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Perspectives on Rangeland Management Education and Research in Argentina

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Argentina's Rangelands

Rangelands account for over two-thirds of Argentina's land area and contribute uniquely to its biodiversity, agricultural livelihood, and cultural identity. Colossal mountain ranges and regional air mass movements create a variety of climates that generate an equally diverse array of rangeland and forest biomes (Table 1; Fig. 1). Humid tropical air currents that flow into the continent from the Atlantic Ocean create a NE–SW gradient of decreasing precipitation across the northern half of Argentina's territory. Along this gradient, subtropical forests are gradually replaced by subhumid woodlands and extensive subtropical and temperate grasslands that eventually give way to semiarid savannas and desert scrublands (Fig. 1). The southern half of Argentina's land area (also known as Patagonia) exhibits climate and vegetation patterns that are controlled almost entirely by the orographic effects of the Cordillera de los Andes. This mountain range, which runs in a N–S direction along Argentina's western border, stands in the way of mid-latitude westerlies and thus creates a region-wide rain shadow that hosts some of the continent's most extensive cold deserts and semi-deserts.

Argentina's rangelands are not exempt from land use pressures that occur in similar environments across the globe. Challenges ranging from tilling of rangelands to replace natural vegetation with crops to woody plant encroachment and desertification of arid grazing lands have been the focus of several decades of research, education, and outreach. Argentina's rangelands will set the stage for the upcoming IX International Rangeland Congress (IRC) in April 2011, and in this paper we seek to 1) provide insights into the current state of rangeland management

education and research in Argentina, 2) spark curiosity about Argentina's rangelands, and 3) elicit interest in the Rosario 2011 IRC, which will be the first of its kind to be hosted by a South American country (www.irc2011.com.ar).

History of Range Science in Argentina

The applied practice of range science in Argentina is now more than 60 years old. Some of the earliest rangeland-related research was published at the beginning of the twentieth century and dealt with livestock husbandry on rangelands of Patagonia,¹ geobotany,² the description of grasslands detailing native and introduced grasses in Argentina and their importance and effect on livestock production,³ as well as detailed accounts of the relationships between sheep grazing and vegetation in northern Patagonia.⁴ Beginning in 1948, Alberto Soriano, Professor of Agronomy at the Universidad de Buenos Aires, initiated a long series of well-documented descriptions of the vegetation and the impact of grazing on vegetation and soils in Patagonia including Tierra del Fuego. He detailed native vegetation composition and its response to grazing and lack of appropriate management and suggested measures to mitigate negative impacts.⁵

Alberto Soriano may not have been the first, but he became the most influential range researcher because he related the full ecosystem concept to livestock practices. In a sense, the laboratory and field studies initiated by Soriano along with many of his co-workers and students continue today and have extended our knowledge, not only of Patagonia, but also of the humid and subhumid Pampas including the Flooding Pampas of the Province of Buenos Aires. Students trained in Soriano's philosophy and work

