

## Arid and semi-arid rangelands: two thirds of Argentina

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### ABSTRACT

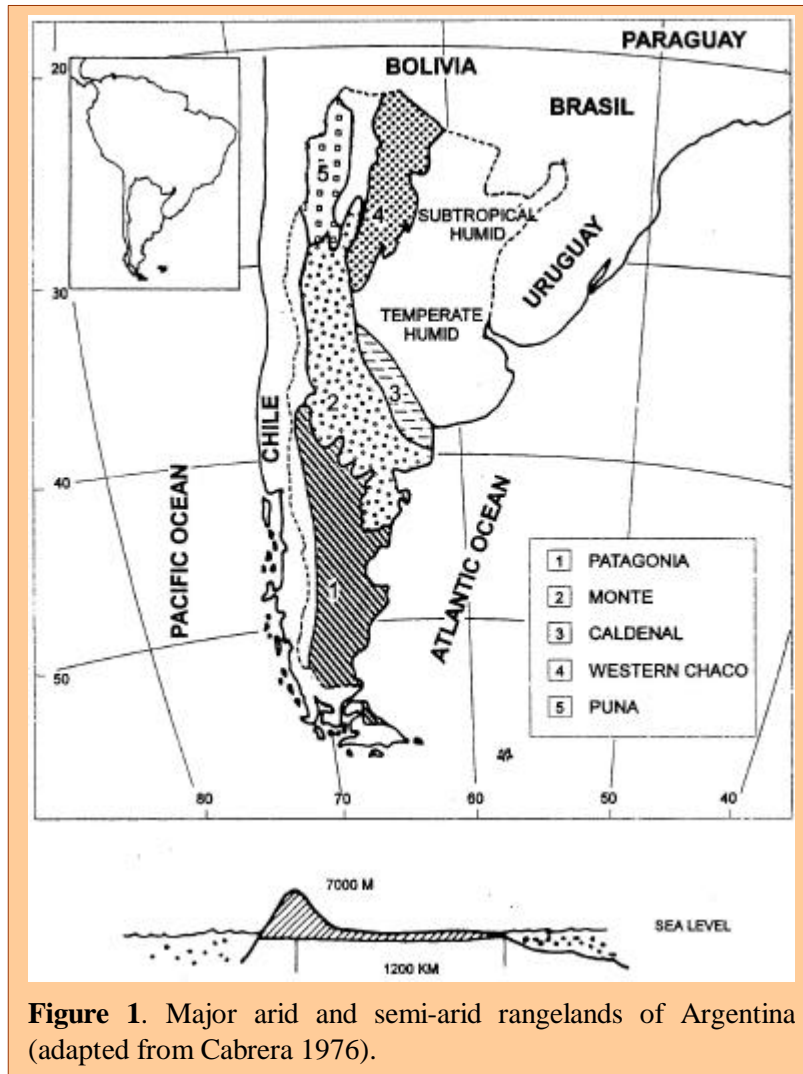
Argentina is 3 million km<sup>2</sup>, with altitudes ranging from 7000 m in the Andes in the west to sea level in the east. Therefore, the diversity in vertical and horizontal biogeographical regions is of extraordinary magnitude. About two thirds of this vast territory is associated with arid and semi-arid rangeland ecosystems. This work provides a comprehensive assessment showing the distribution of the main rangeland phytogeographical regions ranging from the hot deserts and semi-deserts in the north to the cold subantarctic arid zones in Patagonia. The intensive use of these lands was initiated with the arrival of Europeans in the region about 120–150 years ago. Although population density always remained very low, they introduced their new domestic animals which contributed to vegetation degradation and soil erosion because of overgrazing and poor management. Deforestation, fuelwood harvesting, and occasionally plowing of non-arable lands were contributing factors to the present situation in these regions where progressive signs of the various forms of land degradation are clearly evident. Desertification has become one of the most serious environmental problems for the rangeland territories of Argentina. Fortunately the present devastation has not reached an irreversible stage. We can foresee improvements in land use which may ensure its sustainability.

**Key words:** Argentina, degradation, desertification, rangelands, Patagonia.

### INTRODUCTION

Argentina extends from latitude 22 to 55°S with a surface of 3 million km<sup>2</sup>, and is 3300 km in length and about 1200 km wide at its widest point. Altitude ranges from 7000 m in the Andes at the west to sea level in the east. The diversity in vertical and horizontal biogeographical regions is of extraordinary magnitude over such a vast territory, including subtropical rain forests; central temperate, fertile mollisol soils in the Humid Pampas; extensive western arid and semi-arid regions bordering the Andes and cold subantarctic zones at the south of the country. About two thirds of continental Argentina are associated with arid and semi-arid rangeland ecosystems: the arid zone is 170×10<sup>6</sup> ha (60%) and the semi-arid zone is 48×10<sup>6</sup> ha (15%).

Environmental conditions of the major phytogeographical rangeland regions of Argentina (Figure 1) allow for the development of a more or less continuous plant cover where the vegetation is usually a combination of grass, herbaceous and woody species. Fernández et al. (1989a) have described the general characteristics and composition of shrublands in South America. There is naturally a broad ecological variation in environmental factors within the territories shown in Figure 1, making each of them unique in several ways. Some of these regions such as the Monte have shrubs as the dominant plant strata, whereas others like the Caldenal constitute a very rich grass savanna with isolated trees and shrubs. The cold Patagonian desert is characterized by a low shrubby steppe intermingled with tussock grasses. As expected, the boundaries among these phytogeographical formations are characterized by the development of wide ecotones.



**Figure 1.** Major arid and semi-arid rangelands of Argentina (adapted from Cabrera 1976).

The rangeland territories of Argentina were sparsely populated compared to the pre-Columbian situation of other parts of South and Central America (e.g. Peru, Mexico) which have been the preferential settlement of high density populated civilizations. The few native people occupying these regions lived in a semi-nomadic situation feeding upon plants and animals in a kind of ecological equilibrium with the natural environment; they had no horses until the arrival of the Spaniards. The situation has not changed much to date: 0.6 or 0.05–1.3 people per km<sup>2</sup> in Patagonia or the Caldenal, respectively (Soriano 1983, Morris and Ubici

1996). This places Argentina in a very different situation when compared with other arid and semi-arid regions of the world where environmental deterioration is largely associated with rapidly increasing human populations (see Narjisse 2000).

