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THE CHALLENGE OF RANGELAND DEGRADATION IN A TEMPERATE SEMIARID REGION OF ARGENTINA: THE CALDENAL

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ABSTRACT

The phytogeographical region known as the **Caldenal** comprises an area of approximately 10 million ha in the central temperate part of Argentina (35–40° S, 62–66° W). The original physiognomy of the vegetation consisted of a gramineous steppe with isolated shrubs and trees. Rangeland deterioration was initiated in the early-1900s with the introduction of livestock by the colonizing European ranchers. After a few decades of inappropriate use, the **Caldenal** proved to be a fragile environment. Major environmental impacts were: (a) The replacement of the most abundant palatable grasses *Poa ligularis*, *Stipa clarazii*, *S. tenuis*, *Piptochaetium napostaense* and *Digitaria californica* by low nutritive unpalatable grasses such as *Stipa gynerioides*, *S. tenuissima*, *S. ambigua*, *S. bracychaeta* and *Elyonurus muticus*; (b) The conversion of extensive areas dominated by grasses to a scrubland. There, frequent species are: *Condalia microphylla*, *Lycium chilense*, *Prosopis alpataco*, *Larrea divaricata* and *Chuquiraga erinacea*; (c) Depletion of plant cover resulting in incipient but increasing soil erosion in extensive areas. With the purpose of reversing this situation, the remit initiated 25 years ago was to develop management guidelines conducive to sustainable productivity while preserving the natural resources of the region. This work provides a comprehensive assessment of the impact of major stresses (drought, herbivory, fire) on grass and shrub responses, as well as more basic studies on the ecophysiology of these species. We have gained knowledge which is extremely useful to initiate rangeland utilization based on scientific information, facilitating increased sustainable rangeland productivity while preserving the natural resources.

KEY WORDS: rangeland degradation; vegetation change; desertification; Argentina; **Caldenal**

AREA DESCRIPTION

About 70 per cent of the overall 2·8 millions km^2 of Argentina is related to semiarid and arid rangeland ecosystems in terms of structure and function. The vegetation is commonly a combination of herbaceous and woody species in which shrubs frequently represent the predominant plant stratum. The major phytogeographical rangeland territories of the country are shown in Figure 1. There are pronounced ecological differences in environmental factors within these territories, which range from hot and high mountain deserts in the north to the cool Subantartic zones in Patagonia, making each of them unique in several ways. A brief description of these regions, including vegetation and land use, has been given by Fernández and Busso (1999).

The **Caldenal** is a temperate, semi-arid region in central Argentina covering about 10 million ha. In terms of phytogeographical units it corresponds to the southern subregion of the **Espinal Province** known as the **Calden District** (Cabrera, 1976) or **Bosque Pampeano** (Parodi, 1964). It is an ecotone, where grasslands begins to be replaced by woody vegetation between the Monte desert to the west with precipitation of 200 mm y^{-1} or less and the cultivated **Humid Pampa** to the east.

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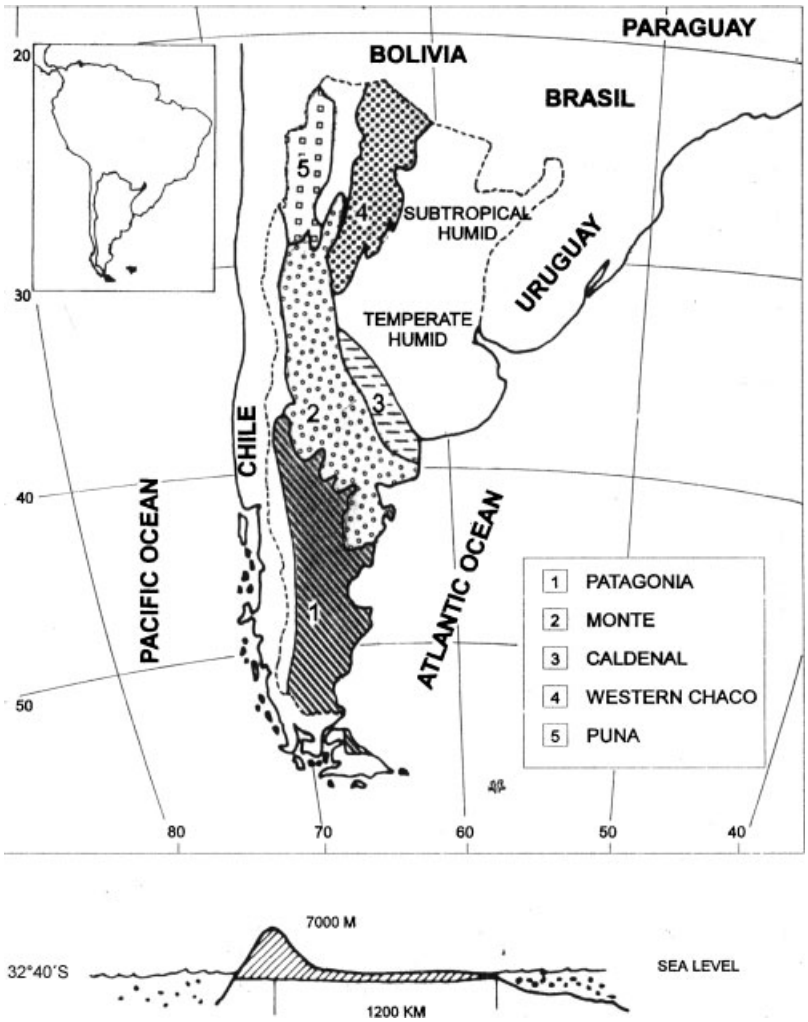

Figure 1. Major arid and semiarid rangelands of Argentina. The **Caldenal** appears as an ecotone in between the Monte desert to the west and the cultivated **Humid Pampa** to the east. (Adapted from Cabrera, 1976 and Fernández and Busso, 1999).