Table 1. Rangeland types of Argentina

	Rangeland type	Area (ha)	Mean rainfall (mm/year)	Plant communities (physiognomy)	Dominant plant species
Arid and semiarid grasslands, shrublands, and woodlands*	Patagonia (cold deserts and semi-deserts)	60 million	300	Shrub steppes	<i>Mulinum spinosum</i> , <i>Adesmia campestris</i> , <i>Junellia tridens</i> , <i>Stipa humilis</i> , <i>Stipa speciosa</i> , <i>Poa ligularis</i>
				Grass steppes	<i>Festuca pallescens</i> , <i>Festuca gracillima</i> , <i>Poa dusenii</i> , <i>Beberis heterophylla</i>
				Meadows (valley bottoms)	<i>Festuca pallescens</i> , <i>Juncus balticus</i> , <i>Holcus lanatus</i> , <i>Poa pratensis</i>
	Monte (hot and cold deserts and semi-deserts)	46 million	80–300	Shrub steppes	<i>Larrea divaricata</i> , <i>Prosopis alpataco</i> , <i>Lycium chilense</i> , <i>Trichloris crinita</i> , <i>Eragrostis argentina</i> , <i>Bouteloua aristidoides</i>
	Caldenal (semiarid woodlands)	2.3 million†	350–500	Woodlands	<i>Prosopis caldenia</i> , <i>Condalia microphylla</i> , <i>Prosopis alpataco</i> , <i>Prosopis flexuosa</i> , <i>Stipa tenuis</i> , <i>Stipa gynerioides</i>
	Western (dry) Chaco (semiarid woodlands and savannas)	65 million	320–800	Mid- to low forests and savannas	<i>Schinopsis lorentii</i> , <i>Aspidosperma quebracho-blanco</i> , <i>Prosopis alba</i> , <i>Prosopis nigra</i> , <i>Leptochloa virgata</i> , <i>Paspalum inaequalva</i>
Subtropical humid forests and savannas*	Eastern (wet) Chaco (subhumid forests and savannas)‡	25 million	800	Forests and savannas	<i>Schinopsis lorentzii</i> , <i>Aspidosperma quebracho blanco</i> , <i>Schinopsis balansae</i> , <i>Prosopis alba</i> , <i>Prosopis nigra</i> , <i>Elionurus muticus</i> , <i>Sorghastrum agrostoides</i> , <i>Panicum prionites</i> , <i>Paspalum intermedium</i> , <i>Paspalum alnum</i> , <i>Paspalum urvillei</i> , <i>Spartina argentinensis</i> , <i>Juncus capillaceus</i> , <i>Juncus macrocephallus</i>
					Forests and savannas
	Espinal (forests, woodlands, savannas)	3 million	1,000–1,200	Forests and savannas	<i>Prosopis alba</i> and <i>Prosopis nigra</i> , <i>Prosopis algarrobilla</i> , <i>Butia yatay</i> , <i>Setaria geniculata</i> , <i>Bothriochloa laguroides</i> , <i>Paspalum urvillei</i> , <i>Paspalum dilatatum</i>
Temperate humid grasslands*	Pampas (temperate grasslands and grass steppes)	50 million	700–900	Grasslands	<i>Paspalum dilatatum</i> , <i>Lolium multiflorum</i> , <i>Stipa neesiana</i> (uplands); <i>Bothriochloa laguroides</i> , <i>Stipa papposa</i> (plains); <i>Leersia hexandra</i> , <i>Glyceria multiflora</i> (humid lowlands); <i>Distichlis spicata</i> (alkaline lowlands); <i>Paspalum quadrifarium</i> (uplands, plains, and humid lowlands)
Sub-Antarctic forests*	Nothofagus forests (temperate semideciduous forests)	2 million	≥ 1,000	Forests and savannas	<i>Nothofagus pumilio</i> , <i>Nothofagus antarctica</i> , <i>Berberis</i> spp., <i>Holcus lanatus</i>

* See Further Readings online at <http://dx.doi.org/10.2111/RANGELANDS-D-10-00016.s1> for supporting references.
† Originally, 7.5 million.
‡ Includes subtropical grasslands and wetlands.

ethic continue to labor in the field and publish in prestigious scientific journals on basic range research and principles of best management practices for a wide range of ecosystems.

Two important milestones shaped the beginning of federally funded, nationwide applied rangeland management research and outreach programs in Argentina. The first

occurred in 1953, with an International Course on Pastures co-organized by the Instituto Interamericano de Cooperación para la Agricultura (IICA), the United Nations (FAO), and the Argentine government. Peter Sears, a sheep expert from New Zealand, and Joe Woolfolk, a charter member of the Society for Range Management from Montana, offered this

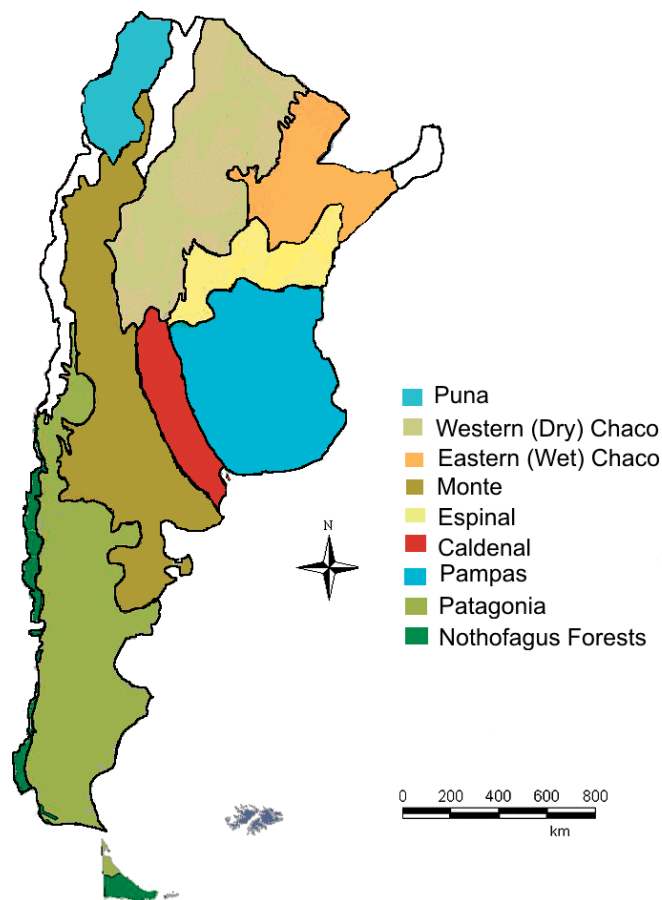


Figure 1. Rangeland types of Argentina. (P. Lagorio, INTA Bariloche)

course at three locations (Esquel, Chubut; General Acha, La Pampa; and Tandil, Buenos Aires) and addressed range management as a discipline discussing sheep and cattle husbandry and grazing practices through visits to different ranches (*estancias*) and experiment stations. About 20 professionals from Argentina, Chile, Brazil, and Uruguay were trained through this program and later joined many of the incipient rangeland research and extension teams across the country.