From the anthropogenic point of view, rangeland deterioration in Argentina was initiated about one to one hundred and fifty years ago with the settlement of the colonizing Europeans ranchers, frequently under very harsh conditions. This occurred after a period of Argentina's history known as the "conquest of the desert" with participation of the army, and when the native communities were clearly the losers. This sequence has some similarity to that occurring almost at the same time in the Great Plains of North America. Although human population always remained very low, the new settlers began a livestock production industry across the landscape based on grazing of natural vegetation, with little knowledge or no consideration about environmental impact or ecosystem management techniques. The wildland ecosystems proved to be extremely fragile and were easily injured by abusive use; all rangelands in Argentina are currently experiencing some form of deterioration or desertification. Contributing factors to this situation have been deforestation, uncontrolled wood harvesting for fuels, livestock overstocking, and in some areas plowing of non-arable lands.

The deserts and semi-deserts were at the outer edge of the central Humid Pampas which made those regions marginal and less important in economical terms when compared with the productivity of cultivated crops such as cereals, sunflower, soybean or cultivated pastures. Historically, political and government activities were oriented towards development of the richer regions in the country. Agricultural experimentation and training of technicians and university graduates were clearly focused on the productivity of the humid regions.

The contrast between irrational exploitation of the land and its proper use starts to be considered when signals of deterioration are clearly evident. It is in general a response to a situation of ecological crisis which prevails today in about 70% of the Argentinean territory. Overall, the Argentinean rangelands have suffered less degradation than most other arid land regions of the world due to their low human population density. Today the society appears to be aware of the magnitude and severity of the problem, and that it will become worse if no adequate measures are taken.

A brief description of the environmental characteristics of each territory comprising relief, soil, climate and vegetation follows. It includes discussion of the effects of past and current rangeland utilization and assessment of desertification problems in these regions.

## DESCRIPTION AND USE OF MAJOR RANGELAND REGIONS

### *Patagonia*

This territory extends from latitude 40 to 55°S and from the Atlantic Ocean to the Andean piedmont in the west, and occupies nearly 60 million ha of the southern portion of Argentina (Soriano 1983). Most of it is quoted by Cabrera (1976) as the Patagonian Province. It is one of the few cold semi-arid rangelands of the world. The landscape consists of a system of plateaus and hills of flattened surfaces. A noticeable feature characterizing the plateau surfaces is the presence of Patagonic or “tehuélfes” boulders of glaciofluvial origin. These boulders form a desert pavement due to the strong winds which prevents the deposition of material. Soil horizons at greater depth have consisted of gravel in western Patagonia, probably forming a continuous layer reaching from the Andes into the eastern foothills which makes subsurface flow of water highly possible. The existence of free water at greater depth would be contributing to the maximum rooting depth in the Patagonian arid region (Schulze et al. 1996). Soil water was available at 2–3 m soil depth within a 140-km transect from *Nothofagus* forest through grassland to desert in Patagonia, and roots reached this depth at all these sites (Schulze et al. 1996). However, further research is needed to answer the question of when and why roots of plant species in western Patagonia grow deep, since various fronts of water coming from distinct rain events were not used to a greater extent (Schulze et al. 1996). Soil water at greater depths originated from rainfall in the last or even prior to the last rainy seasons rather than water from recent rain events (Schulze et al. 1996). The observed vegetation zonation in western Patagonia cannot be explained by using water balance alone (Schulze et al. 1996); seedling establishment in the dry period may limit migration of species into drier habitats, and light competition during the active growing period may limit migration of arid species into wetter habitats. A detailed summary of the geology and soils, climate and vegetation of Patagonia has been published by Soriano (1983).

The central rangeland plateaus of Patagonia show a typical arid cold-temperate climate with four well defined seasons. Among the most noticeable characteristics of the Patagonian climate are the prevailing strong winds from the west which blow all year round. These winds, which average  $16 \text{ km h}^{-1}$  on a yearly mean basis, lose their moisture over the Andes and subsequently rainfall ranges from 100 to  $200 \text{ mm yr}^{-1}$ . In the northern plateaus and the coastal oceanic border rainfall increases slightly but it remains below  $300 \text{ mm yr}^{-1}$ . Soil moisture is strongly influenced by the recharge through precipitation (Coronato and Bertiller 1996). Soil water depletion begins in spring with decrease in precipitation, and increase in temperature and evapotranspiration. Soil water is almost depleted by late summer. Most precipitation occurs during autumn and winter and the highest soil moisture values are measured at the end of winter after snowmelt. For the Patagonia area as a whole, the annual average temperature varies from  $6\text{--}14^\circ\text{C}$ . Absolute maximum and minimum temperatures vary from  $30$  to  $40^\circ\text{C}$  and  $-15$  to  $-20^\circ\text{C}$ . Dryness of Patagonia results from a combination of low rainfall, high temperatures during the summer months, and strong winds which cause high evaporation rates. Mean annual evapotranspiration ranges from 550 to  $750 \text{ mm yr}^{-1}$ . All these values tend to decrease from the northeast to the southwest. Mean annual frequencies are 60 or more days for frost and 5 to 20 days for snowfall which occurs mainly in the west and south.

There is considerable variation in the vegetation within the Patagonian territory. Soriano (1983) has published a comprehensive review of its vegetation and quoted six floristic districts for this region. Other authors have described the vegetation for Central Patagonia (Bertiller et al. 1977, 1981a, 1981b) or the ecotone vegetation between the north of this region and the characteristic scrub of the Monte (Soriano 1949, 1950, Ragonese and Piccinini 1969, Ruiz Leal 1972). The Patagonian vegetation is characterized by a low shrubby steppe intermingled with tussock grasses. The grass family is prevalent in its floristic composition, and the genus *Stipa* is dominant including *S. humilis*, *S. speciosa*, *S. ibari*, *S. neaei*, *S. psylantha*, and *S. subplumosa*. Other significant components of the grass flora are *Poa ligularis*, *P. lanuginosa*, *Festuca argentina*, *F. pallescens*, *F. gracillima*, and *Bromus setifolius*. Large areas are physiognomically characterized by shrubs with cushion-like appearance and less than 1 m high. The most frequent shrub species are *Chuquiraga avellanadae*, *Colliguaya intergerrima*, *Mulinum spinosum*, *Senecio filagiroides*, *Verbena tridens*, *Pseudoabutilon bicolor*, *Berberis heterophylla*, *B. cuneata*, *Baccharis darwinii*, *Anarthrophyllum rigidum*, *Nassauvia glomerulosa*, *Lycium chilense* and *Trevoa patagonica*. Total cover varies from 15 to 60% depending on the environmental location and the particular range management. Low lands frequently present halophytic vegetation characterized by communities of *Frankenia patagonica*, *Atriplex lampa*, and *A. sagittifolia*. *Schinus polygamus*, which can reach a height of three meters and is one of the biggest shrubs of southern Patagonia. It has been almost extinguished from large areas because of its excellent properties as firewood.

