding upon grasses that concentrate dominance in ungrazed conditions (Facelli 1988, Sala 1988, Facelli *et al.* 1989), relaxing its competitive strength.

Grazing allow the invasion and subsequent dominance of low-growing subordinate and exotic dicotiledon and grasses (Sala *et al.* 1986, Facelli *et al.* 1989, Oesterheld and Sala 1990), and thus increasing plant species diversity when compared with areas that have been excluded to grazing by large domestic herbivores. The grazed grassland had a higher number and cover of native and exotic forbs, but comparable numbers and cover of both cool and warm grasses (Rusch and Oesterheld 1997). This addition of exotic species has been accompanied by a decline in ANPP, indicating that ecosystem function can vary substantially regardless of the number of species present. This suggests that the displacement to subordinate positions seems to have had a major impact on the grassland's production.

The identity of dominant species, rather than the number per se, can have a significant influence on ecosystem function processes.

Grassland Use Experiments in Humid Flooding Pampa

We considered that observed reductions in primary production and other malfunctions caused by continuous overgrazing of these grasslands were basically caused by (i) weakening and disappearance of certain desirable functional groups caused by overgrazing and, (ii) reduced water infiltration in increasingly nude soils.

Assuming that is possible to revert such situation through management practices that allow periodic rests in order to benefit some functional groups and improve ecosystems function we designed grazing experiments in different locations of the Flooding Pampa. Experimental layouts were made in cow-calf commercial farms located in four different areas of the Flooding Pampa region. In each farm we oriented the grazing management of around 1,000 ha of native grasslands, where grass grew yearlong because of its mild weather (Deregibus 2000).

A group of studies were conducted in midland and lowland communities (B and C "sensu" León, 1975), which occurs on shallow and infertile soils whose surface pH varies between 6 and 7 (Berasategui and Barberis, 1982). Species of C_4 genus (*Paspalum, Bothriochloa, Sporobolus, Panicum*, and C_3 *Stipa, Briza, Piptochaetium* and *Danthonia*) dominate midland community. Lowland community is dominated by palustric C_4 species *Paspalidium paludivagum* (Hitchc. et Chase) Parodi and the C_3 grasses *Leersia hexandra* (Sw.), *Chaetotropis elongata* (H.B.K.) Björkm. and *Lolium multiflorum* Lam. Grasslands of all farms had been continuously stocked for more than 25 years with 420 kg live-weight cows (Angus and Hereford breeds) and their calves, that were weaned and sold during April at six months of age with an average live-weight of 170 kg. The annual stocking rate average 0.6-0.7 breeding cows(.) ha^{-1}.

The alternative grazing methodology applied over the last decade, consists of the following procedures:

1) Concentration of animals in large herds, which are moved through paddocks, designed to separate and subdivide areas of homogeneous vegetation. Because a large proportion of the grazing area is rested, grazed plants are allowed an opportunity to regain its vigour.

2) Autumn and winter non-selective grazing with dry cows of slow growing or dormant summer vegetation (C_4 grasses) during. Such intense and slow grazing movement through the paddocks, performed when plant growth and animal nutritive requirements are low, tends to stimulate establishment, tillering and growth of perennial or annual cool-season (C_3) grasses.

3) Spring and summer selective grazing by lactating cows and their calves. This lenient and fast grazing, ensures maximum animal intake and fulfilment of its high nutrient requirement, as well as high plant growth and abundant flowering.

The effect of varying the grazing methodology on each plant community was evaluated through (i) the variation in plant cover as a consequence of the imposed grazing situation and (ii) the variation in species diversity (H). Both communities (midlands and lowlands) were sampled in four paddocks per farm during summer (December) and winter (July) during three consecutive years, registering basal cover of each species along a 10 m transect. Comparisons were made with the same plant communities that grew in neighbouring farms, grazed at similarly high stocking rates (annual average 0.9-0.95

breeding cows ha$^{-1)}$. Species diversity was calculated by Shannon-Weiner index (Goldsmith *et al.*, 1986):

$$H = - \sum_{i=1}^{s} (p_i)\,(\log_2 p_i)$$

where H =index of species diversity derived from the information statistics, S = number of species and p_i = proportion of total sample belonging to the i^{th} species. With the same data was estimated the proportion of soil covered by litter or plants and some functional groups density.