The second milestone can be traced back to the establishment of the first rangeland research program at the Instituto Nacional de Tecnología Agropecuaria (INTA, Argentina's agricultural research and extension service) in 1965 under the direction of David Lee Anderson, who together with Guillermo Covas and Eduardo Cano are considered the founders of INTA's rangeland programs. Research activities began on a few acres of native pasture in the semiarid woodlands of San Luis and consisted initially of collecting and keying of native plant species. This was followed by the establishment of a local herbarium and documentation of plant phenology for all the major range species, which involved recording observations on key plant species every 15 days for 20 years. Cattle diet preference trials were then conducted, and a list of animal preference for the plant species composing range pastures in

open calden (*Prosopis*) woodland/grassland was developed. Gradually, as ranchers found out about INTA's interest in researching and managing rangelands, they generously offered their ranches and facilities to test hypotheses and new techniques for improving livestock production through innovative range management grazing systems. Permanent vegetation-monitoring transects were installed at many of these ranches, vegetation-type maps were developed, and available forage-mass to be used in determining potential stocking rates for the grazing systems were estimated.

Much of this early work applied principles and ideas proposed by Stoddart and Smith, Whittaker, Weaver, and Clements, Cook, Dyksterhuis, and Daubenmire (see Further Readings online at <http://dx.doi.org/10.2111/RANGELANDS-D-10-00016.s1> for the citations of these seminal pieces). Since those early days, a large number of researchers, many of whom pursued graduate degrees in rangeland-related disciplines abroad, have contributed to the growth of Range Science in Argentina through their work at national universities, federal research laboratories (Consejo Nacional de Investigaciones Científicas y Técnicas [CONICET]), and INTA. A number of Argentina's rangeland researchers today are considered to be in the forefront of the art and science of rangeland ecology and management.

Current Undergraduate Rangeland-Related Education Programs in Argentina

Argentina's universities have a longstanding tradition of excellence in training college students for agricultural professions; however, the creation of undergraduate-level programs focusing specifically on natural resource management is fairly new. Most natural resource professionals in Argentina today, particularly those involved with managing Argentina's rangelands, were trained in five- to six-year Agronomy (and to a lesser degree Biology) undergraduate-level programs.

Argentina's first two Agronomy programs were established at the beginning of the twentieth century at public universities¹ (Universidad de Buenos Aires in 1909, www.uba.ar; and Universidad Nacional de La Plata in 1905, www.unlp.edu.ar), and since then the number of programs nationwide has grown to 30, the majority of which (24) continue to be offered at public universities. Five public universities currently offer four- to five-year renewable natural resources (RNR) management programs with slightly different regional emphases depending on the geographic location of each institution. Four of these programs were created within the last 10 years, and although 60% of the Agronomy degrees are granted by universities located in the Pampas region, all RNR programs, except one, are located in remote arid and semiarid areas of Argentina.

¹The public university system in Argentina offers government-funded free college education to all citizens.

A minimum of 3,000–4,000 class hours are required to obtain a RNR degree in any of the five universities that offer this major. The course load of RNR programs in Argentina appears to be comparable to that of Bachelor of Science degrees in the United States, which require four years of course work and approximately 120 credits (or 3,600 class hours). Even so, RNR curricula in Argentina tend to be of a generalist nature and offer less diversity in areas of specialization compared to the U.S. university system. Argentina's RNR undergraduate programs do not offer students the possibility to choose from potential areas of emphasis such as Rangeland Resources Management, Ranch Management, Watershed Management, Wildlife Habitat Management, Natural Resources Economics and Planning, Rangeland Restoration, and Natural Resources Conservation, all of which are offered, for example, to students at New Mexico State University (www.nmsu.edu).

A great deal of variation exists in faculty training and employment status (full versus part time) among Agronomy programs in Argentina recently accredited by the National Higher Education Assessment and Accreditation Commission (CONEAU). Programs with the ability to develop improved curricula are those offered by institutions with a higher percentage of full-time faculty (54% with 40 hours or more per week) and with over 50% of graduate-level education among faculty, including Specializations, Master of Science, and Doctoral degrees obtained at either domestic or foreign universities.^{6,7} Faculty resources and infrastructure of RNR programs have not undergone a detailed analysis to date. Three of these programs are more than 10 years old, and the other two are only five years old, suggesting that their faculty bodies are possibly in consolidation or still in the process of being trained.