Factors affecting species composition and diversity in the Patagonian steppe include landscapes of contrasting topography (flat vs. mountain landscapes) through their direct effects on abiotic environmental heterogeneity (Jobbagy et al. 1996). Environmental controls on community composition, however, appear to depend on plant functional type since shrub and grass, but not forb, species distributions responded to

environmental gradients ( Jobbagy et al. 1996). North-eastern slopes can be drier than uplands which may be due to the protection of these slopes from strong westerly winds prevailing in the area, which are stronger in summer, and that results in a more favourable thermic balance on these slopes as compared with uplands (Coronato and Bertiller 1996). North-eastern slopes are sensitive places for land degradation which eventually may have a restricted restoration potential imposed by physical changes in the upper soil and limited soil water availability (Coronato and Bertiller 1996).

In this region, vascular plant species can be grouped in three growth -form based groups: shrubs, grasses and forbs (Aguiar et al. 1996). Shrubs include evergreen and deciduous species which are taller than 0.5 m and without a well-developed main stem. Grasses are tufted, and have the C3 photosynthetic pathway and stiff green leaves all year round. Forbs include annual and perennial evergreen or deciduous species which are mostly dicots. Shrubs and grasses differ in their strategies to cope with limited soil water availability, an important constraint to plant growth in Patagonia. Shrubs mainly use resources from lower soil layers (Soriano and Sala 1983, Fernández and Paruelo 1988) and rely primarily on winter recharge of deep soil water. The tussock grasses, however, use resources mainly from the upper soil layers with their root systems (Soriano and Sala 1983, Soriano et al. 1987). Grasses and shrubs are less numerous than forbs but constitute most of the aboveground production (Golluscio et al. 1982, Fernández et al. 1991). Total plant biomass sharply decreased with decreasing precipitation along an aridity gradient in western Patagonia, but belowground biomass decreased at a lower rate than aboveground biomass, resulting in increased root:shoot ratios (Schulze et al. 1996). The depth of the soil horizon (0.50–0.80 m) that contained 90% of the root biomass along this gradient was similar for forbs and grasslands, but was shallower in the desert (0.30 m) ( Schulze et al. 1996).

Shrubs and grasses play a main role in community functioning by forming patches (Soriano and Sala 1986, Aguiar et al. 1992, Aguiar and Sala 1994) and controlling community dynamics (Sala et al. 1989, Mazzarino et al. 1996). Vegetation patches constrain ecosystem functioning by determining the spatial pattern of soil organic matter, soil texture, nutrient cycling and water dynamics (Aguiar and Sala 1994, Mazzarino et al. 1996). Tussock grasses (0.2 m in height) and hemispheric shrubs (0.6 m in height) are arranged in two kinds of structural patches, one formed by scattered tussocks interspersed with bare-soil areas and the other made up of shrubs each tightly surrounded by a dense ring of grasses (Soriano et al. 1994). This different vegetation structure creates microsites of different suitability for seedling establishment (Aguiar et al. 1992, Aguiar and Sala 1994, Soriano and Sala 1986). Bare -soil areas are more favourable microsites for seedling establishment than are microsites close to individual plants. Most recruitment takes place in less favorable microsites (Aguiar and Sala 1994) because patterns of recruitment are predominantly determined by seed availability, not by seedling establishment (Aguiar and Sala 1997). Recruitment patterns near existing vegetation tend to maintain and reinforce the current spatial heterogeneity (Aguiar and Sala 1997). Also, seedling establishment of desirable forage grasses in bare soil patches can be limited by summer drought, grazing and wind (Defos sé et al. 1997).

Natural vegetation in Patagonia has been used for sheep production since the end of the last century (Morrison 1917). The stocking rate varies from 400 to 1500 heads per

square league (2500 ha). Animals have been kept on rangelands throughout the year, except for summer and winter pastures which are managed separately. Sheep herding for over 100 years has resulted in a broad, noticeable desertification process. Decreased grass cover accompanied by increased shrub cover and bare ground has led to a decrease in herbivore biomass, soil water losses through evaporation and deep drainage, and reduced transpiration at the western edge of Patagonia which is occupied by grass steppes (Aguiar et al. 1996). Little of the original natural vegetation remains, and the soil is in a progressive state of erosion, intensified by the permanent strong winds from the west (Rostagno and del Valle 1988). A steady reduction of plant cover induced by grazing may intensify the concentration of nutrients in the remnant undisturbed plant patches or in newly formed patches, leaving larger areas of bare soil with limited nutrient reserves and supplies (Mazzarino et al. 1996). This regression trend induced by grazing may cause a nonsteady state of the system, where recolonization of bare patches by grasses might be limited by fertility. Fortunately, the actual process of desertification in large areas may still not have reached the level of irreversibility if simple conservation rangeland management practices are followed.

### *Monte*

The Monte desert extends from north to south in central and western Argentina. It is an extensive, almost continuous and rather uniform area of shrublands comprising about 50 million hectares. The northern portion presents a typical landscape of intermountain depressions, valleys and slopes belonging to the pampean hills. Rivers are intermittent and large salty flats are frequent. The central portion is an undulating to depressed loessic plain of fluvial, lacustrine and Quaternary eolic origin. The third, southernmost region occurs on a plateau landscape forming a wide ecotone with northern Patagonia. The Monte constitutes the most arid rangeland of the country.