The area is a flat to gently undulating plain covered with recent loessic sandy sediments of eolian origin. The climate, soil and vegetation have been described by INTA *et al.* (1980). Prevailing soils are calciustolls, they usually have a petrocalcic hard pan horizon at a depth of 0·4–1 m. Soils have been classified as thermic and arid, and grouped in three defined landscape units: lowlands (deeper and loamy-sand), uplands (shallower and sandy-loam) and slopes (deeper than uplands and sandy). Soils have a pH from neutral to alkaline, 0·1–0·2 per cent total N and 2–4 per cent organic matter (Castelli *et al*., 1995).

The climate is temperate semi-arid, and aridity increases westward and southward. Mean annual temperature is 15·3°C, and mean monthly temperatures of the warmest (January) and coldest (June) months are 23·6°C and 7·4°C, respectively. Absolute maximum and minimum temperatures have been 42·5°C and −12·8°C, respectively. The frost-free period is 188 days. Mean relative humidity is 60 per cent with a minimum in December (47 per cent) and a maximum in June (76 per cent). The occurrence of strong winds is a common phenomenon during spring, the annual mean wind speed is 14 km h^{-1}. Precipitation varies from 300–400 mm and is concentrated during spring and

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fall. Droughts of greatest intensity occur in late spring and summer (November through February). Annual potential evapotranspiration is 800 mm.

The physiognomy of the vegetation is represented by a grassland savannah with isolated woody plants. It encompasses a great plant diversity in which many different plant species occur within a few square metres. Percentage cover in the south-eastern zone of the **Caldenal,** where we have conducted most of our studies (38°45′ S, 63°45′ W), vary from 50–75 per cent for a 2 m high woody layer, 35–50 per cent for the herbaceous layer and 30–45 per cent for bare soil (Bóo and Peláez, 1991). A dominant component for the whole territory is *Prosopis caldenia* Burkart, commonly known as '**caldén**', which is the typical and almost exclusive tree giving the name to the area. The '**caldén**' is an endemic, xerophytic deciduous tree that may exceed 10–12 m height. Tree presence diminishes going westward and southward, where the woody vegetation gradually becomes an open shrubland.

The shrub layer is very rich; it is represented by caducifolious species such as *Prosopis flexuosa* De Candolle, *P. alpataco* (Phill.), *Condalia microphylla* Cavanilles, *Geoffroea decorticans* (Gill.) Burk, *Prosopidastrum globosum* (Hill. ex Hook. et Arn.) Burk, *Lycium chilense* Miers, *L. gilliesianum* Miers, and the evergreen perennial, *Chuquiraga erinacea* Don, *Larrea divaricata* Cavanilles, *Baccharis ulicina* (Hook. et Arn.), *Capparis atamisquea* Kuntze; other almost aphyllous species are *Ephedra triandra* (Tul.), *Ephedra ochreata* Miers and *Senna aphylla* (Cav.) Irwin & Barneby. The presence of halophilous steppes of *Cyclolepis genistoides* (Don.), *Atriplex lampa* Gill. ex Moquin and *A. undulata* (Moq.) Dietrich is frequent in poorly drained areas. Covas (1971) carried out an inventory of the woody species from which cattle and sheep feed, *Lycium chilense* and *Ephedra triandra* are possibly the two most palatable shrubs in this territory; legume trees and shrubs are important fruit suppliers, the '**caldén**' tree, *P. alpataco* and *P. flexuosa* are valuable for the production of palatable pods. *Geoffroea decorticans* drupes are also eaten by livestock.

One characteristic of this region is the richness of its native productive grasses making the **Caldenal** one of the richest natural grasslands of the country as a function of coincidence of favourable conditions of climate and soil with a precipitation which may appear high for strictly arid lands; but this is not enough for intensive crop production. The herbaceous layer is dominated by cool season perennial grasses. Based on animal preference, Distel and Bóo (1995) grouped the species in three categories: mid preferred grasses, mainly represented by *Stipa longiglumis* Philipi, *Poa ligularis* Ness, and *Stipa clarazii* (Ball.); short preferred grasses including *Stipa tenuis* Philippi and *Piptochaetium napostaense* (Speg.) Hackel, and non-preferred grasses represented largely by *S. gynerioides* Philippi and *S. tenuissima* Trinius. Two introduced annuals, *Medicago minima* (L.) Grufberg and *Erodium cicutarium* (L.) L'Herit., are known for the high quality forage they provide during spring in overgrazed areas.

Ecological Deterioration of the Caldenal

Ecological deterioration of the **Caldenal** as a consequence of anthropogenic actions began early in the 20th century with the settlement of colonizing European ranchers. Historically, in human terms this is almost an empty land; population density has been, and still is today very scarce, 0·05–1·3 habitants per square kilometre (Morris and Ubici, 1996). The settlers initiated a livestock production industry based on natural grazing of the vegetation, in absence of knowledge of, or with no concern about, ecosystem conservation and management. Present use of the land is almost fully dedicated to cow-calf production, and the stocking rate currently ranges from 5 to 7 ha cow^{-1} y^{-1} (Llorens, 1995; Distel and Bóo, 1995). The ranches are commonly units between 1000 and 10 000 hectares in size (Morris and Ubici, 1996). No areas have escaped foraging and decades of inappropriate use of the land showed the **Caldenal** to be a fragile environment where vegetation is readily damaged, and at times is impractical to recover. Most of the study area is in a progressive stage of degradation.

Major environmental impacts as a result of rangeland mismanagement were the shift in species composition, changes in community structure and soil erosion. Floristic changes induced by continuous intensive grazing in native rangeland by livestock have been recurrently recorded throughout the world (Archer, 1989; Noy-Meir *et al*., 1989; Laycock, 1991; Milchunas and Lauenroth, 1993; Briske and Richards, 1994; Wiegand and Milton, 1996).