According to a recent nationwide accreditation process conducted by CONEAU that assessed standards of quality of the undergraduate Agronomy programs,ⁱⁱ the amount of time allocated to research activities by faculty in each program also varies across institutions. Between 1999 and 2003 there were on average 65 faculty-driven active research projects per program; however, distribution among institutions was fairly uneven, ranging from zero to 186 per program. Research is funded either by the universities themselves (72.6%), federal or provincial research funding agencies (15.4%), or companies or private institutions (11.9%). Overall, university in-house research budgets are insufficient to fund complex projects. Research results are mostly presented at scientific and professional conferences (63.5%) but are also published in peer-reviewed journals, indexed or not (29.8%), published as books or book chapters (5.9%), or patented as intellectual property (0.8%). Approximately 98% of the scientific production associated with Agronomy programs is generated by faculty at public universities.

ⁱⁱ M. A. Brizuela served on this accreditation committee.



Figure 2. Chaco rangelands. Shrub invaded fachinal (upper left), open savanna (upper right), roller chopper treatment (bottom left), prescribed burn (bottom right). (Photo credits: Carlos Kunst)

Current Research and Management of Argentina's Chaco, Pampa, Caldenal, and Patagonia Rangelands

The enormous variety of rangeland environments of Argentina naturally calls for diverse and often unique research and management approaches. This section covers current research and management endeavors in four contrasting rangeland environments that occur along a 5,000-km N–S latitudinal gradient. We begin our journey in the Chacoⁱⁱⁱ rangelands of the north, continue through the world-famous Pampas of central-eastern Argentina, and cross the semiarid Caldenal woodlands that provide a transition into the wind-swept rangelands of Patagonia, which reach deep into the southernmost tip of the South American continent.^{iv}

Woodlands, Savannas, and Grasslands of Argentina's Chaco Region

The Chaco (Fig. 2) comprises a mosaic of forests, woodlands, grasslands, savannas, and shrublands. Forests typically occupy upland sites, whereas woodlands and savannas are located on intermediate and lowland sites, respectively. Historical records suggest that until the early twentieth century grasslands and forests shared the Chaco landscape in almost even proportions. Fire was probably responsible for that balance, since it was extensively used by the Native Americans for hunting and war.⁸ Today, large areas of the Chaco are covered with dense shrub thickets and secondary forests, a phenomenon that seriously restricts livestock and timber operations.

ⁱⁱⁱ A Native American (*quichua*) word meaning "a place for hunting" and "a place where I am self-sufficient."

^{iv} Despite its ecological importance and geographic expanse, a discussion of the Monte Region (Table 1; Fig. 1) is not included in this section. An in-depth review of research addressing the ecology and management of the Monte can be found in a recent special issue of the *Journal of Arid Environments* (2009, vol. 73, issue 2).

The region exhibits hot summers (38°C) and cold winters (-10°C) with marked summer precipitation seasonality. Annual rainfall is variable and tends to decrease from 700–800 mm in the NW to 200–300 mm toward the south.⁹ The entire region is a vast plain, with a slight slope toward the southeast and crossed by several major rivers, such as the Bermejo, Salado, and Dulce. Sediments carried by these rivers and streams from the mountains and sierras on the west form the parent material of soils, which despite being undeveloped (A–A/C horizons) usually have no severe limitations for root growth. Some areas toward the south, however, exhibit clayey textures and severe salt accumulations that seriously restrict plant growth, particularly in the lowland sites.

Livestock raising (cattle, mules, goats, and horses) has been the most important historic use of the land south of the Salado River since European settlement, which occurred with the Spanish conquest (ca. 1500). Intensive settlement of the Chaco north of the Salado River, on the other hand, did not begin until the early twentieth century, and native forest timber operations became the most important trade, providing fence posts, firewood, charcoal, and railway ties. Timber operations declined around 1960, and large areas of land were cleared for crops, mostly sorghum and soybean, in the “best” areas. Today cattle ranches alternate with crop farms and areas with small-scale landowners.

One of the key challenges facing range managers in the Chaco region is to match stocking rates with highly variable forage production.¹⁰ The basic tool used to improve forage availability of a paddock in poor condition is summer resting for one (annual rotational grazing) or several seasons and subsequent moderate stocking. Summer rest and stocking rate adjustments complemented with “good” rains can increase forage yields up to 300% in ranges in poor and fair condition, even in places with severe soil restrictions if shrub and tree encroachment is not severe.¹⁰ The introduction of electric fencing using solar panels has greatly improved the success of such grazing systems, whereas the sowing of gatton panic (*Panicum maximum* cv. *Gatton panic*) and buffel grass (*Cenchrus ciliaris* cv. Texas 4464 and Biloela) has significantly increased the general productivity of ranches as a whole.¹¹

