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Overview of the geography of the Monte Desert biome (Argentina)

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ABSTRACT

The compilation of published results on the geography of the Monte Desert biome of Argentina that we present here offers a review of its boundaries and ecotones, and of its biophysical and socio-economic characteristics. In relation to socio-ecological issues, the focus is on a case study in the province of Mendoza. An analysis is presented about the ecological-economic issues and the sustainable investment policies in rangelands of the Patagonian Monte. In addition, this biome is compared with other South American arid biomes and their North American counterparts. We identified some gaps in the current knowledge, especially at a mesoscale level, where studies on Monte borders are deemed necessary as well as explicit boundary criteria for ecosystem differentiation. Also the ecological-economic relations and feedbacks between livestock herbivory, soil erosion and market behaviour should be considered within the framework of wider socio-ecological research.

1. Introduction

The Monte Desert is a South American subtropical to warm temperate desert and semidesert located in western Argentina (Fig. 1). This biome extends from 24°35′S in Salta province to 44°20′S in Chubut province, lying in the inner basins of the Andes of Catamarca and La Rioja, in the Precordillera, the Sierras Pampeanas and the basins of San Juan, Mendoza and San Luis, in western La Pampa, eastern Neuquen, central Rio Negro and northeastern Chubut. It is bordered on the west by the Andes, on the south by the Patagonian semidesert, and on the east by the dry subtropical woodlands of Chaco and Espinal (Morello, 1958; Cabrera, 1976).

The Monte Desert constitutes the most arid rangeland of Argentina (Fernández and Busso, 1997). Agriculture is confined to irrigation valleys, where fruit, vegetables and forage crops are grown under intensive agriculture.

The climate is semiarid to arid, with high evaporation enhanced by windy conditions, especially in the south (Patagonian Monte). Mean annual rainfall varies between <100 and 450 mm, strongly conditioned by the surrounding relief (Fig. 2a). Mean annual temperature varies between <10 and 18 °C; lowest values are found in the north of the area, where isotherms are clearly topography-dependent (Fig. 2b). Rainfall occurs overwhelmingly in the summer in most of the Monte (up to 70% of the total in the north). A tendency to a reverse seasonality appears south of 40°S, where westerly circulation becomes dominant and summers yield less than 20% of the annual rainfall (Prohaska, 1976). Long rainless periods may extend over seven months in the northern Monte but very seldom occur in the south, because of the alternation of air mass origins (Paruelo et al., 1998a). Differences between summer and winter temperatures, as well as diurnal ranges, clearly depict the continentality of the temperature regime, enhanced by topographic enclosure (Le Houérou, 1999). The predominant wind direction changes according to latitudinal variations; westerly winds predominate all the year round in the southern Monte, whereas in the northern Monte winds from the south and east prevail (Rundel et al., 2007).

The natural Monte areas are shown in Appendix 1a, b (electronic version). The northern area of the Monte (27–29°S) occupies the basins of La Rioja and Catamarca and because of its latitude it is a transitional area towards the tropical summer rainfall regime that exists in Tucuman, Salta and Jujuy (24–26°S). The amount of rainfall is limited by the shadow effect produced by Sierras Pampeanas, which restrains the flow of Atlantic air. This blocked condition is also that of the Central Monte in San Juan, Mendoza and western San Luis, which occupies the basins lying between the Precordillera and Sierras Pampeanas (30–35°S). Here, under the typical subtropical horse latitudes, the ecotone between the Monte and the arid Chaco is the driest area of Argentina with some annual records below