In the **Caldenal,** the shift in species composition involved the replacement of palatable grasses by unpalatable ones, and in a number of cases by woody perennials. Following an historical perspective, the beginning of

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the development of this new ecological layout was mainly associated with the appearance of a new type of herbivore with its novel sort of foraging behaviour, in a territory in which, from the end of the Pleistocene to European colonization, large herbivores had been very scarce (Webb, 1978; Bucher, 1987). Therefore, the pristine natural equilibrium model started to change in a way to a new structure and order, the day that the first domestic ruminant was brought and foraged selectively on the available natural vegetation composed of a diverse mix of grasses, herbs, shrubs and trees. Animal diet preference for a given type of plant is thought to be influenced by palatability, which is considered a complex phenomenon that integrates odour, taste and texture with the postingestive effects of nutrients and toxins in food (Provenza, 1995; Provenza and Villalba, 2006).

The state-and-transition model of vegetation changes in the region have been described by Distel and Bóo (1995). In areas that have been closed to grazing for 10 or more years, *S. clarazii* and *Poa ligularis,* two of the most preferred species, would be dominants. They are highly competitive in the absence of grazing but are very sensitive to continuous herbivory (Moretto and Distel, 1995). At locations with constant moderate utilization, these species have been replaced by other desirable grasses more tolerant to grazing, where *Stipa tenuis* and *Piptochaetium napostaense* behave clearly as dominants. Long term intensive grazing has been the rule since the introduction of the livestock in the **Caldenal**. Under these conditions it was shown that selective defoliation of dominant palatable species confers a competitive advantage to unpalatable ones, which could ultimately lead to the disappearance of desirable grasses and hence a community shift in favour of unpalatable species, with the dominance of *S. gynerioides* and *S. tenuissima* (Distel and Bóo, 1995; Moretto and Distel, 1999).

Today, this is the situation for extensive areas in this region where the natural grassland that was characterized by the majority of the most productive and palatable grasses has been transformed into a very low quality one (low nutritive value, high lignin content) (Figure 2). Considering this new ecological system from the strictly conservation viewpoint, as long as a grass cover is present, the ecosystem is still reasonably protected in its integrity. Soil erosion is averted, nutrient, water and energy cycles are somehow safeguarded, the rich animal biodiversity is not so endangered. However, from the economical or land owner point of view, the new ecological equilibrium reached can be a disaster.

For the temperate semiarid rangeland under study, shrub encroachment is another important vegetation shift. Woody species, originally presented as an open shrubland or confined to reduced areas, have slowly and relentlessly invated to become weeds that are advancing on a vast region, threatening cattle raising activity. As in many other parts of the world (Knoop and Walker, 1985; Brown and Archer, 1989, 1999; Archer, 1995; Van Auken, 2000), this type of vegetation change is attributed to a combination of heavy continuous grazing, lack of fire and the availability

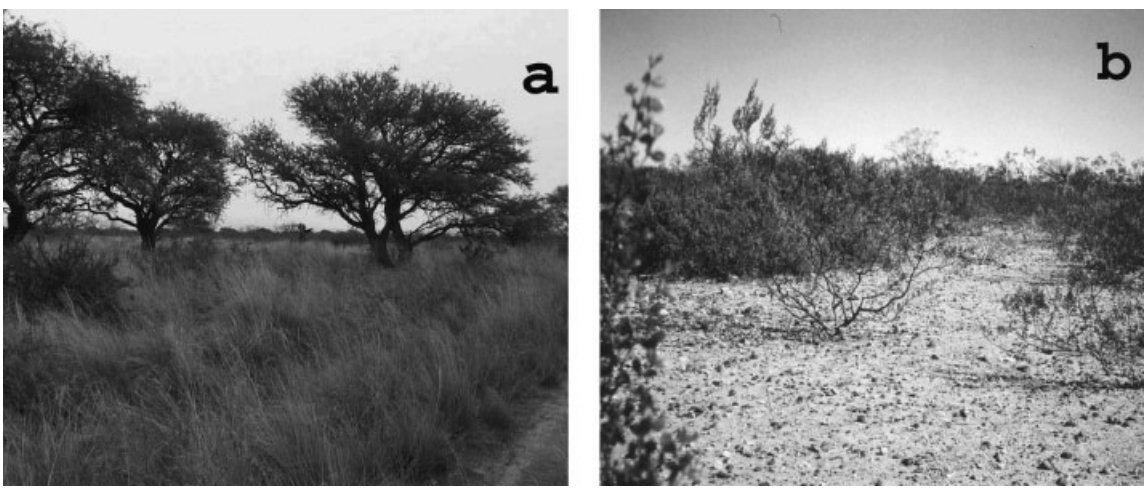

Figure 2. (a) A good rangeland condition composed mainly by *Stipa tenuis, Piptochaetium napostaense, Stipa clarazii and Poa ligularis.* Situations like this are rarely found. Because of unconcern or little knowledge of natural ecosystem management techniques the landscape may repeatedly exhibit degraded conditions as in (b).

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of shrub propagules. The significant advance of *Geoffroea decorticans* in the northern **Caldenal** has been attributed by Anderson (1977) to fire suppression, overgrazing and the cultivation of marginal lands and their subsequent abandonment. Fire frequency is considered a fundamental natural issue associated with vegetation dynamics. Based on historical observations it appears that fire occurred at 5-year intervals before the introduction of livestock into the area (Distel and Bóo, 1995). Ever since, fire frequency has decreased owing to a reduction of fire fuels and the prevention of fire by land owners (Cano *et al*., 1985; Distel and Bóo, 1995). The reduction of the grass layer due to overgrazing affects their competitive capacity favouring establishment of shrub seedlings in concordance with opportune rainfalls (Peláez *et al*., 1992, 1996; Distel and Bóo, 1995; Bóo *et al*., 1997). In turn, sites dominated by *P. napostaense* and *S. tenuis* have been transformed into dense shrublands, where *P. flexuosa, C. microphylla, L. divaricata*, *Chuquiraga erinacea* and *G. decorticans* have become dominants. Primary productivity of the grassland layer under the dense shrub canopy is always very low, and in the case of some valuable fodder shrubs, like *Lycium chilense* and *Ephedra triandra*, continuous browsing provoked their replacement by other less palatable or non-palatable thorny species. A critical consideration once shrub encroachment has occurred is that the woody dense vegetation will persist for ever; any attempt at ecological restoration to a more desirable productive state would not be viable unless the woody species were cleared; adjusting the stocking rate or/and resting periods would not be sufficient. Several local works (Bóo, 1980, 1990; Distel and Bóo, 1995; Bóo *et al*., 1996, 1997) indicate that appropriate use of fire in association with proper grazing management could be an effective and economic approach to encourage vegetation to recover.