Overall Monte has a dry climate, being warm in the north and gradually becoming cooler towards the south. Aridity in the northern portion is related to its position between the Andes to the west and the pampean hills to the east both of which intercept the humid winds coming from the Pacific and the Atlantic, respectively. Rains occur mainly in the summer ranging from 80 to 200 mm yr<sup>-1</sup>, and annual potential evapotranspiration decreases from 1000 mm in the west to 700 mm in the east. Annual average temperature is between 15 and 19°C. The accentuated continental climate of the intermediate region is influenced by warm and dry winds coming from the west. The summers are very warm: absolute maximum temperatures may reach 40 to 45°C, and absolute minimum temperatures may be as low as -15 to -20°C. Rainfall ranges from 250 to 500 mm yr<sup>-1</sup> and potential evapotranspiration is about 800 mm annually. The Patagonic, southern portion of the Monte has a colder climate. Its average annual temperature is 12 to 14°C and rainfall is scanty with 200 to 300 mm yr<sup>-1</sup> concentrated in winter and spring; average annual evapotranspiration is similar to that in the other two northern regions.

Classic studies of the vegetation at the Monte are those of Hauman-Merk (1913) and Morello (1958). Other studies include works of Roig (1970), Bocher et al. (1972), Ruiz-Leal (1972), Cabrera (1976) and Balmaceda (1979). Monte vegetation is a steppe scrub dominated by microphyllous xerophytic shrubs from 1 to 3 m high. It tends to be uniform in terms of its physiognomy and floristic composition despite the

vast area occupied for this territory with the associated variability in soils and climate. The most characteristic plant community dominating large areas of the Monte is the “jarillal” (Zygophyllaceae), with the presence of *Larrea divaricata*, *L. cuneifolia* and *L. nitida* as the most abundant genus. These evergreen shrubs have several mechanisms to cope with the common, severe droughts in the region (Ezcurra et al. 1991). Other evergreen shrubs are *Atamisquea emarginata* and *Zuccagnia punctata*. Deciduous shrub species include *Plectocarpa rougesii*, *Prosopidastrum globosum*, *Prosopis alpataco*, *P. flexuosa*, *Lycium chilense* and *Geoffroea decorticans*. The Cactaceae family is well represented with the *Opuntia* and *Cereus* genera whose abundance increase northward in the ecotone with the Chaco forest. Aphyllly is frequently found in the vegetation as in *Bulnesia retama*, *Neosparton aphyllum*, *Cassia aphylla*, and *Monttea aphylla*; photosynthesis takes place mainly in the green stems and branches in these species. The herbaceous understory is represented by *Cottea pappophoroides*, *Munroa argentina*, *Pappophorum mucronulatum*, *Aristida adscensionis*, *Bouteloua aristidoides*, *B. barbata*, *Euphorbia serpens*, *Boerhavia paniculata*, *Pectis sessiliflora*, *Tricholoris crinita*, *Tribulus terrestris*, *Eragrostis argentina*, and others. Some of these species are summer or winter short-lived ephemerals whose abundance is strictly dependent on seasonal rainfalls.

The Monte vegetation has been degraded by overgrazing and wood collection for over 100 years (Guevara et al. 1997). The net result of overgrazing has been the disappearance of desirable perennial forage grasses followed by invasion of unpalatable shrubs, weedy forbs and annual grasses, and the increase in bare soil. Rangelands are frequently dominated by unpalatable vegetation; palatable perennial grasses are rare and only found under the protection of spiny shrubs (*Prosopis* spp., *Condalia microphylla*), and even palatable shrubs (e.g., *Brachyclados lycioides*, *L. chilense*, *Atriplex lampa*, *Acantholippia seriphioides*, and *Bredemeyera microphylla*) have become rare (Guevara et al. 1997). Changes in plant species composition have also determined changes in the type of herbivores within the area: cattle and sheep have been replaced by goats, although recently a 5% decline per year has been detected for goats in the northern part of the plains (Guevara et al. 1997).

Low aboveground net primary productivity estimates for the herbaceous and woody components of the system, with subsequent low livestock productivities, have recently been given by Guevara et al. (1997). These low values have been the result of continuous grazing, uncontrolled fires, lack of fencing and scarcity of watering points. Research at the central Mendoza plains during the last 10–25 years allows prediction of primary production and carrying capacity for a given year, based on rainfall probabilities, and then to determine proper stocking rates (Guevara et al. 1997). Improved range management practices in these plains have allowed substantial increases in stocking rate (from 28 to 21 ha per animal unit) and animal performance in comparison to the traditional management system (Guevara et al. 1997). The economic analysis of cattle operations in the Mendoza plains has showed that most of them are negative which emphasizes the need for increasing the economic productivity of animal production systems through better range and herd management.

Shrub control by hand-cutting, mainly of *Larrea divaricata* and *Larrea cuneifolia*, has resulted in the replacement of undesirable species with productive and palatable forage (Passera et al. 1996). This control, however, is only advisable in areas with

poor forage species cover and carrying capacity, such as *Larrea cuneifolia* communities in this region (Passera et al. 1996). Since various mechanical shrub control methods have shown similar effects on carrying capacity on rangelands in the eastern foothills of the Andes, Allegretti et al. (1997) recommended that less drastic methods, such as hand-cutting and roller-chopping, should be favoured over extreme measures such as root-plowing. Despite shrub control through different management alternatives can improve forage production in the Monte, rainfall appears to be the limiting factor controlling rangeland productivity in any given year (Giorgetti et al. 1997). In addition, cattle browsing has represented 48% of the relatively dry season overall diet and 34.5% on an annual basis in the Monte rangelands (Guevara et al. 1997). Adequate chemical composition of both herbage and browse species explain why stock keep in good condition through the annual six-month dry season and supplemental feeding is not necessary (Guevara et al. 1997). Thus, brush control should not be indiscriminate nor excessive and further research should seek to find methods for selective brush control and evaluate their long-term consequences for the overall functioning and productivity of the ecosystem (Guevara et al. 1997).

Trees have also been cut as timber and/or fuel such as *Prosopis* spp., *Acacia* spp. and *Condalia mycophylla*. Hunziker et al. (1986) discussed the abusive exploitation of the *Prosopis* woods in Argentina and the urgent need for genetic conservation of the most valuable and promising species. They can provide human food, animal fodder, gums and tannins, and these species can be used by the parquet flooring and furniture industry. They are also valuable for erosion control and can even be used for alcohol and honey production. These species occur in most of the Argentine territory, except for Southern Patagonia and Misiones, and the highest number of species occurs in the phytogeographical Provinces of Monte, Espinal and Chaco (Cabrera 1976). Since Argentina is the center of the greatest species diversity in America, Africa and Western Asia, the country should take a very active role in saving valuable germplasm of these species (Hunziker et al. 1986).