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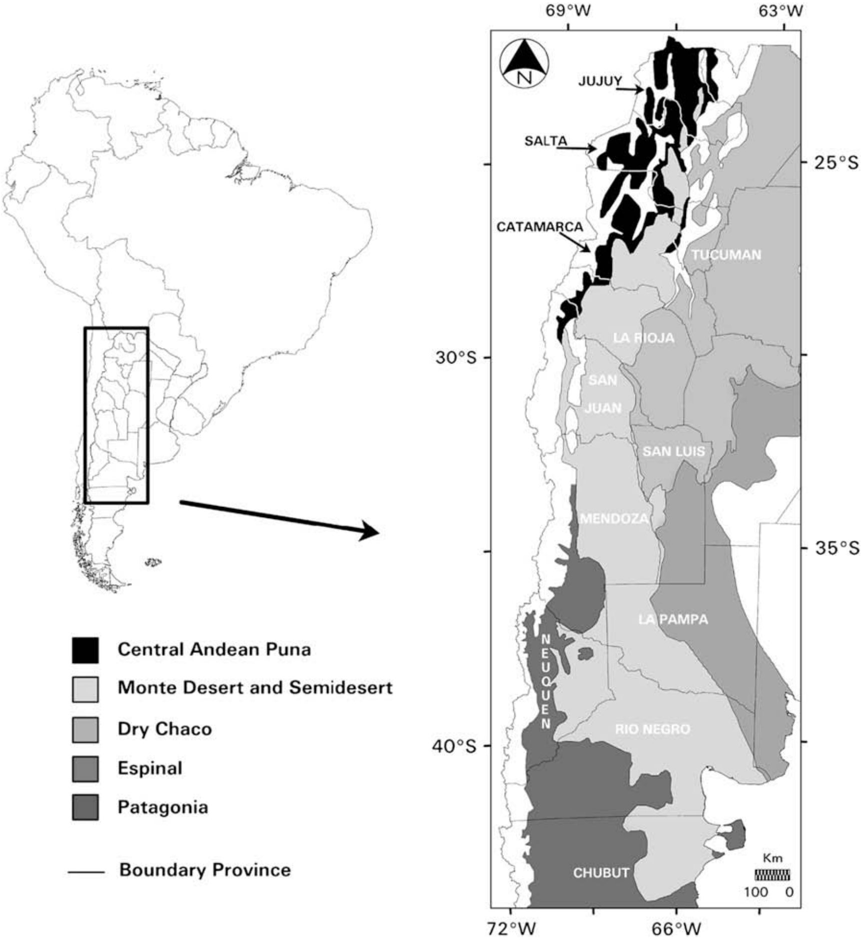

Fig. 1. Location of the Monte Desert biome and transitions with Prepuna (Central Andean Puna), Dry Chaco, Espinal and Patagonia phytogeographic provinces. Only Provinces sharing the Monte Desert biome are shown.

100 mm. The southern Monte stretches from southern Mendoza (35°S) to northern Chubut (44°S), including vast areas of La Pampa, Neuquén and Río Negro. It is a temperate region with a Mediterranean-like rainfall regime produced by the westerlies from the Pacific Ocean affected by the rain shadow effect of the Andes.

Another classification of the natural areas in the Monte is represented by the high and low elevations. The high Monte is characterized by mountain and bolson landforms and occurs primarily in the northern Monte, whereas the low Monte is characterized by piedmonts, hilly country, plains and landforms of major desert stream valleys (central and southern Monte).

In spite of the vast area occupied by the Monte (about 467 000 km^2) and the consequent variability in soils and climate, the vegetation of this biome is rather uniform in terms of physiognomy and floristic composition. Shrub steppes with dominance of *Larrea* spp. (Zygophyllaceae) are the typical landscapes, although several species of *Prosopis* occur in open woodlands where groundwater is accessible (Morello, 1958; Cabrera, 1976). These evergreen shrubs and trees have several mechanisms to cope with the common, severe droughts in the region (Ezcurra et al., 1991).

2. Boundary and ecotone issues

Macroscale boundaries of the Monte were delineated by Morello (1958) according to ecological criteria. More recent and detailed studies have modified these borders in some areas (Cabrera, 1976; Roig, 1998; León et al., 1998; Paruelo et al., 1998b, 2001; Rundel et al., 2007).

At the north end of the Monte, the boundary with Prepuna climbs up to 2000–3400 m a.s.l. depending on latitude (Cabrera, 1976). However, no agreement exists regarding the floristic type of the latter region, while for some authors Prepuna is merely an ecotone between the Monte and Puna, some others believe it should be included in the Monte as a separate district (Morello, 1958; Mares et al., 1985; Rundel et al., 2007).