The eastern part of the **Caldenal** is at the fringe of the cultivated sub-humid Pampa; thus, plowing this marginal land for crops (wheat, oats) represents a perpetual appeal for land owners. Modest and unpredictable rainfall, severe cold or high temperature resulting in high season-to-season variability, in association with a complex natural vegetation mix with trees, shrubs and grasses, poses constraints to agriculture. Most of the time soil cultivation is translated into a poor grain crop, leaving behind a degraded ecosystem in terms of forage production and soil erosion. Laborde *et al*. (2006) propose a non-tillage forage strategy ley farming system based on improved pasture legumes in an attempt to find a cropping strategy that can reduce the restrictions of climate and soil. A naturalized annual exotic species that deserves further attention is *Medicago minima*, native to the Mediterranean region which was already quoted in 1913 by Hauman-Merck (1913) as a constituent of the adventitious flora of Argentina. Its persistence is ensured by its capacity to colonize open, overgrazed areas as well as to grow in association with perennial grasses. Several local studies (Fresnillo Fedorenko *et al*., 1991, 1994, 1995) showed that it has high phenotypic plasticity under unfavourable environmental conditions, enhancing its capacity to survive and reproduce. The only planted pasture with a margin of success in favourable small areas (50–200 ha) is weeping love grass (*Eragrostis curvula* (Schrad.) Nees), a drought resistant species which after a successful implantation gives a permanent pasture during many years; though its nutritional value is from medium to poor, it provides a maintenance diet for cattle during the summer when the productivity of the poorly managed natural pasture is at a minimum. A comprehensive publication on the biology and utilization of weeping love grass has been edited by Fernández *et al.* (1991).

One of the major concerns about desertification in the **Caldenal** is the extensive damage caused to the soil. The lack of vegetation is always translated into the disappearance of the upper soil layer. Wind and water-sheet erosion are the main degradation processes of a soil which is no longer sheltered by a plant canopy, it becomes loose and movable through the effect of raindrop impact, animal trampling and a poor vegetative root system unable to hold soil in place; the final outcome will be physical degradation and depleted fertility. The process is aggravated by the inherent fragility of the semiarid natural system. With serious soil erosion, one of the critical limiting factors of arid or semi-arid regions is that water utilization will be disturbed and water will run off of the primary productive system; correspondingly, the nutrient and energy cycles will also be altered. A manifest proof of soil erosion is revealed by the profusion of plants growing in a sort of 10–20 cm high podium with greater root exposure. Unabashed soil erosion can have an effect on plant renewal by affecting seed germination sites, seedling establishment and adult plant growth; furthermore, the exhaustion of the seed bank of desirable grasses may well result in the disappearance of these species from the local landscape. Recovery may take many years or may be impractical where there has been a loss of species or changes in plant structure. Beyond a threshold level of

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accumulated soil loss, the ecosystem may undergo irreversible desertification since many of its biotic and abiotic structural constituents will no longer be present.

A correlate feature of desertification is the pressure placed on the rich native animal biodiversity. Vegetation reduction implies to many animals the vanishing of niches for shelter, food and reproduction, and this applies to insects as well as to small and large mammals. In addition, predators or grazing competitors of livestock have been the target of control measures. As a consequence several species (guanaco, rhea, patagonian hare, american lion etc.) are disappearing in extensive areas, or are secluded in limited territories and parks; further, indiscriminate control methods such as poison also affected non-target species (e.g. birds, rodents, armadillos). Conversely, the ecological imbalances caused by man were translated in some cases into excessive population increases in some species which finally became categorized as plagues, such as is the case of the herbivorous rodent '**vizcacha**' (*Lagostomus maximus*), at present almost free of its natural predators.

About 25 years ago an interdisciplinary programme was initiated (Fernández *et al*., 1988) by a research group at CERZOS (Renewable Natural Resources Centre of the Semiarid Region) and the Department of Agronomy, National University of the South, towards a common objective of reversing the path towards catastrophic desertification. The other main objective was to design management guidelines conductive to maintaining or even enhancing sustainable rangeland productivity, while safeguarding soil, water and biotic resources. The approach chosen focused on an integrated analysis of the problem, determining the basic data required for a better understanding of the functioning of the natural ecosystem. This was done in association with the grazing-based livestock industry. Without this basic knowledge, we felt we could not give full measures for solving the problem. An up-to-date synthesis of the major findings published up to 1996 dealing with the main stresses in the region on grass and/or shrub responses, as well as more basic studies on the ecophysiology of the species was presented by Busso (1997). Research is ongoing on subjects related to animal diet (Lindström *et al*., 2001; Pisani *et al*., 2000, 2001; Bontti and Bóo, 2002; Distel *et al*., 2005), mineral composition and nutrient dynamics (Moretto *et al*., 2001; Distel *et al*., 2003; Moretto and Distel, 2003; Gil *et al*., 2003a,b; Busso and Lobartini, 2004; Gil and Fernández, 2004, 2005), fire (Peláez *et al*., 1997, 2003; Castelli and Lázzari, 2002; Bóo *et al*., 2004), seed bank, germination and establishment (de Villalobos and Peláez, 2001; de Villalobos *et al*., 2001, 2002, 2005a,b; Mayor *et al*., 2003), stress and defoliation (Moretto and Distel, 1999; Flemmer *et al*., 2002a, 2003; Fuertes *et al*., 2003a,b; Becker *et al*., 2005), root growth (Saint Pierre *et al*., 2002, 2004a,b,c; Flemmer *et al*., 2002b), phytolitic studies (Gallego and Distel, 2004; Gallego *et al*., 2004), species replacement (Fuertes *et al*., 2003c), mycorrhiza (Saint Pierre *et al*., 2000, 2001) and management (Fernández and Distel, 1999; Distel and Bóo, 2002).