Rangeland improvement efforts are currently focused on restoring the following: 1) shrub thickets and secondary forests known locally as *fachinales* or *renovales* that once established are quite resilient and stable and 2) *peladales* (large areas with bare soils) caused by overgrazing that become important in the drier Chaco toward the south. Empirical and experimental observations indicate that these rangelands cannot be restored by applying “passive” management tools such as removing the degrading agent(s), usually livestock, or by applying a grazing system. The control of native shrub and tree populations above certain thresholds and the seeding of grass species are essential to achieve profitable forage yields and stocking rates.^{10,12}

Although chemical treatments are not widespread in the region, herbicides have been used to control secondary forests of *Prosopis nigra* promoting two- to threefold increases in standing forage biomass (2,600–4,500 kg dry matter/ha) compared with untreated controls (1,400 kg dry matter/ha). The main setbacks to such treatments are their high cost and the environmental side effects, such as elimination of tall trees that provide both shade and forage.

Mechanical clearing is popular among Chaco ranchers because most producers have ample know-how and expertise in developing, adapting, and using agricultural machinery, a phenomenon rooted in the longstanding agronomic tradition of Argentina. Nonetheless, the conventional approach of bulldozing all standing vegetation and replacing it with annual grasses such as *Sorghum*, which was widespread from the late 1950s up until the early 1980s, is being gradually replaced by selective clearing practices using roller choppers (Fig. 2). Areas treated with this machinery exhibit a 200–300% increase of native forage species and forage yields of 8,000–10,000 kg dry matter/ha/year in cases where gatton panic or buffel grass are seeded.¹³ Roller chopper thinning usually requires some kind of follow-up treatment and must be complemented with appropriate stocking rates, prescribed fire, wood residue recycling, and/or chemical treatments to achieve the full ecosystem potential.

Prescribed fires during winter and early spring (late June to early November) are used to control shrubs (e.g., *Acacia aroma*, *Celtis pallida*, and *Schinus* species) and promote grass growth or reduce roller-chopping residues (Fig. 2). When areas are burned at two- to four-year intervals, no significant decrease in Total Organic Carbon and Total Organic Nitrogen in the upper soil horizon is observed.¹⁴ Reintroducing fire into Chaco’s ecosystems in their current state is challenging because it requires dealing with large fuel loads of medium and coarse wood residues of high caloric power left behind by mechanical treatments, in some cases up to 30–40 tons/ha.¹³

Experimental observations suggest that goats may be an option to control shrub populations because they readily feed on *Celtis*, *Acacia*, and other shrub species. However, targeted grazing has not been used in the Chaco to date.

The future of range management in the Chaco region will involve the development of production systems that take advantage of both grasses and woody plants (shrubs and trees). These systems are clearly more appropriate for the Chaco ecosystems from the ecological and agronomical points of view than the “grass only” management paradigm. In fact, the Chaco shrubs and tree species are hardwoods that produce high-quality material for fencing, firewood with high caloric power, wood for furniture, shade, and forage; their foliage is also an important source of soil organic matter. The challenge for the future is to adapt the traditional methods of range management (grazing, fire, mechanical) to generate grazing paddocks that will support productive livestock herds and healthy tree populations. In addition, it will be important to develop skills to evaluate

and adjust stocking rates that will be both profitable and sustainable.

Temperate Grasslands of Argentina's Flooding Pampa

The flooding pampas cover approximately nine million hectares of extremely flat terrain east of the Tandilia hills in the Argentine province of Buenos Aires.¹⁵ The lack of a developed natural drainage network (due mostly to the lack of topographic slope of the region) is responsible for brief flooding events that occur in most years during fall–spring in the lowland areas (Fig. 3).¹⁶ The region exhibits mean monthly temperatures ranging from 6.8°C in the winter to 21.8°C in the summer and average annual rainfall of approximately 900 mm, with no strong seasonality pattern.

Grasslands of the flooding pampas are subjected to the combined effects of grazing, floods, and droughts. Grazing reduces cover of the most palatable grasses and favors colonization of exotic and native forbs, which become codominant along with several sod grasses.¹⁶ This effect can be reverted either by animal exclusion or by floods that eliminate exotic forbs that, unlike the native species, are not adapted to water-logged conditions.¹⁷ Floods tend to improve quality and accessibility of forage.