As may be observed in Table 1(ver observaciones en la tabla), plant species diversity suffered no variation as consequence of a decade of implementation of a different grazing methodology in any of the two communities that were monitored. What was caused by the improved way of using these grasslands is the variation in several structural indices and the presence of certain functional groups. The following beneficial effect of rotational stocking have been observed (Table 2) (see Deregibus *et al.* 1995): (i) a reduction of bare soil and an increase of litter cover, (ii) the density and productivity of cool-season grasses was increased, (iii) a reduction of warm-season creeping grasses and planophile weeds, (iv) an increase in the density of palustric warm-season grasses in lowlands and (v) an increment of 50 % in the average stocking rate. In a similar experiment where primary productivity was evaluated, cool season species doubled and no variation the overall production of biomass (Jacobo *et al.* 2000).

Aiming to understand the effects of varying the grazing methodology in a more rigorous environment, a second grazing study in the halomorphic lowlands of the Flooding Pampa (I community "sensu" León et al. 1979) that, because of its soil lack of structure, shows very low infiltration rates (Alconada *et al.* 1993) and plants are water stressed as in a semiarid environment. This study was carried out in the Northern area of region (57º 30' W, 35º 30' S), located near Veronica town. The soil that occupies the biggest extension in the studied area is the typical Natracualf that is located in the low areas of the landscape, presenting an intricate distribution pattern with typical Natracuol. The native grassland is characterised by an intricate mosaic of communities, being located in the low areas the stands of the halomorphic communities, dominated by *Distichlis spicata* (L.), *D. scoparia*, *Sporobolus pyramidatus* (Lam.) and *S. indicus* (L.). These stands, they are inserted with others where prevail species like *Stipa papposa* (Nees.), *S. charruana* (Nees.), *Stenotaphrum secundatum* (Walt.), *Dantonia montevidenses* (Hack. et Arech.) and *Eryngium ebracteatum* (Lam.), while approaching to the water course we find the stands dominated by *Ludwigia peploides* (H.B.K.), *Alternanthera philoxeroides* (Mart.) and *L. hexandra*.

We assumed it was possible to halt deterioration and encourage a successional process to take place through some structural and functional modifications and that species establishment will increase plant cover and favour water infiltration if we varied the grazing method. With few modifications of the disturbance events and rest periods a similar alternate grazing method to previous experiments was implemented. The objectives of this second study were similar to those described above plus soil water status measurement when covered or not by plants.

In a temperate and humid grasslands where controlled grazing was implemented, a paddock vastly covered with halomorphic communities was reduced in its stock (0.54 cow.ha^{-1}.year^{-1}) and compared with an area continuously grazed at the current stock (0.98 cow.ha^{-1}.year^{-1}) and with another area excluded to grazing of large herbivores. The numbers species and plant cover was measured for each treatment at every climatic season during six consecutive years, along four randomly placed 10 m interception lines. Species diversity (H) was calculated using the Shannon-Weaver index as explained above. Soil water potential was determined using psychrometers and microvoltimeter. Psychrometers were placed randomly at 5 cm under three *S. indicus* plants and in three bare soil positions between plants for each experimental plot.

Plant cover of ungrazed or continuous grazed, were not significantly different to the original value after six years experiment, while a significant difference was measure on the controlled grazed site (Table 3). No change was observed in botanical composition (H and species #) for the continuously grazed treatment, while important changes occurred as a consequence have ungrazed and controlled grazed. The significant reduction in plant species diversity in the ungrazed area was caused by the dominance of salt grass (*Distichlis spp*). On the other hand, in controlled grazed site, biodiversity significantly increased after the third year with important establishment of foraging species (*L. multiflorum, Botriochloa laguroides* D.C., *B. sacharoides* Sw. and *S. indicus).*

During the critical summer time the soil water potential under the plant was higher than that under bare soil being higher the stress in the continuously grazed environment (Table 3). This leads us to conclude that the reduction of the plant cover caused by continuous cattle grazing increases soil water and salinity stress, as infiltration rate of the bare typical Natracualf soil is affected. Controlled grazing encouraged a successional process that did no occur in the areas that were excluded to grazing. Water status decreased steadily as basal plant cover decreased.