Our investigations showed some relevant conclusions which can be summarized in the following points: (a) The introduced livestock in the **Caldenal** selected diets to meet their needs for nutrients and energy by grazing a variety of plants, but they preferentially grazed some more palatable species than others, and ignored some inedible ones.

The Research-Conclusions

This process, after a few decades of overgrazing and mismanagement, transformed the highly diverse and complex vegetation world into a new ecological system, which in human terms was categorized as degraded because productivity to satisfy human needs was threatened, and biodiversity was jeopardized; (b) Poor management of the land and continuous overgrazing reduced the abundance of the more palatable grasses up to a point that recurrently some species have disappeared, even from the seed bank. It is interesting to note that sites which act as reservoirs for these species are associated with the protection given by spiny shrubs where desirable species are kept somewhat out of livestock's reach. The over-all results appear to be a contrasting situation in between the degraded pasture and the eco-physiological aptitude of desirable species. Our studies indicate that desirable grasses are better equipped to behave as dominants in the **Caldenal**, for example, they have higher tolerance of water deficit than undesirable species (with respect to germination, seedling establishment, defoliation and root growth dynamics). Furthermore, the reconstruction of the floristic story of the **Caldenal** of about 100 years ago, as a result of soil phytolithic studies, indicates the prevalence of desirable gramineous species previous to livestock introduction. Thus, if that situation has not persisted it is because of the lack of opportunities generated by human action and because of the manner in which we managed the land in general, and herbivory in particular; (c) Shrub encroachment is coupled with

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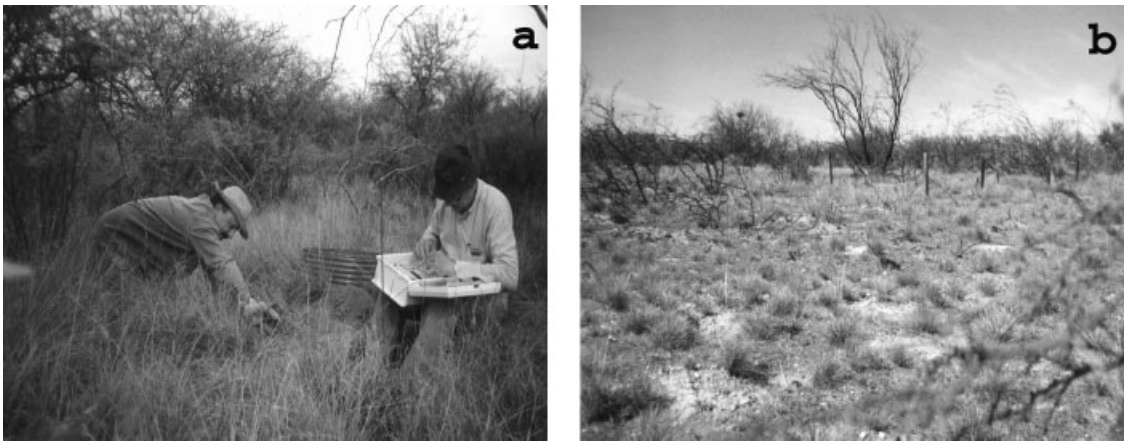

Figure 3. (a) Two CERZOS's researchers, Roberto M. Bóo and Omar R. Elía, installing thermocouples in plants and soil in an area which will be subjected to a prescribed fire. The area is characterized by a heavy shrub invasion and a mixed grass layer dominated by undesirable species. (b) The same place 18 months later, after a prescribed fire showing a floristic change with the predominance of *Stipa clarazii*, one of the more palatable species.

overgrazing and the prevention of natural fires. Our research with provoked fire demonstrated that herbaceous and woody species are fire tolerant, they have evolved with frequent natural fires. However, undesirable grasses and woody species appear to be more sensitive to fire than desirable grasses, therefore prescribed burning can be used as a tool to improve range forage conditions (Figure 3); (d) Controlling selective grazing by manipulating the timing of grazing, and forage pressure on plants, can influence the botanical composition of the pasture in favour of the most desirable species, if availability of established individuals or their diaspores is appropriate. (e) The necessary steps to halt desertification are linked with the management of stocking rate, grazing, breeding herd and fire. The expected results are to achieve increased production of ecological-meat per animal and per hectare in a region which is unsuitable for cultivation, where there is little need for mechanization and where natural vegetation diversity carries on growing without the need of being reseeded; on the whole, a sustainable use of the land.

One of the main social achievements of our research has been the rise in awareness among land owners that desertification is the most serious environmental problem of the **Caldenal**; this consensus is strictly essential in a region where the ranchs are all private property. The answer resides in re-restoring a system based on the understanding that preserving the natural system not merely for the profit of livestock industry, but also for the welfare of the soil, water, biodiversity and the future. Fortunately, the problem is not aggravated as in other arid and semiarid rangelands of the world by the presence of a high density human population; as stated above, this is almost an empty land in human terms, the interlocutors are few, and generally gathered in rancher's associations, in such a way that it is easy to get in touch with them.

Till date, landscape degradation in the **Caldenal** ecosystem has not reached the level of devastation as in other parts of the world where desertification is an irreversible end result. The ecological system and species still exist, we can anticipate improvement in land use which may ensure sustainability and biodiversity.