Historically, cow-calf ranching operations accounted for most of the agricultural industry of the region. Over the last decades, a large number of ranches have increased their secondary productivity by adding grass-fed yearling finishing programs to their production system. The introduction of seeded pastures based on tall wheatgrass (*Thinopyrum ponticum*), tall fescue (*Festuca arundinacea*), and bird's foot trefoil (*Lotus tenuis*)¹⁸ together with nitrogen (N) and phosphorous (P) fertilization of both seeded pastures and native rangelands have enabled these system changes. Annually,

2.4 million calves, mainly of British breeds (e.g., Aberdeen Angus and Hereford), are raised in Argentina's flooding pampas. A high percentage of these calves are sent to ranches for pasture-based finishing or to feedlots in different areas of the country, where they are later sold for slaughter once they reach a weight of approximately 440 kg (steers) or 320 kg (heifers). Currently, there are 8.8 million head of cattle on flooding pampas, which account for 16% of the country's cattle population (54 million head).¹⁹

Although a considerable amount of work dealing with the structure and function of grasslands of the flooding pampas was published over the last four decades (see Further Readings online at <http://dx.doi.org/10.2111/RANGELANDS-D-10-00016.s1> for published works on the flooding pampas), strategies of grassland utilization were developed only fairly recently. These strategies involve dividing paddocks into grazing units, which segregate the different plant communities (high vs. low-lying areas) and grazing each community at times of the year when they provide the best nutrition for cattle.²⁰

Flooding pampas grasslands can sustain year-round growth; however, forage production during the spring–summer period is approximately eight to 10 times higher than in winter, a phenomenon that undoubtedly affects livestock production. If soil moisture and P levels are adequate (20 kg P/ha), winter N fertilization can increase both late winter forage production (i.e., spring regrowth begins 25 to 30 days earlier) and overall annual production, with forage accumulations of 8–10 tons DM/ha/year, four to five times higher than those obtained without fertilization.²⁰ In addition, N fertilization promotes an increase in the production of high-quality forage (up to 2.5–3.0% N and 75% dry matter digestibility), which enables ranchers to establish grass-fed yearling finishing programs.²¹ Currently, plant community-specific fertilization is used by approximately 20% of ranchers²² as a tool to increase forage production and modify the pattern of annual forage distribution by extending the growth season of C₃ grasses.

The use of glyphosate as a means of promoting winter pasture productivity has been widely adopted in recent years. Natural vegetation is replaced by annual ryegrass, a strategy that has unfortunately led to a reduction in the abundance of the native cool and warm season grasses of high nutritive value and has favored perennial weed and annual grasses of low forage value. Consequently, grasslands treated repeatedly with herbicides currently exhibit a forage production peak during the winter–spring period at the expense of a decrease in summer grass production. To counter this, prescribed grazing is being successfully used as an alternative to herbicides. This strategy consists of intense grazing during Argentina's summer (January–February) to avoid the accumulation of growth and thus facilitate the emergence and establishment of annual ryegrass without affecting warm season species abundance.

Traditional year-round continuous grazing has led to a reduction in cool season grasses, an increase in weeds and



Figure 3. Aerial view of flooding Pampa rangelands located between Balcarce and Coronel Vidal showing plant community heterogeneity associated with topography in a wet year (upper left), late spring cow-calf grazing of rangelands dominated by *Paspalum quadrifarium* tussocks (upper right), winter cow-calf grazing of flooding Pampa rangelands (bottom left), late summer field day with ranchers on a dallisgrass (*Paspalum dilatatum*) dominated rangeland after a period of extended floods (bottom right). (Photo credits: Miguel A. Brizuela)

bare soil, and overall grassland degradation, which have resulted in decreased carrying capacity, poorer animal performance, and lower profitability. More recently, many of the better soils have been plowed to grow crops, a phenomenon that has posed the challenge of maintaining the same number of livestock in a smaller area. This has given way to new management strategies that propose seasonal adjustments of the instantaneous stocking density.^{20,21} A number of studies have shown that rotational grazing can double cool season grass production (including annual ryegrass which can account for as much as 77% of cool season biomass increase) and promote an increase in forage quality and a decrease in undesirable plants and bare soil. This increase in winter forage productivity allowed rotational systems to be stocked at almost twice the rate of traditional continuous systems (1.0 vs. 0.6 AU/ha). Proposed rotational grazing systems can improve grassland condition and enhance the nutrition of grazing animals. Less intensive systems involving continuous grazing with variable stocking rates in fertilized pastures have also shown promising results.²¹

The reduction of rangeland area available for traditional cow-calf operations and the displacement of animal agriculture to less productive rangelands have been singled out as a critical bottleneck in Argentina's beef production chain today.^v The application of substantially higher fertilization rates and improved nutritional and reproductive management of the herd have been suggested as the only way to maintain historical mother cow herd numbers. More research is needed to develop management guidelines to meet the challenges of this new land management scenario.

The Caldenal Region of Central Argentina

The caldenal is a southern continuation of the "espinal" ecoregion (Fig. 1) and comprises an ecotone between the Pampa grasslands and the Monte desert to the west, growing along a precipitation gradient that ranges between 600 and 400 mm/year. This ecosystem is dominated by *Prosopis caldenia*, an endemic deciduous tree that forms monospecific stands with a well-developed grass layer which includes short perennial thin grasses (e.g., *Piptochaetium napostaense*, *Stipa tenuis*, *Poa ligularis*, *Aristida subulata*, *Trichloris crinite*, and *Digitaria californica*). Low palatability perennial bunchgrasses include *Stipa tenuissima*, *Stipa ichu*, *Stipa brachychaeta*, and *Stipa ambigua* (Fig. 4).