### *Caldenal*

The Caldenal lies in the ecotone between the Monte desert and the cultivated Humid Pampa grasslands to the east. It corresponds to the southern subregion quoted by Cabrera (1976) as the Espinal Province, where woody vegetation begins to replace grasslands. We have identified this area as the Calden District. Recent papers have reviewed rangeland research and social and management aspects in this region (Morris and Ubici 1996, Busso 1997).

The Caldenal is a level to gently undulating plain covered with recent loessic sandy sediments of eolian origin. Dominant soils are Calciustolls with a petrocalcic hard pan horizon (tosca) at a depth of 0.5 to 1 m. The climate is temperate semi-arid, and aridity increases westward and southward. Precipitation varies between 350 and 550 mm annually and is concentrated during spring and autumn. Annual potential evapotranspiration is 800 mm. 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.



This territory is physiognomically characterized by the Caldén tree, which is the typical and almost exclusive tree, giving its name to the area; it is endemic, xerophytic, deciduous and may exceed 10 m height. Presence of trees diminishes going westward and southward, and the woody vegetation gradually becomes an open shrubland. One of the characteristics of this region is the richness of its herbaceous layer with grasses of high forage value with isolated shrubs and Caldén trees under good management conditions. In some areas in the north of this region, extensive grasslands combine with sparse large trees and shrubs to form a natural park of great beauty. The grass herbaceous cover, locally known as “flechillas”, is dominated by perennial species including *Stipa tenuis*, *Piptochaetium napostaense*, *S. speciosa*, *S. gynerioides*, *P. lanuginosa*, *Digitaria californica*, *Bromus brevis*, *Aristida subulata*, *Setaria mendocina* and *Trichloris crinita*. There are some patches of *S. clarazii* and *Poa ligularis*. Two introduced annuals, *Medicago minima* and *Erodium cicutarium*, are known for their high quality forage. However, their productivity is limited by a short growing season and little rainfall (Fresnillo Fedorenko et al. 1991).

The shrub strata is very rich and the most frequent species are *Condalia microphylla*, *Prosopis alpataco*, *P. flexuosa*, *Prosopidastrum globosum*, *Geoffroea decorticans*, *Lycium chilense*, *L. gilliesianum*, *Atamisquea emarginata*, *Ephedra triandra*, *Larrea divaricata* and *Baccharis ulicina*. Inland saline habitats in this region contain a spectrum of halophytes where shrubs like *Cyclolepis genistoides*, *Atriplex ondulata* and *A. lampa* become dominants. Other halophytes species include the grasses *Distichlis scoparia* and *D. spicata* and the shrub *Salicornia ambigua*.

The cattle production industry is the most important economic activity within the Caldenal where the grass steppe is used as the main food source for animals. Rangelands have been overgrazed since the introduction of domestic cattle at the beginning of the 1900s, and stocking rates currently range from 5 to 7 ha cow<sup>-1</sup> year<sup>-1</sup> (Distel and Boo 1996). Appropriate range management practices are seldom used. The ecological system has been degraded by inappropriate use affecting both plant and animal productivity and in many places the physical sustainability of the land itself. Another common herbivory of the grasslands and semi-arid scrubs of Argentina are large herbivorous rodents named vizcachas (*Lagostomus maximus*); males 4.5–9 kg; females 2.5–4.5 kg. They can alter the temporal and spatial heterogeneity of shrub habitat and the composition of plant communities in these regions (Branch et al. 1996). They live in social groups that share a communal burrow system and forage in a common home range around it (Branch 1993ab, Branch and Sosa 1994, Branch et al. 1994c). Intense vizcacha herbivory can depress forb and grass cover, and their effects are compounded by increased susceptibility of open sites to erosion by heavy winds common to the area (Branch et al. 1994b, Branch et al. 1996). Vizcachas can pull up root stock of bunch grasses, as well as removing foliage, which may have a large effect on the potential of grasses to regenerate afterwards (Branch et al. 1996). The effects of vizcachas on plant communities that have not been affected by domestic herbivory are unknown, however, because virtually all grassland and semi-arid scrub in Argentina have been subjected to domestic livestock grazing, most for many decades (e.g. Busso 1997, Guevara et al. 1997). Predation on vizcachas is very high and may restrict foraging distances and provide important selection pressure (Branch 1993a, Branch et al.

1994a, Branch 1995), both of which contribute to the impact of vizcachas on plant communities (Branch et al. 1996).

An additional unpredictable environmental factor in this region are natural, accidental, and sometimes provoked fires. They occur mainly during the hottest part of the year when they can get out of control and cover many thousand hectares. Busso (1997) has recently reviewed some beneficial and damaging effects of fire on the Caldenal ecosystem.

Fire and grazing history influence the dominance of a particular species group in any given area (Distel and Bóo 1996). *Stipa clarazii* and *P. ligularis* would dominate vegetation under exclosure or light grazing conditions. These species are sensitive to grazing but highly competitive in the absence of grazing, and are thought to be part of the pristine vegetation (Cano 1988, Moretto and Distel 1997). They have been replaced by other desirable perennial grasses more tolerant of grazing like *S. tenuis* and *P. napostaense* at sites where moderate grazing has been continuous. All these desirable perennial grasses, however, have been replaced by undesirable grass species (e.g., *S. gynerioides*, *S. tenuissima*) when exposed to heavy, continuous grazing. Sites dominated by *S. tenuis* and *P. napostaense* have been converted to a scrubland with a diverse herbaceous layer under conditions favouring shrub seedling establishment and of availability of shrub propagules, lack of fire or low fire frequency and heavy continuous grazing. Under these circumstances, *S. tenuis* and *P. napostaense* are dominant grass species, and *P. caldenia*, *P. flexuosa*, *C. microphylla* and *L. divaricata* are dominant woody species. If mismanagement persists, undesirable perennial grasses replace desirable ones, and annuals become common during spring within a woody layer of *Prosopis*, *Larrea* and *Condalia* species. Plant communities may return to a more desirable and productive species composition from a more degraded stage of both the soil and vegetation if the intensity and duration of fire and/or grazing are properly managed, and availability of established individuals or diaspores of the desirable species is appropriate (Distel and Bóo 1996).