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REFERENCES

Anderson DL. 1977. Las causas de la invasion del chañar en el area medanosa de pastizales e isletas de chañar. In *Limitación en la Producción Ganadera de San Luis Debido a las Leñosas Invasoras*. Agencia Extensión Rural San Luis. INTA: San Luis, Argentina; 11–13.

Archer S. 1989. Have southern Texas savannas been converted to woodlands in recent story? *The American Naturalist.* **134**: 545–561.

Archer S. 1995. Tree-grass dynamics in a *Prosopis*-thornscrub savanna parkland: Reconstructing the past and predicting the future. *Ecoscience* **2**: 83–99.

Becker GF, Gittins C, Souto C, Siffredi G, Busso CA. 2005. Efecto de la frecuencia de defoliación de *Poa ligularis*: Relación entre la producción de biomasa aérea y la disponibilidad de carbohidratos no estructurales. *Resúmenes 3° Congreso Nacional sobre Manejo de Pastizales Naturales*, Paraná, Entre Ríos, Argentina; 106.

Bontti EE, Bóo RM. 2002. Sample numbers for microhistological estimation of fecal vizcacha diets. *Journal of Range Management* **55**: 498–501.

Bóo RM. 1980. El fuego en los pastizales. *Ecología Argentina* **4**: 13–17.

Bóo RM. 1990. Algunos aspectos a considerar en el empleo del fuego. *Revista de la Facultad de Agronomía, Universidad Nacional de La Pampa* **5**: 63–80.

Bóo RM, Peláez DV. 1991. Ordenamiento y clasificación de la vegetación en un área del sur del Distrito del Caldén. *Boletín de la Sociedad Argentina de Botánica* **27**: 135–141.

Bóo RM, Peláez DV, Bunting SC, Elia OR, Mayor MD. 1996. Effect of fire on grasses in central semi-arid Argentina. *Journal of Arid Environments* **32**: 259–269.

Bóo RM, Peláez DV, Bunting SC, Mayor MD, Elia OR. 1997. Effect of fire on woody species in central semi-arid Argentina. *Journal of Arid Environments* **35**: 87–94.

Bóo RM, Peláez DV, Mayor MD, Elia OR, Bontti EE. 2004. Efecto de fuegos controlados en una comunidad vegetal del sur del Caldenal. *Resúmenes II Reunión Binacional de Ecología*. Asociacíon Argentina de Ecología-Socieded de Chile. Mendoza, Argentina; 197.

Briske DD, Richards JH. 1994. Physiological responses of individual plants to grazing: Current status and ecological significance. In Vavra M, Lycock WA, Pieper RD (eds), *Ecological Implications of Livestock Herbivory in the West*. Timber Press: Denver; 297.

Brown JR, Archer S. 1989. Woody plant invasion of grasslands: establishment of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) on sites differing in herbaceous biomass and grazing history. *Oecologia* **80**: 19–126.

Brown JR, Archer S. 1999. Shrub invasion of grassland: Recruitment is continuous and not regulated by herbaceous biomass or density. *Ecology* **80**: 2385–2396.

Bucher EH. 1987. Herbivory in arid and semi-arid regions of Argentina. *Revista Chilena de Historia Natural* **60**: 265–273.

Busso CA. 1997. Towards an increased and sustainable production in semi-arid rangelands of central Argentina: Two decades of research. *Journal of Arid Environments* **36**: 197–210.

Busso CA, Lobartini JC. 2004. Mineral composition of *Medicago minima* and *Erodium cicutarium* under various water regimes. *Soil Science and Plant Analysis* **35**: 2243–2267.

Cabrera AL. 1976. Regiones fitogeográficas Argentinas. In Ferreira Sobral EF (ed.), *Enciclopedia Argentina de Agricultura y Jardinería*, ACME: Buenos Aires; 1–85.

Cano E, Estelrich HD, Holgado H. 1985. Acción del fuego en los estratos graminosos y arbustivos de un bosque de caldén. *Revista de la Facultad de Agronomía, Universidad Nacional de La Pampa* **1**: 81–95.

Castelli LM, Lázzari MA. 2002. Impact of fire on soil nutrients in Central semiarid Argentina. *Arid Land Research and Management* **16**: 349–364.

Castelli LM, Lázzari MA, Landriscini MR, Miglierina AM. 1995. Características químicas de un suelo superficial del sur del Caldenal (Provincia de La Pampa, Argentina). *Ciencia del Suelo* **13**: 44–46.

Covas G. 1971. Árboles y arbustos forrajeros nativos de la Provincia de La Pampa. In *IV Reunión nacional para el estudio de las regiones áridas y semiáridas. Resúmenes Comunicaciones Universidad Nacional La Pampa*. Santa Rosa: Argentina; 24–25.

de Villalobos AE, Peláez DV. 2001. Influences of temperatureand water stress on germination and establishment of *Prosopis caldenia* Burk. *Journal of Arid Environments* **49**: 321–328.

de Villalobos AE, Peláez DV, Bóo RM, Elía OR. 2001. Efecto del fuego en la germinación de *Prosopis caldenia* Burk (caldén). *Gayana Botanica* **58**: 82.

de Villalobos AE, Peláez DV, Bóo RM, Mayor MD, Elía OR. 2002. Effect of high temperatures on seed germination of *Prosopis caldenia* Burk. *Journal of Arid Environments* **52**: 371–378.

de Villalobos AE, Peláez DV, Elía OR. 2005a. Factors related to establishment of *Prosopis caldenia* Burk.: Seedlings in central rangelands of Argentina. *Acta Oecologica* **27**: 99–106.

de Villalobos AE, Peláez DV, Elía OR. 2005b. Growth of *Prosopis caldenia* Burk.: Seedlings in central semi-arid rangelands of Argentina. *Journal of Arid Environments* **61**: 345–356.

Distel RA, Bóo RM. 1995. Vegetation states and transitions in temperate semiarid rangelands of Argentina. *Proceedings of the Fifth International Rangeland Congress*. Salt Lake City: UT; 117–118.