The Caldenal occurs in valleys with loamy, well-developed soils and with a thin petrocalcic layer at variable depths from few centimeters to more than 1.5 m. Tallest trees are found in well-developed soils in the northern and central part of the region, while in less developed soils with lower precipitation, other woody species become important (e.g., *Prosopis flexuosa*, *Condalia microphylla*, *Geoffroea decorticans*,



Figure 4. Rangelands of the Caldenal region of central Argentina. Open *P. caldenia* woodland with understory dominated by palatable fine grasses (upper left) or unpalatable bunchgrasses (upper right). Calden invasion of a degraded dune grassland (lower left) and fire-maintained shrub thicket structure (lower right). (Photo credits: H. Raúl Peinetti)

Schinus fasciculatus, and *Jodina rhombifolia*). *P. caldenia* can reach more than 12 m height with approximately 1.5 m of main stem diameter. The oldest dated trees were more than 250 years old. This tree produces an indehiscent pod that is considered a valuable forage resource for livestock.

The characteristics of the Caldenal depend in large part on factors that control the balance between woody and grass vegetation, as occurs in other arid and semiarid regions of the world. Human disturbances including livestock grazing, logging, and changes in fire frequency and intensity have largely altered this balance. Livestock was introduced in this area as early as the 1700s by nomadic herding Indians who moved livestock from the Argentinean pampas to southern Chile. The impact of this herding activity is evident today. Major ecological changes occurred in the early 1900s when livestock began to be raised in fenced paddocks at high stocking rates. Sheep grazing was prevalent during the first half of 1900s and were then replaced by cattle that have grazed this area until today. Two severe periods of logging devastated the Caldenal in the 1910s and 1940s. The original cover range of the Caldenal woodlands has been largely fragmented by clearing areas to grow crops or to establish cultivated pastures. Fire intensity and frequency have also been altered by human activities since European settlement of this area.

Livestock dispersal of *P. caldenia* seeds as well as favorable conditions for establishment of other woody species (*C. microphylla*, *S. fasciculatus*) has led to an increase in woody plant density in the savanna and the spread of woody species to contiguous semiarid grasslands²³ (Fig. 4). The increase in woody plant density alters the structure of the caldenal from a savanna parkland to a dense woodland/forest with a well-developed shrub layer. This highly dense woody plant formation dramatically increases the intensity of fires that kill aboveground woody biomass, stimulating resprouting of

^vAccording to a recent unpublished report produced by Daniel Rearte, INTA Balcarce.

woody plants and generating shrubby thickets with few medium-size trees (6–10 m) and very low grass cover. Positive feedback loops between woody plant density and fires have severely reduced desired open savanna vegetation structure in this area nowadays.

A major problem in areas of the Caldenal where woodland structure is considered to be in better condition is the replacement of palatable grass species (*fine grasses*) in the herbaceous understory by bunchgrasses of low palatability due to continuous grazing,²⁴ so much so that some of the palatable grass species have disappeared from the seed bank. The reconstruction of the floristic history of the area using soil phytolith studies, which go back approximately 100 years, indicates the prevalence of desirable grass species prior to livestock introduction. Current areas of Caldenal dominated by unpalatable bunchgrasses most probably are the result of high livestock grazing pressure. Prescribed burning appears to improve range forage condition but cannot be used to reduce shrub encroachment. Current management in the Caldenal focuses almost exclusively on improving forage availability for livestock; however, there is a need for an integrated management approach to restore a degraded ecosystem.^{25,26}

Cold Deserts and Semi-Deserts of Argentina's Patagonia

Patagonia includes almost half of Argentina's arid and semi-arid shrublands and grasslands (780,000 km²), which exhibit a relatively high rate of endemism and biodiversity. Most of the region is classified as a cold semi-desert with mean annual temperatures that rarely exceed 10°C and rainfall levels ranging from 150 to 250 mm/year. Patagonia's landscapes span more than 13° in latitude and exhibit altitudes



Figure 5. Rangelands of Patagonia. Sheep herding on the fescue grass steppes of southern Patagonia at INTA's Potrok Aike Experimental Range (upper left), dwarf shrub steppes of the plateaus of southcentral Patagonia (upper right), mesic fescue grass steppes surrounding the Straits of Magellan (bottom left), a group of rangeland specialists conducting rangeland survey training on rangelands of the Andes foothills (bottom right). (Photo Credits: Gabriel Oliva)

that range from sea level to over 3,800 m. The region includes twelve bio-zones, seven of which are arid-scrub or grasslands²⁷ (Fig. 5).