The western boundaries of the Monte are relatively sharp since they are determined by Andean and Pre-Andean mountains, or indeed where soil cryoturbation processes begin. In western Mendoza this phenomenon occurs between 1500 – 1700 m a.s.l. (Roig et al., 1980; Abraham and Garleff, 1985). Further north the boundary ascends, reaching 2800–3000 m a.s.l. in the province of La Rioja between 28 and 30°S (Garleff and Stingl, 1984).

While the west boundaries of the Monte are sharp since they are topographically controlled, the plains eastwards allow broad ecotones between the Chaco (northeast), Espinal (east) and Patagonia (southeast). In the first two cases, transition is governed by the rainfall gradient, which increases eastwards. Monte elements gradually lose to Chaco ones whereas vegetation structural complexity, diversity, and cover increase (Morello, 1958; Cabido et al., 1993). On the other hand, the transition to Patagonia responds to Atlantic air masses dominating northwards and Pacific air masses southwards (Paruelo et al., 1998a). This entails the gradual change from summer rainfall regime to the winter regime existing in Patagonia (Prohaska, 1976). Excepting some areas with important altitudinal changes and geomorphic discontinuities where the border is well marked, most of the Rio Negro and Chubut portion of

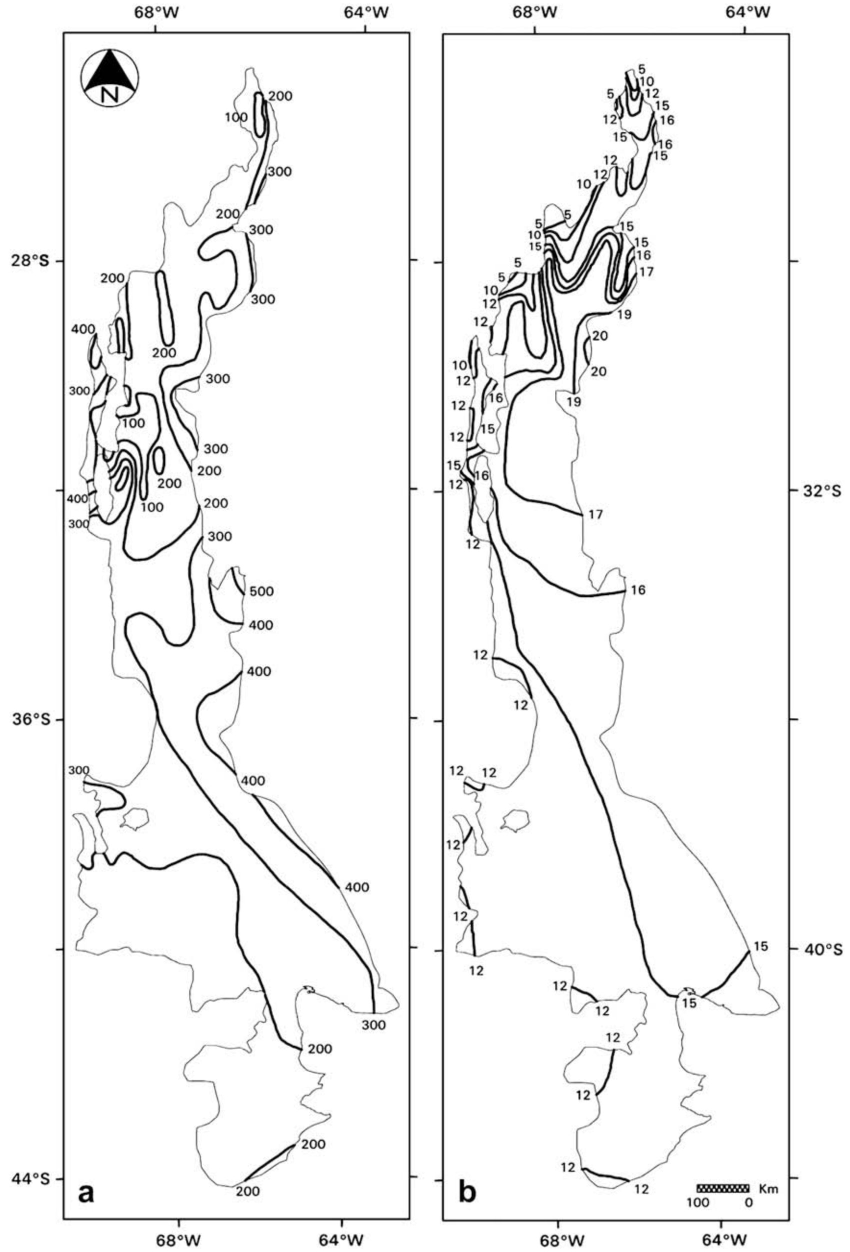

Fig. 2. Mean annual rainfall (2a) and temperature (2b) in the Monte. Source: SSRH-INA (2002).

the Monte is an ecotone where Monte and Patagonian elements coexist (Roig, 1998; Rundel et al., 2007).

According to León et al. (1998) the Patagonian Monte presents a notable floristic physiognomic homogeneity that makes recognition of subunits difficult. In the opinion of these authors, slight differences in flora are only found in the eastern area, probably because of higher rainfall (>250 mm). In that study, two separate ecotones are indicated: the Rionegrino and the Valdes Peninsula; del Valle et al. (1998) include Punta Ninfas as part of the latter. Another ecotone area has been identified in Mendoza province on the basis of transition communities at different altitudes (1450–1650 m a.s.l.) in the north and in the south (Roig et al., 1980).