Distel RA, Bóo RM. 2002. Unidad demostrativa de cría bovina en el sur del Caldenal. *Resúmenes del Congreso Argentino de Producción Animal*. Buenos Aires: Argentina; 334–335.

Distel RA, Moretto AS, Didoné NG. 2003. Nutrient resorption from senescing leaves in two *Stipa* species native to central Argentina. *Austral Ecology* **28**: 210–215.

Distel RA, Didoné NG, Moretto AS. 2005. Variations in chemical composition associated with tissue aging in palatable and unpalatable grasses native to central Argentina. *Journal of Arid Environments* **62**: 351–357.

Fernández OA, Busso C. 1999. Arid and semi-arid rangelands: Two thirds of Argentina, *Rala Report 200—Case Studies of Rangeland Desertification, Proceedings of the Rangeland Desertification—International Workshop*. Agriculture Research Institute: Reykjavik, Islandia; 41–60.

DOI: 10.1002/ldr

Fernández OA, Distel RA. 1999. Management guidelines for sustainable use in rangelands of central Argentina. *VI International Rangeland Congress Proceedings*. International Rangeland Society: Townsville, Australia; 1026–1027.
Fernández OA, Brevedan RM, Distel RA. 1988. An ecological approach to the use and improvement of a natural grassland area in semi-arid Argentina. *Ecological Bulletins* **39**: 48–50.
Fernández OA, Brevedan RM, Gargano AO (eds). 1991. *El Pasto Llorón: Su Biología y Manejo*. Universidad Nacional del Sur: Bahía Blanca, Argentina; 394.
Flemmer AC, Busso CA, Fernández OA. 2002a. Bud viability in perennial grasses: Water stress and defoliation effects. *Journal of Range Management* **55**: 150–163.
Flemmer AC, Busso CA, Fernández OA, Montani T. 2002b. Root growth, appearance and disappearance in perennial grasses: Effects of the timing of water stress with or without defoliation. *Canadian Journal of Plant Science* **82**: 539–547.
Flemmer AC, Busso CA, Fernández OA, Montani T. 2003. Effects of defoliation under varying soil water regimes on aboveground biomass of perennial grasses. *Arid Soil Research and Management* **17**: 139–152.
Fresnillo Fedorenko DE, Fernández OA, Busso CA. 1991. Forage production of the annual legume *Medicago minima. Proceedings IVth International Rangeland Congress*; 372–374.
Fresnillo Fedorenko DE, Fernández OA, Busso CA. 1994. Factores en la germinación de dos especies anuales forrajeras de la región semiárida Argentina. *Turrialba* **44**: 95–99.
Fresnillo Fedorenko DE, Fernández OA, Busso CA. 1995. The effect of water stress on top and root growth in *Medicago minima*. *Journal of Arid Environments* **29**: 47–54.
Fuertes MC, Fernández OA, Busso CA. 2003a. Seedling survival and above biomass in two native grasses of semiarid Argentina grown under various soil water levels. *African Journal of Range & Forest Science* **20**: 92.
Fuertes MC, Fernández OA, Busso CA, Burgos MA, Didoné MG. 2003b. Efecto del estrés hídrico sobre componentes del crecimiento en dos gramíneas nativas del Caldenal. *Resúmenes 2° Congreso Nacional sobre Manejo de Pastizales Naturales* San Cristóbal, Santa Fe, Argentina; **1**: 34–35.
Fuertes MC, Gil ME, Fernández OA. 2003c. Cambios florísticos y pérdida de sustentabilidad en pastizales naturales de la región semiárida central, Argentina. *Resúmenes del V Congreso Venezolano de Ecología*. Sociedad Venezolana de Ecología Isla Margarita, Venezuela; 81–82.
Gallego L, Distel RA. 2004. Phytolith assemblages in grasses native to central Argentina. *Annals of Botany* **94**: 865–874.
Gallego L, Distel RA, Camina R, Rodríguez Iglesias RM. 2004. Soil phytoliths as evidence for species replacement in grazed rangelands of central Argentina. *Ecography* **27**: 725–732.
Gil ME, Fernández OA. 2004. Descomposición y contenido de nitrógeno en residuos de *Medicago minima* (L.) Grufberg provenientes del sur del Caldenal. *Resúmenes II Reunión Binacional de Ecología*. Asociación Argentina de Ecología-Socieded de Ecología de Chile Mendoza, Argentina; 358.
Gil ME, Fernández OA. 2005. *Descomposición y contenido de nitrógeno en residuos senescentes de cuatro especies típicas del distrito del Caldén*. *Resúmenes 3° Congreso Nacional sobre Manejo de Pastizales Naturales.* Asociación Argentina de Manejo de Pastizales Naturales. Paraná, Entre Ríos, Argentina; 47.
Gil ME, Fernández OA, Distel RA. 2003a. Leaf litter dry weight loss and associated nutrient dynamics from *Prosopis caldenia* Burk. and *Prosopis flexuosa* D.C. in an incubation experiment. *African Journal of Range & Forest Science* **20**: 93.
Gil ME, Fernández OA, Distel RA. 2003b. Dinámica de nutrientes asociada a la descomposición del follaje de dos especies de *Prosopis* típicas del Caldenal. *Resúmenes 2° Congreso Nacional sobre Manejo de Pastizales Naturales*, San Cristóbal, Santa Fe, Argentina; **1**: 37–38.
Hauman-Merck L. 1913. Étude phytogéographique de la Región du Rio Negro inférieur (République Argentine). *Anales Museo Nacional Buenos Aires, Argentina* **24**: 289–443.
INTA, Provincia de La Pampa, Universidad Nacional de La Pampa. 1980. *Inventario integrado de los recursos naturales de la Provincia de La Pampa*. INTA: Buenos Aires; 493.
Knoop WT, Walker BH. 1985. Interactions of woody and herbaceous vegetation in a southern African savanna. *Journal of Ecology* **73**: 235–253.
Laborde HE, Brevedan RE, Fioretti MN. 2006. Technology and sustainability for the development of the Caldenal. In *Management of Natural Resources, Sustainable Development and Ecological Hazards*, Conti ME, Brebbia CA, Tiezzi E (eds). Wit Press: Southampton; 297–304.
Laycock WA. 1991. Stable states and thresholds of range condition on North American rangelands: A viewpoint. *Journal of Range Management* **44**: 427–433.
Lindström LI, Mujica MB, Bóo RM, Lutz EE. 2001. Silica bodies in perennial grasses of the southern District of the Caldén in central Argentina. *Phyton* **69**: 127–135.
Llorens EM. 1995. Viewpoint: The state and transition model applied to the herbaceous layer of Argentina's calden forest. *Journal of Range Management* **48**: 442–447.
Mayor MD, Bóo RM, Peláez DV, Elía OR. 2003. Seasonal variations of the soil seed bank of grasses in central Argentina as related to grazing and shrub cover. *Journal of Arid Environments* **53**: 467–477.
Milchunas DG, Lauenroth WK. 1993. Quantitative effects of grazing on vegetation and soil over a global range of environments. *Ecological Monographs* **63**: 327–366.
Moretto AS, Distel RA. 1995. Competencia interespecífica en gramíneas perennes del Caldenal. 2. Experimento a campo *Resúmenes XVII Reunión Argentina de Ecología*, 131–132.
Moretto AS, Distel RA. 1999. Effects of selective defoliation on the competitive interactions between palatable and unpalatable grasses native to a temperate semi-arid grassland of Argentina. *Journal of Arid Environments* **42**: 167–175.
Moretto AS, Distel RA. 2003. Decomposition of and nutrient dynamics in leaf litter and roots of *Poa ligularis* and *Stipa gynerioides*. *Journal of Arid Environments* **55**: 503–514.
Moretto AS, Distel RA, Didoné NG. 2001. Decomposition and nutrient dynamic of leaf litter and roots from palatable and unpalatable grasses in a semi-arid grassland. *Applied Soil Ecology* **18**: 31–37.
Morris A, Ubici S. 1996. Range management and production on the fringe: The Caldenal, Argentina. *Journal of Rural Studies* **12**: 413–425.