Another consequence of grazing and fire mismanagement, and plowing of non arable marginal lands with subsequent abandonment, has been the unabated advance of *Geoffroea decorticans* on the native understory during the last 60 years. This small tree is very aggressive, and multiplies by seeds and vegetatively from its gemiferous (adventitious) roots forming an almost monospecific continuous shrubland layer. Primary productivity under the canopy of this species is very poor (Anderson 1977). During the First World War woody species were overused as an energy source to run engines of vapor trains. At present, harvesting of some shrubs (e.g., *Condalia microphylla*) for fuelwood for barbecue in the cities is one of the preferred uses of woody vegetation.

The eastern part of the Caldenal is at the fringe of the arable humid or sub-humid Pampas which run up to the Atlantic Ocean. Plowing of this marginal land for crops is a permanent temptation for land owners. Most of the time, this is translated into poor grain crop, leaving behind an impoverished ecosystem in terms of plant quality and soil erosion. Wind and water erosion continue to be a major cause of soil degradation in the province of La Pampa within the Caldenal. Approximately  $160 \times 10^3$  ha are

moderately affected by wind erosion in plowed areas at the eastern part of this Province, while  $185 \times 10^3$  ha have suffered severe damage (Covas and Glave 1988).

Vegetation cover and size of soil aggregates are the two most important factors that affect soil losses through wind erosion (Michelena and Irurtia 1995). Land management must contemplate the utilization of short agricultural periods (not more than 4 years), use of perennial pastures, and application of conservation tillage systems to maintain surface residues. More studies are needed to consider other land management types and conservation practices in areas with the highest wind erosion rates. One of such practices has been cultivation of relatively small and selected areas (50–200 ha) with weeping lovegrass (*Eragrostis curvula*), a drought tolerant species, which gives a permanent pasture during many years after successful implantation. Nutritional value of weeping lovegrass is from medium to poor; however, it does provide a maintenance diet for animals during the summer when the productivity of the poorly managed rangeland vegetation is at a minimum. A comprehensive work on the biology and utilization of weeping lovegrass for the semi-arid region of the country has been edited by Fernández et al. (1989b).

### *Western Chacho*

The region known as the Gran Chaco is a huge low elevation outwash plain of about 65 million ha build up of sediments derived from the eastern Andes. It comprises the north of Argentina, west of Paraguay and the southeast of Bolivia, broadly coinciding with the Chaqueña Province described by Cabrera and Willink (1980). Rainfall increases uniformly from west to east with increasing distance from the Andes. In Figure 1, only the west portion of the Argentine Gran Chaco is indicated. This region is referred to as the Western Chaco and represents the driest part of the Gran Chaco while the most humid east portion of this extensive sedimentary basin is covered by forests, savannas, marshes and subtropical wet forests. The limits for this region correspond to those established by Morello (1968) for the Chaco Leñoso and broadly overlap with those of the Parque Chaqueño Occidental described by Ragonese and Castiglione (1970) or the Distrito Chaqueño Occidental by Cabrera (1970).

The climate of Western Chaco is characterized by its humid and hot summers (October to April) and mild, dry winters (May to September). Absolute maximum temperatures can reach over  $48^\circ\text{C}$ , while absolute minimum temperatures can go to  $-8^\circ\text{C}$ . There is a general impoverishment in species richness and replacement of taxa with a subsequent general structural impoverishment associated with the rainfall decreases from the Chaco forest and woodlands to the east ( $800 \text{ mm yr}^{-1}$ ) to the Monte scrub and desert to the west ( $320 \text{ mm yr}^{-1}$ ) (Cabido et al. 1993).

The predominant soils of this territory are coarse textured, of a high base status, without an argillic horizon, but they have a epipedon darkened by organic matter. Frequently there are also alluvial soils on the floodplains of the rivers. The soil moisture regime was determined as aridic and hyperthermic or thermic for the north and south portions, respectively.

The Western Chaco vegetation consists of a medium and low forest of mesophytic and xerophytic trees with a dense understory of shrubs of Cactaceae and Bromeliaceae. There may be a prairie rich of grasses of good forage value among the woody vegetation represented by *Leptochloa virgata*, *Paspalum inaequivalve*, *P. unispica-*

tum, *Melica argyrea*, *Setaria gracilis*, *S. argentina*, *Trichloris crinita*, and others. Red (*Schinopsis lorentzii*, Anacardiaceae) and white (*Aspidosperma quebrachoblanco*, Apocynaceae) quebracho woods constitute the climax association for the region. They can be 15–20 m tall in the more humid parts. These species have been overexploited for charcoal production, and *S. lorentzii* also for tannin extraction. *Bulnesia sarmentoi* (Zygophyllaceae) wood is much appreciated because of its sweet perfume and greenish color. Legume trees are locally abundant. For example, *Prosopis alba* and *P. nigra* are considered to be among the most useful species of the Western Chaco. Their pods constitute an important supply of food for humans and livestock and they provide lumber and medicinal products. *Cesalpinia paraguariensis* is another particularly interesting tree with several practical uses for men (Aronson and Saravia Toledo 1992). Other legumes include *Acacia aramo*, *A. caven*, *Prosopis chilensis*, *P. flexuosa*, *P. ruscifolia*, *P. kuntzei*, *Geoffroea decorticans*, and others. Common representatives of the frequently dense shrub vegetation are *Bulnesia foliosa*, *B. bonariensis*, *Bougainvillea praecox*, *B. infesta*, *Castela coccinea*, *Ruprechtia apelata*, *R. triflora*, *Schinus piliferus*, *S. sinuatus*, *Mimosa detinens*, *Acacia furcatispina* and *Larrea divaricata*.