These experiments are very illustrative of the possibilities of managing some of temperate and humid grasslands of the Flooding Pampa in an alternative and improved way. Knowing what is required for an ideal functioning of the grazing ecosystem is possible to design an harmonic combination of actions (disturbing events, rest periods, etc.) that aims to improve primary and secondary productivity without affecting, or even improving, its condition. Sound-grazing management consists in assigning correctly a stock rate and distribute it seasonally throughout the grazing area. Forage plant growth and invigourment is achieved through periodic rest periods while vegetative multiplication and seedling establishment is stimulated through time controlled disturbance events of variable intensity. Such management procedures also allows purposely shifting the structural characteristics of the sward and orient plant succession for enrichment with desired forage plants and increase in plant density. Through time controlled grazing pasture condition was improved in our experiments but showed no consistency with plant diversity values. No variation in plant diversity was observed in two of the plant communities while, in the halomorphic one, an increase in plant diversity was observed when compared with the continuous grazing or with an area excluded to large herbivores grazing.

Conclusions

The key to understand the effect of good grassland use sprouts when analysing variations in species composition rather than using plant diversity indexes. As has been shown, good forage grasses thrived into the grasslands replacing native and exotic forbs in the first experiment reported, or colonising in-between the dominant species ramnets in the more rigorous halomorphic environment. This agrees with Sala *et al.*. (1996) assertion that the effect of disturbances on ecosystem function is not related to the number of species, but to which species are added or deleted. Because of this, the effect of species diversity on production should be assessed with reference to which species have been deleted, and with respect to the driving forces behind the observed changes in diversity, rather than the diversity itself. Recent experimental evidence (reviewed by Chapin *et al.* 2000 and Mc Cann 2000) generally supports the idea that diverse species ecosystems are generally more stable and function better. We have seen that this is not always true as, improved grassland use should look after altering species occurrences and their relative abundance due to management actions, such as changes in livestock grazing and/or any other disturbance regimes.

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Table 1 - Grazing effect on species diversity (H) in two commun of different areas of looding Pampa grassland.

Grazing Method	Season	Area Syte			
		Vieytes	Rauch	Veronica	Alvear
	Summer		Midland community		
Controlled		3.33	2.73	3.16	3.50
Continuous		3.17	2.37	3.14	3.46
	Winter		Midland community		
Controlled		3.00	3.37	2.94	2.86
Continuous		3.37	3.62	3.22	2.48
	Summer		Lowland community		
Controlled			2.45	2.51	2.53
Continuous			2.47	2.70	2.96
	Winter		Lowland community		
Controlled			3.13	2.54	2.92
Continuous			2.88	2.70	2.32

Table 2 - Variation in structural and functional characteristics of humid communities grazed in a controlled way with respect to continuously grazed sites.

Keystone species and Functional groups	Times
Cool-season annual grasses	+ 3.60
Cool-season perennial grasses	- 0.05
Warm-season bunch grasses	- 0.10
Palustric warm-season grasses	+ 1.66
Legumes	+ 2.10
Dicotyledons	- 0.48
Other Structure Values	
Bare soil	- 0.70
Litter	+ 1.90
Aboveground Biommass Production	
Winter	+ 2.16
Annual	- 0.08

Table 3 - Structural and functional characteristics in halomorphic communities under continuous-, controlled- and non-grazed conditions.

	1986		1991	
	Continuous grazing	Continuous Grazing	Controlled grazing	Excluded to grazers
Biodiversity				
# Species	12	12	16	10
H	3.3	3.3	4.3	1.8
Total Basal Cover	42.50%	44.10%	60.00%	51.10%
Keystone species and Functional groups				
Distichlis sp.	9.70%	11.40%	9.80%	20.60%
Forage grasses	1.30%	0.90%	10.80%	5.60%
Other grasses	22.50%	20.80%	30.70%	14.50%
Weedy species	2.80%	4.10%	2.30%	4.10%
Soil condition				
Water Potential (Mpa)				
Under Bare Soil		-9.6	-7.1	-5.5
Under Plant Cover		-6.3	-4.8	-6.2
	1986		1987	
Infiltration Rate (cm/h)	0.029	0.096	0.144	0.096
PH	8.4	8.54	8.73	8.3
Elec.Cond. (mmhos/cm)	2.59	5.18	2.35	2.02
SAR	51.48	90.14	33.93	38.28