DOI: 10.1002/ldr

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

Parodi LR. 1964. Las regiones fitogeográficas argentinas. In *Enciclopedia Argentina de Agricultura y Jardinería*, ACME (ed.): Buenos Aires, Argentina (vol. 2); 1–14.

Peláez DV Bóo RM Elía OR 1992 Emergence and seedling survival of caldén in the semiarid region of Argentina. *Journal of Range Management* **45**: 564–568.

Peláez DV, Bóo RM, Elía OR. 1996. The germination and seedling survival of *Condalia microphylla*. *Journal of Arid Environments* **32**: 173–179.

Peláez DV, Bóo RM, Elía OR, Mayor MD. 1997. Effect of fire intensity on bud viability of three grass species native to central semi-arid Argentina. *Journal of Arid Environments* **37**: 309–317.

Peláez DV, Bóo RM, Elía OR, Mayor MD. 2003. Effect of fire on growth of three perennial grasses from central semi-arid Argentina. *Journal of Arid Environments* **55**: 657–673.

Pisani JM, Distel RA, Bontti EE. 2000. Diet selection by goats on a semi-arid shrubland in central Argentina. *Ecología Austral* **10**: 103–108.

Pisani JM, Distel RA, Didoné NG. 2001. Goat preference for *Prosopis caldenia* and *Prosopis flexuosa*. *Journal of Arid Environments* **47**: 173–179.

Provenza FD. 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. *Journal of Range Management* **48**: 2–17.

Provenza FD, Villalba JJ. 2006. Foraging in domestic vertebrates: Linking the internal and external milieu. In *Feeding in domestic vertebrates: From structure to function*, VL Bels (ed.). CABI Publishers: Oxfordshire, UK; 210–240.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T. 2000. Contribuyen las micorrizas a la capacidad competitiva y tolerancia a la defoliación de especies de gramíneas perennes C_3? *Resúmenes de las XVII Jornadas Científicas de la Asociación de Biología de Tucumán*. Asociación de Biología de Tucamán: Tafí del Valle, Tucumán, Argentina; 45.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T, Bravo OA, Andrioli RJ. 2001. Micorrizas vesiculares-arbusculares y la nutrición fosfatada de especies de gramíneas perennes natives. *Resúmenes de las XVIII Jornadas Científicas de la Asociación de Biología de Tucumán,* Asociación de Biología de Tucamán: Tafí del Valle, Tucumán, Argentina. Trabajo n° 86.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T, Bravo OA. 2002. Root proliferation in perennial grasses of low and high palatability. *Plant Ecology* **165**: 161–169.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T, Bravo OA. 2004a. Defoliation tolerance and ammonium uptake rate in perennial tussock grasses. *Journal of Range Management* **57**: 82–88.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T, Bravo OA. 2004b. Direct assessment of competitive ability and defoliation tolerance in perennial grasses. *Canadian Journal of Plant Science* **84**: 195–204.

Saint Pierre C, Busso CA, Montenegro OA, Rodríguez GD, Giorgetti HD, Montani T, Bravo OA. 2004c. Soil resource acquisition mechanisms, nutrient concentrations and growth in perennial grasses. *Interciencia* **29**: 303–311.

Van Auken OW. 2000. Shrub invasions of North American semiarid grasslands. *Annual Review Ecological Systems* **31**: 197–215.

Webb SD. 1978. A history of savanna vertebratea in the new world. Part II: South America and the great interchange. *Annual Review of Ecology and Systematics* **9**: 393–426.

Wiegand T, Milton SJ. 1996. Vegetation change in semiarid communities. Simulating probabilities and time scales. *Vegetatio* **125**: 169–183.

DOI: 10.1002/ldr