The oblique NW–SE austral boundary is given by the gradual change in rainfall regime, from summer to winter prevailing rains. Thus, in the southern Monte – from the south of Mendoza southwards – seasonality of rainfall is quite balanced. This change in rainfall regime and in prevailing air masses stems from the swift decrease in altitude of the Andes south of 36°S. The high, heavily ice-caped chains disappear in southern Mendoza (35°30°S) and gradually give way to an increase of the Pacific influence and the beginning of a Mediterranean-like arid climate.

The eastern boundary is vague, forming ample ecotones with the neighboring phytogeographic provinces (Rundel et al., 2007). In the north of the Monte the *jarillales* of *Larrea* appear accompanied by Chaco elements like *Bulnesia schickendantzii*, *Prosopis nigra* or *Tragia geraniifolia*, that penetrate from the east, as is observed in the northeast of San Juan or La Rioja. On the other hand, 800 km further south, beyond the Colorado River, the *jarillales* are accompanied by Patagonian species like *Grindelia chiloensis*, *Chuquiraga hystrix* or *Chuquiraga avellaneade*.

The penetration of elements of the neighboring units, in addition to their own modifications originating along such an extended latitudinal gradient, determines floristic differences within the Monte itself. This justifies the designation of at least three districts, whose characteristics are summarized by Roig et al. (2009).

The analysis based on functional attributes derived from the seasonal curves of the Normalized Difference Vegetation Index (NDVI), derived from the Advanced Very High Resolution Radiometer (AVHRR) sensor on National Oceanic & Atmospheric Administration (NOAA) satellites for a 10-year period, allows the definition of a clear boundary between the Monte and the Patagonian steppes (Paruelo et al., 1998a, 2001). The attributes used were: (a) the annual integral as an estimate of the fraction of photosynthetic active radiation absorbed by the canopy and hence of primary production, (b) the relative range of NDVI, and (c) the date of maximum NDVI, both of which were used to capture the seasonality of primary production. The location of this boundary corresponds well with the southernmost area of influence of the Atlantic air masses.

3. Geographical characteristics

3.1. Geology and landforms

Morello's (1958) review of the geomorphology of the Monte has since been updated by regional and local studies (Fidalgo and Riggi, 1970; Abraham, 1979, 2000; González Díaz and Malagnino, 1984; Garleff, 1987; Godagnone et al., 2001). These studies were used to compile the geomorphic map legend (Table 1, Fig. 3a).