The natural ecosystems of this territory have been altered because of forest exploitation and overgrazing of the herbaceous grassland vegetation (Morello and Saravia Toledo 1959a). One of the main rangeland uses is cattle production. Anywhere grass forage tends to decrease or disappear, cattle increase browsing pressure on shrubs and tree seedlings. In areas strongly degraded by overstocking cattle is replaced by goats, which are capable of browsing on almost any type of available plant growth. This sequence in rangeland use determines disappearance of both the wood characterizing the climax situation and the herbaceous cover in many locations. It can induce the growth of a thorny dense chaparral almost useless for forage production. The shrub *Prosopis ruscifolia*, commonly known as vinal, is a good example of this in the north of this territory where it has become a serious weed. Colonizing mechanisms of vinal indicate that natural ecosystems were exposed to periodic pulses of fire and floods prior to cattle introduction which hindered the advance of this shrub (Morello 1970, Morello et al. 1971). Elimination of these two natural influences on the system allowed the explosive invasion of this species. Other genera with similar dispersion patterns that form dense shrubby communities are *Acacia*, *Celtis* and other *Prosopis*.

Although the area has overall suffered less damage than many other subtropical semi-arid and arid forests of the world, it is clear that the whole territory is subjected to a progressive degradation of the vegetative cover and soil erosion. Fortunately, there are in this region a few encouraging examples of agroforestry systems that are focused towards a more rational land use with an increased and sustained cattle industry, timber and wildlife preservation.

### *Puna*

The arid Puna covers plateaus, high plains and slopes of the Andes at elevations between 3200 and 4400 m from Bolivian border to about 27°S. It constitutes one of the coldest ecosystems of the world at these elevations. Features of this region are the characteristic basins and the subsequent internal drainage system. Interior mountains create plateaus, valleys and gulches. The predominant soils have been reported by

Etchevehere (1971) as Haplargids and Plaeorthids; dunes and extensive colluvial - alluvial accumulations with salty soils are also common.

The climate of the Puna is very harsh. It is characterized by precipitation under 200 mm yr<sup>-1</sup> which is concentrated in a wet summer season, high insolation and wide daily temperature amplitudes. The mean annual temperature is mostly under 10°C, and night temperatures below 0°C occur daily during the whole year. Snowfall is on average less than 5 days per year. The mean annual potential evapo -transpiration ranges from 500 to 600 mm.

The flora and ecology of the Puna have been reported by Cabrera (1957, 1968). A detailed study on the distribution, morphology and phenology of 115 species of this region and the Pre-Puna mountain belt has also been prepared by Ruthsatz (1974). The vegetation of the Puna is very closely related to that of Patagonia. Many of the dominant genera are frequent in both regions such as *Junellia*, *Fabiana*, *Chuquiraga*, *Nardophyllum*, *Adesmia* and *Mulinum*. Few of the Puna's genera are not present in Patagonia (Cabrera 1976). The predominant life forms are nanophanerophytes of 0.3 to 1.0 m high. The climax community is widely represented by a steppe rich in shrubby species leaving wide soil spaces among them. Dominant shrubs are *Fabiana densa*, *Adesmia horriduscula* and *Baccharis boliviensis*. Other species frequently found are *Adesmia spinossima*, *Junellia seriphioides*, *Baccharis incarum*, *Senecio viridis*, *Acantholippia hastulata*, *Ephedra breana*, *Tetraglochin cristatus*, etc. A few cactuses are present such as *Opuntia soehrensii* and *Tepherocactus atacamensis*. The herbaceous cover is sparse and only partially covers the soils. The most frequent grass species are *Stipa cespitosa* and *S. leptostachya*. Other herbaceous species representing the local flora mainly during the rainy season are *Mutisia friesiana*, *M. hamata*, *Paraonichia cabreræ*, *Mitracarpus brevis*, *Hoffmanseggia gracilis*, *Conyza deserticola*, *Portulaca perennis*, *P. rotundifolia*, and *Dichondra argentea*. *Atriplex microphylla* becomes dominant in salty plains reaching 0.3 to 0.4 m height. *Baccharis caespitosa*, *Distichlis humilis*, *Festuca hypsophila* and *Triglochin maritima* are commonly found at the border of salty flats (Cabrera 1976).

Grazing by livestock such as goats, sheep, llamas (*Lama glama*), donkeys and cattle is the principal economical activity in the Puna. Land cultivation is limited to small areas of corn and quinoa (*Chenopodium quinoa*). About 25% of the shrubs are valuable as fodder plants. Some of the more palatable species are *Ephedra breana*, *E. rupestris*, *Krameria iluca*, *Buddleja hieronimy* and *Acantholippia hastulata* which are the target of intensive browsing (Ruthsatz 1974). The poorly regulated domestic livestock grazing has had adverse impact on the natural ecosystem. Some areas are markedly deteriorated by the loss of vegetation cover, disappearance of desirable species, and soil erosion.

## DISCUSSION AND FUTURE RESEARCH NEEDS

A detailed map of utilization of the Argentinean rangelands will show that only the non-accessible areas are free from anthropogenic perturbation. A large part of the grazing industry depends on natural ecosystems for food. Most of these regions have only a thin soil or are either rugged, too dry or sparsely vegetated for practical intensive or abusive economical utilization. Direct perception of degradation of this system occurs through a number of stages which frequently are not noted at a local or re-

gional scale. Ignorance of subtle changes in ecosystem quality has been widespread throughout the arid and semi-arid non cultivable territories of the country. It is possible for ranchers and land managers to remain ignorant of the slow deterioration of desirable vegetation and the time lag for the disappearance of good forage plants with subsequent consequences on field carrying capacity. Thus, ranch owners of today tend to think that the present stage of the land is the natural situation and not the result of more than one hundred years of mismanagement.

Proper identification of the progressive rangeland degradation in the country is important. Beyond a threshold level of accumulated loss, the natural system will fall into a degree of deterioration where reversibility will be impossible, at least in terms of human life-span. A succession of good years can delay the perception of the degradation process which is usually associated with intensification of land use. This optimistic ignorance facilitates the way towards irreversible desertification.

As in many other parts of the world, ecological degradation of arid and semi-arid regions in Argentina is associated with overgrazing, timber extraction, fuelwood harvesting, soil erosion and poor management. Livestock will graze not only grasslands but also brushlands, forests, and almost any accessible place with some kind of forage or browse. They will eat almost everything in dry years.

Trying to explain the adverse impact of livestock grazing upon the vegetation and the ecosystem as a whole is a difficult task. It will require the use of adequate methodologies under the supervision of rangeland specialists. Not many of the primitive natural plant associations remain today.