Sheep were introduced in the region in the late 1800s and reached 20 million by 1950. There are currently 13,000 livestock producers in the region, 80% of which are small-holders that operate subsistence enterprises, 17% run mid-scale operations, and 3% manage large ranches. Most of the land is grazed continuously, with some seasonal use of higher altitude rangelands and a few mobile pastoralists. Low-input sheep ranching is practiced across the region, with little use of supplementation or winter feeding. Land was overstocked by European settlers, and overgrazing at a regional scale was the rule for over half a century. In recent decades, rangeland degradation, low wool prices, and higher production costs induced a reduction in flocks to 8.4 million sheep.

Approximately 400 midsized ranches of central Patagonia comprising 10 million ha have been abandoned. Approximately 85% of the area is affected by different degrees of desertification. In fact, land degradation is one of the most urgent ecological issues in the region. Biological invasions are not important in most of the region, although exotic herbivores (rabbits and beavers) and forb species such as the mouse ear hawkweed (*Hieracium pilosella*) pose significant management challenges in subhumid rangelands of southern Patagonia. Oil and gas production have a widespread impact over vast areas, and mining is responsible for more concentrated impacts affecting both vegetation and soil and water quality.

Although overgrazing-related degradation is thought to have caused a reduction in plant diversity (75 plant species were listed as endangered)²⁸ and sheep grazing has been linked to a reduction or local disappearance of preferred grasses,²⁹ long-term stocking rate studies have shown that moderate sheep grazing can maintain or even slightly increase plant species richness.^{29,30} Other authors have found that some degree of rest or grazing deferment is necessary to allow for rangeland regeneration.³¹

Changes in Patagonian plant communities triggered by overgrazing have been described in terms of state-and-transition theory³² and generally involve the replacement of grasses by shrubs, the loss of fine topsoil particles (silts) along with organic matter and nutrients,³³ and the increase of bare soil. Degraded rangelands also lose structural attributes that connect a network of source and sink patches. Nutrients, soil, and plant propagules that are displaced by aeolic erosion are lost from the system.

Over the last 20 years, techniques have been developed to promote sustainable range management. A set of such techniques widely applied in southern Patagonia is known as the Low Input Management Technology packet (Tecnología de Manejo Extensivo [TME]). Briefly, TME proposes a rangeland inventory using remotely sensed images followed by a field assessment of forage availability.³⁴ Information on animal production indices is obtained and

production and marketing goals are clearly established with the rancher. A grazing plan is then designed ensuring that nutritional needs of the flock are met while leaving adequate forage residue (approximately half the above ground biomass of preferred forages). The “take half leave half” rule of thumb ensures regeneration of most plant species including palatable grasses. When possible, recovery is further promoted using rest and deferred rotation, especially in paddocks that include meadows (*mallines*). In northern Patagonia, where smallholders predominate, sustainable production also involves strategic investment in infrastructure (fencing, shelters for livestock, water supply, etc.). The goal is to increase smallholders’ income through improved meat and wool production.³⁵

Grazing plans are combined with a series of improved animal husbandry practices, including the adjustment of flock age structure, pre-lambing shearing, Tally Hi or Bowen shearing, wool conditioning and classification, as well as the use of noncontaminating packaging for wool bales. Rams are examined to avoid reproductive diseases, and breeding dates are adjusted to ensure optimal lambing and weaning seasons. A genetic improvement and flock health management plan is established, and selective predator control methods are recommended. In some cases forage reserves are also recommended, especially in areas with a high risk of severe winter snow storms.

In southern Patagonia only 6% of sheep ranchers (~2 million ha) have adopted the TME packet. This low adoption rate is explained by the strong traditional component of sheep production and poor financial results that may have prevented ranchers from seeking technical advice. Although sheep ranching as a whole has lost importance in the regional economy relative to other activities, it still constitutes part of the traditions and cultural heritage of the region and contributes to sustainable occupation of the land. In fact, the future of livestock grazing on Patagonian rangelands can be viewed with moderate optimism. A combination of better international commodity prices, a tendency shifting toward markets that prioritize environment-friendly agricultural products and new management tools based on appropriate technology may jointly help to avoid land degradation and attain sustainable production.

The 2011 International Rangeland Congress

Argentina will be the first South American country to host an International Rangeland Congress. The theme of the 2011IRC will be *Diverse Rangelands for a Sustainable Society* and will cover aspects of agricultural, ecological, and social sustainability of rangeland ecosystems. Pre-congress tours to several regions including those outlined in this paper will offer a unique opportunity for firsthand experience and in-depth discussion about local rangeland management issues with researchers and managers from both the local and international rangeland community (www.irc2011.com.ar). This paper seeks to contribute to providing perspective and background for colleagues and friends who are planning

to attend what promises to be a truly memorable rangeland congress.

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