Detailed geological studies with emphasis on mapping of bedrock units, description of stratigraphic sections, and structural geology are listed for the mountain area (Ramos, 1999; Rapela et al., 2001). Primary lithologies include igneous and metamorphic rocks (Precambrian undifferentiated, Paleozoic–Mesozoic intrusives, Mesozoic volcanics, Cretaceous–Tertiary volcanics and Quaternary volcanics) and sedimentary rocks (Cretaceous, Tertiary and Quaternary). The mountain ranges of the northern Monte constitute part of the sub-Andean ranges formed by the uplift of the Andes. Both ranges are N–S oriented anticlines and have cores mostly of metamorphosed, phyllitic basement rocks of Precambrian age. The central Monte is an undulating to depressed loess-like sandy plain of quaternary fluvial, lacustrine and aeolian origin. The southern Monte is in part covered by gravel deposits locally named "*Rodados Patagónicos*" of Pliocene–Pleistocene age (Fidalgo and Riggi, 1970). Older geologic units are exposed in the erosion fronts of plains and depressions, and in the littoral cliffs; they consist mainly of Tertiary marine sediments of Miocene age (Haller et al., 2000).

Table 1
Geomorphic map legend (see also Fig. 3a).

Geomorphologic units (see Fig. 3a)	Area	
	km^2	%
Structural-denudational units		
1. High and low mountains	69 333	14.9
2. Hilly country and foothills	3467	0.7
3. Dominant volcanic landforms	34 421	7.4
Denudational units		
4. Badlands	6 504	1.4
5. Rolling and irregular plains	3114	0.7
6. Structural plains and pediments	13 960	2.9
7. Destructional plains, residual hills and erosion fronts	7719	1.7
8. Peneplains, hilly country and depressions	44 710	9.6
Fluvio-denudational/aeolian units		
9. Closed depressions/Salinas	3648	0.8
10. Alluvial-aeolian plains	56 445	12.1
11. Intermontane basin (bolson) landforms	39 287	8.4
Fluvioglacial-denudational/fluvial unit		
12. Gravel plains (different levels)	87 630	18.7
Fluvial units		
13. Alluvial plains	53 179	11.4
14. Alluvial fans	12 132	2.6
Aeolian units		
15. Aeolian plains	28 686	6.1
16. Active sand dunes/dunefields	2088	0.5
Coastal-denudational unit		
17. Littoral environments	652	0.1
	466 975	**100.0**

The relief intensity of the Monte region is one of the most significant discriminating terrain factors observed by the Shuttle Radar Topography Mission (SRTM) global elevation data (Fig. 3b). This figure shows the range of altitudes in a shaded relief form.

The distribution of alluvial and aeolian landscapes reflects an alternating balance between the wetter and drier climatic phases of the Quaternary. Gently undulating sandplains and active sand dunes are found near Cafayate (Salta), in Campo del Arenal and Belen (Catamarca), near Vinchina and Guandacol (La Rioja), in the Médanos Grandes desert (San Juan) and in northeastern Rio Negro province (near Caleta de los Loros). Deposits of finer textured aeolian material also occur extensively both in alluvial environments and on more undulating plains.

3.2. Watershed boundaries

The area occupied by the Monte is drained by 22 watersheds, although in most of them neither the headwaters nor the mouth are located in the Monte itself (Appendices 2 and 3a, electronic version).

Localized marsh environments (San Juan, Mendoza, Tunuyan, Colorado, Negro, and Chubut watersheds) are biologically the richest places in the Monte (Appendix 3b, electronic version). The most difficult issue in conserving the biological value of these permanent rivers is the assurance of water flow, due to several reasons such as uncertain permanence and dam diversion. Salinity may affect these rivers and their floodplains (del Valle et al., 2008). In the irrigated valleys the return flow may also carry residues of agricultural chemicals and toxic trace elements.

The most important wetland is the system of lagoons in Guanacache and Rosario in the Mendoza province; it is a Ramsar site (strong protection from international agreements) that is home to an interesting diversity of aquatic and migratory birds (Sosa, 1999).

Basin characteristics are shown in Appendix 4 (electronic version). Most water bodies are dry, seasonally or for years at a stretch. The dry water bodies and playa lake/salinas are prolific sources of dust. In the southern watersheds, lakes and dams offer much bigger surfaces that might be biologically important, although this is not well known.