Floristic impoverishment of natural pastures has led to changes in the kind of livestock in many areas of the Argentinean rangelands. Areas initially capable of supporting cattle raising have been changed to caprine livestock production. Goats are able to survive with the remnant rustic food, a consequence of previous misuse of pasture resources. Successive stages for vegetation replacement in the Monte have been as follows: (a) Non-regulated overgrazing has been mostly the routine management, (b) the primitive climax vegetation disappears as a result, (c) cattle will browse on shrubs and tree seedlings after the herbaceous layer has been degraded, (d) cattle is replaced by goats in the most affected areas which are able to eat on any kind of plant growth, (e) this sequence ends with presence of a new ecosystem where much of the natural vegetation has been replaced by a poorly productive, thorny chaparral, (f) a final situation may be characterized by soil erosion by water and wind. Plant species or livestock can be different in different regions but the final result may be equivalent. Sheep replace cattle in most of Patagonia; the end result is similar: it includes desertification and bare soil covered by a pavement of boulders as the upper soil layer is being taken off by the strong winds.

Loss of plant diversity in the native flora may affect the potential use of many species producing resins, gums, wax, chemical and pharmaceutical products. There are several plants in the Puna with therapeutic value like *Pellaea nivea*, *Chenopodium graveolens*, *Artemisia copa*, *Ephedra americana*, *E. breana*, *Azorella compacta* and *Haplopappus rigidus* (Cabrera 1957, Ruthsaz 1974). We could include many other examples of desert plants which may represent valuable materials for human use in the country according to circumstantial and historical evidence. Disappearance of wild

species is representing a definitive loss of genetic materials. On the whole this is a subject poorly studied from a scientific point of view. Parodi (1934) has cited many woody species of our arid and semi-arid rangelands as ornamentals for parks, gardens and streets.

One of our most serious concerns about rangeland desertification is the extensive damage caused to the soil. There exist good records of vegetation deterioration but only a few of soil degradation. Excessive reduction of plant growth deprives the soil of its protective plant cover thereby exposing it to soil erosion. This process is intensified by the inherent fragility of the natural system. Dominant forms of degradation are associated to wind and water-sheet erosion of a soil which is no longer sheltered by a plant canopy and therefore lost by raindrop impacts and animal trampling. Intensive and continuous trampling can reduce plant renewal by affecting seed germination sites and seedling and adult plant growth. A clear evidence of wind or sheet soil erosion is shown by the abundance of plants growing in a kind of pedestal with increasing root exposure. The end result is a depleted fertility and in some cases physical degradation of the top soil layer due to a decline in soil structure. Unabated soil erosion is considered to be one of the most serious environmental problems of our country's rangelands.

With a depleted plant cover and incipient or accentuated soil erosion, one of the most precious and limiting factors of dry areas is affected: the water cycle. Water will run away from the primary productive system. The geochemical and energy cycles will also be altered. Recovery may take many years where there has been a change in plant structure or a loss of species. The ecosystem may undergo irreversible desertification where the top soil has also been lost since many of the biotic and abiotic structural constituents are no longer present there.

A side effect of the grazing livestock industry has been its impact on the native fauna. Several species of animals are disappearing in extensive areas, some of them with exploitable potential. With depleted vegetation, many animals have less shelter and food, and fewer places to reproduce in, and this applies to small animals such as insects as well as to large mammals. Twenty to forty years ago, guanacos and ostriches were common representatives of the fauna in extensive regions. Today, however, they have completely disappeared from the landscape and are secluded in more inaccessible areas or are under the protection of national parks, and occasionally in private ranches. Many animals in the native fauna have been considered predators or grazing competitors and thereby undesirable for the rangeland livestock industry. As such, they have been the target of an indiscriminate battle and "control programs" including foxes, pumas (American lion), guanacos, American ostriches (lesser rhea), deers, etc. Indiscriminate control methods like poisons or traps have also seriously damaged non target species (e.g., birds, rodents, armadillos, etc.). Some predators have been efficient in keeping under control serious pests of today such as comadrejas and some rodents. Fortunately, human awareness of the importance of preserving the very rich native fauna of the country is rapidly increasing, leading to some research projects on its biology and utilization.

Desertification has recently become one of the most serious environmental problems of the country. The degradation process has to stop now. If not, it could be too

late after one or two forthcoming generations and large areas may be transformed to unproductive habitats. Argentines are learning that the insidious process of land degradation is in the way of breaking up about seventy percent of the national territory due to ignorance, shortsightedness or indifference. System recovery may take many years after applying adequate corrective measures to control desertification.

One of the main recent achievements has been the raise of public awareness (individual land owners, rancher's associations, government agencies) of the problem. This is strictly necessary in a country where rangelands are mostly private properties, except for limited areas under the control of provincial governments or national parks. Generation of local, regional and national programs to control desertification is an increasing activity under the supervision of agricultural agencies, universities and research institutes.

Future concerted, comprehensive, interdisciplinary research should focus on determining causes and rates of environmental degradation, subjects of which a paucity of information exists in Argentina. Several scientific and technical national and international research programs have emerged recently headed to obtain guidelines for a more rational management of natural resources, and to understand ecological functioning of arid and semi-arid ecosystems in Argentina. Current training of postgraduate students in range science abroad and in the country constitutes a very favourable step towards a proper management of these territories.

Basic research on resource inventory and fundamental ecological processes has been extensive at the Monte, Caldenal and Patagonian steppes (Soriano 1983, Busso 1997, Guevara et al. 1997). Although research on these lines should continue, future programs should rather integrate research on applied ecology for management with investigations on basic rangeland ecological processes. These programs should outline and quantify the effects of various resource management alternatives on overall range productivity. Introduction of new production alternatives such as game ranching, for example, would however lead to further investigations on basic ecological processes. Finally, more research should be focussed on increasing our knowledge of the importance of the deep soil for nutrient and water balances since deep roots are likely important for C and water dynamics in ecosystems that experience periodic droughts (Jackson et al. 1996).

To date, devastation of Argentinean rangelands has not reached levels of environmental degradation as in other parts of the world where desertification is already an irreversible phenomenon. Although degraded, the ecological system and species still exist over large areas. We can foresee improvements in land use which may insure its sustainability.

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