3.3. The soil cover

Soil cover diversity deals with the density of soil bodies and the variety of soil species present. The general soil map (Fig. 4a,b) shows the geographic distribution of the major soils in the Monte (Godagnone et al., 2001). Table 2 shows the approximate area in square kilometers and the percentages of soil orders and suborders (USDA, 2003). The relative soil importance per natural area is as follows:

- $>$ Orthents $>$ Psamments $>$ Udepts (High Monte/northern Monte)
- $>$ Psamments $>$ Argids $>$ Calcids $>$ Orthents $=$ Fluvents $>$ Cambids $>$ Gypsids (Low Monte/central and southern Monte)

Entisol properties are determined largely by the parent material. Most Entisols have no diagnostic horizons, other than an ochric epipedon, and a very few an anthropic, albic or histic epipedon. Entisols are the dominant soils on gentle to steep slopes and

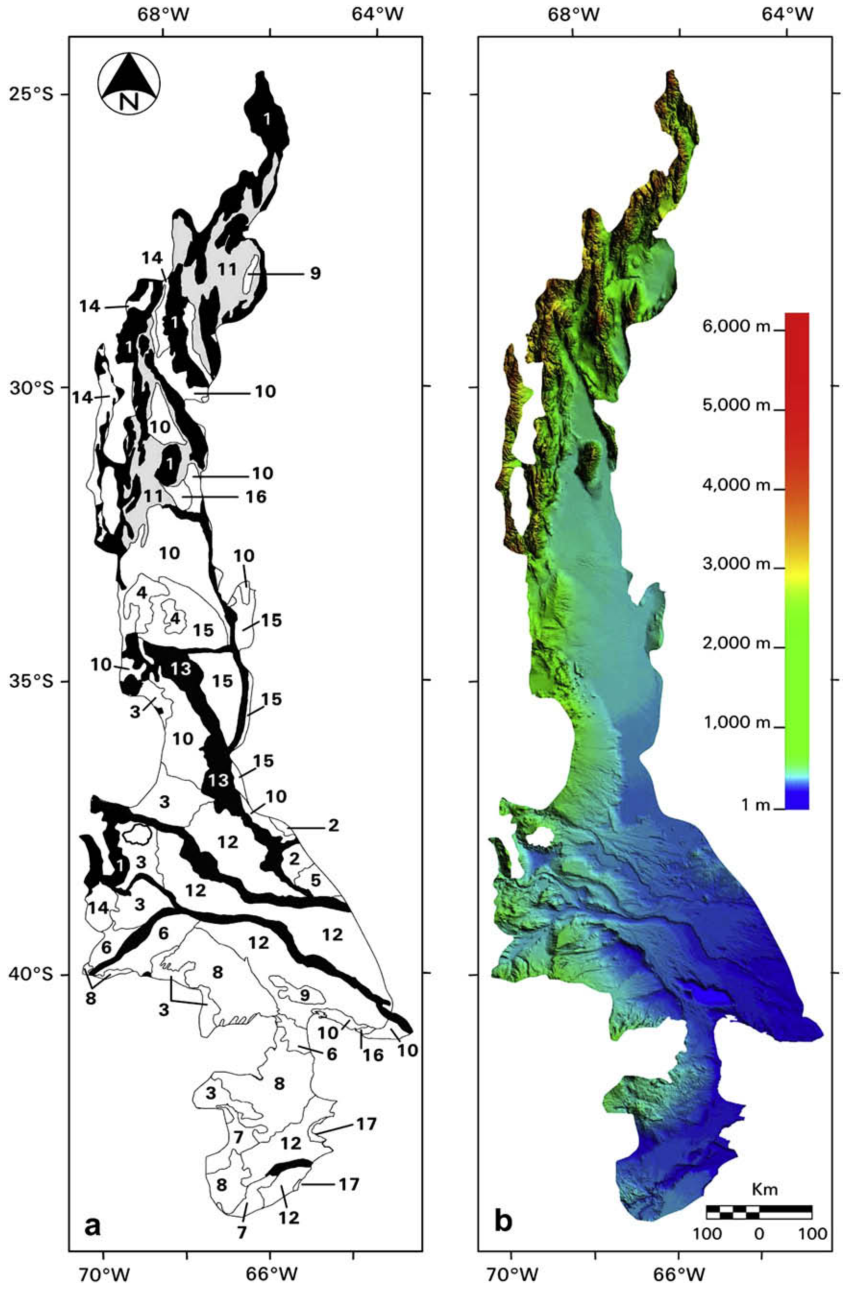

Fig. 3. (3a) Geomorphic landscape and map units review (see also Table 1). Structural-denudational units (1–3); Denudational units (4–8); Fluvio-denudational/aeolian units (9–11); Fluvioglacial-denudational/fluvial unit (12); Fluvial units (13, 14); Aeolian units (15, 16); Coastal-denudational unit (17). (3b) Elevation data (90-m spatial resolution) from Shuttle Radar Topography Mission (SRTM). Source: courtesy from Global Land Cover Facility, http://www.landcover.org.

represent 54.5% of the soils of the region. This order corresponds to cold soils, aridic soils, soils of river deposits, sandy materials, areas with shallow soil and local alluvium. The temperature regime of these soils is mesic, thermic and cryic, and the soil moisture regime torric, xeric and aquic. Three suborders were identified: Orthents (soils on old and recent erosional surfaces), Psamments (sandy soils) and Fluvents (soils formed in water-deposited sediments).

Aridisols represent 22% of the soils of the region and they are found mainly on gentle slopes and occur on a variety of landforms, lithologic types, and on stable land surfaces of the late Pliocene–Pleistocene or greater age. They have at least a cambic horizon, or an argillic or natric horizon, or a calcic or petrocalcic horizon, or a gypsic or petrogypsic horizon, or a duripan, or a salic horizon. The soil temperature regime ranges from frigid to isothermic. The soil moisture regime is dominantly aridic and torric but some Aridisols have ustic or xeric regime. The four suborders classified were: Argids (accumulation of clay), Calcids (accumulation of carbonates), Cambids (translocation and/or transformation of material) and Gypsids (accumulation of gypsum).

Inceptisols in the Monte region occur on geologically young sediments or landscapes and in areas where the environmental conditions inhibit soil development. The soil temperature regime is mesic or isomesic and the soil moisture regime is xeric. The suborder founded was the Udepts (0.5%).

The arrangement of soils is not always the same from one landscape to another and productivity of landscapes varies with the character and areal distribution of component polypedons (USDA, 2003). The Monte soils vary considerably depending upon the nature of their parent materials and site history. Variation in soil conditions within the total landscape can be divided into three

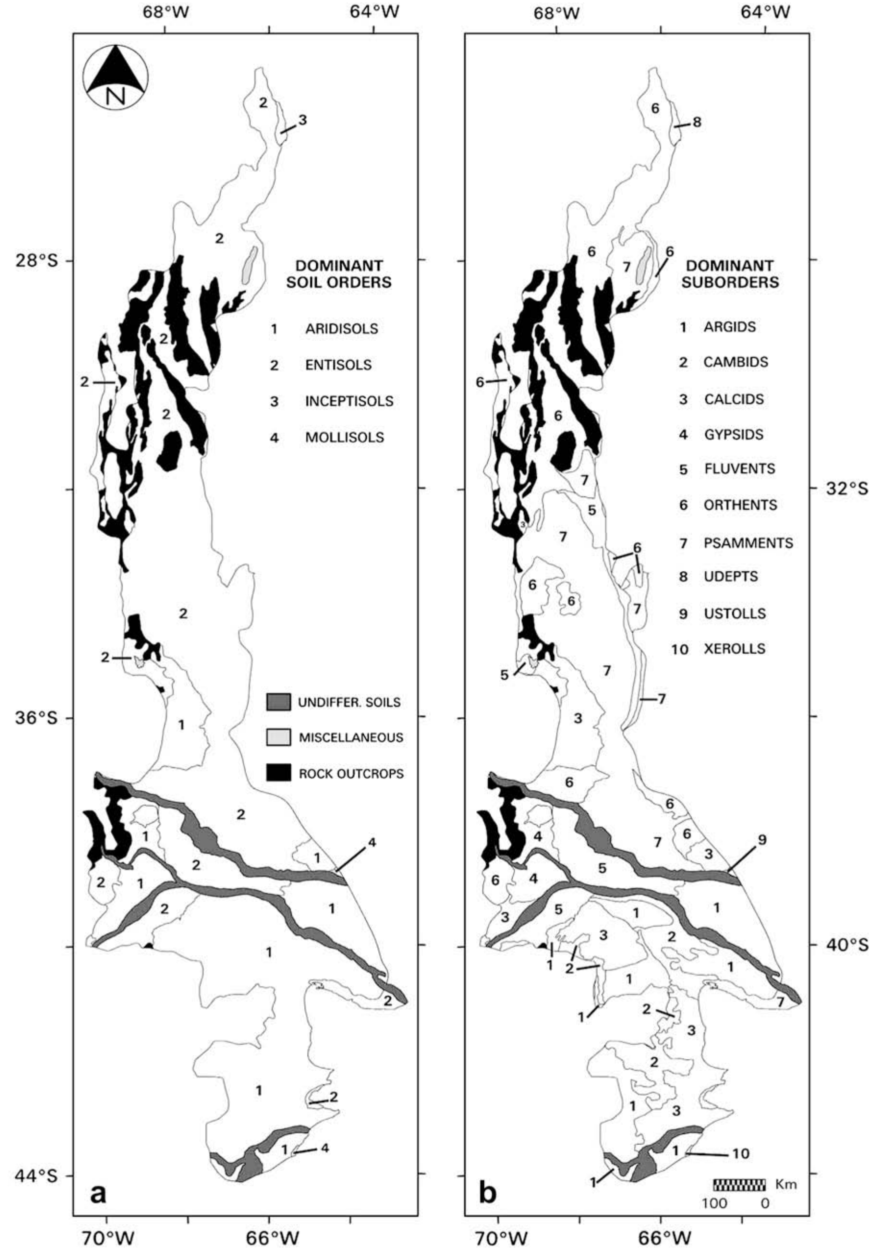

Fig. 4. Main soil taxa of the Monte (100–60% dominant taxa). (4a) Dominant Soil Orders. (4b) Dominant Soil Suborders (see also Table 2).

main components: (a) variation within individual landforms or geomorphic elements (summit, shoulder, backslope and toeslope); (b) variation between landforms of the same soil category; and (c) variation between landforms of different soil categories.

Soils in the Monte present characteristics mostly related to the arid conditions under which they have evolved. The spatial variability of these features increases with the degree of aridity (del Valle, 1998).

4. Socio-ecological issues of the Monte: case study in Mendoza

In the Monte, the territory is structured following a pattern that distinguishes between two subregions: irrigated oases and non-irrigated lands. The former occupy small territory portions, but concentrate the most valued regional resources, most of the population, and the most dynamic production undertakings. The latter have minimum water allocations, its lands are unfit for crops, they maintain high rurality indices, and are based on subsistence activities linked to livestock (Cony, 1995; Prieto and Abraham, 1998, 2000; Abraham and Prieto, 2000; Torres et al., 2003, 2005; Villagra et al., 2004). Non-irrigated lands are described as marginal (Abraham and Prieto, 1981), unobserved (Montaña et al., 2005) or integrated into irrigated lands in a condition of subordination (Torres et al., 2005).

Studies analyzing the socio-economic dimensions can be organized in three stages. The first, during the late 1970s and mid-80s, reflects the initial efforts to grasp the environment–man relationship, and analyzes human and cultural dimensions. Abraham (1979), Triviño (1980) and Triviño et al. (1981) describe the ways of life of the inhabitants of drylands in the northern and central Monte, their economic activities, housing, customs, traditions and the systems of natural resource use.

In the second stage, from the 1980s to the end of the 20th century, Abraham and Prieto (1981) and Prieto and Abraham (1998) counteract the prevailing views with the methodology of

Table 2
Main soil taxa of the Monte (see also Fig. 4).

Orders and Suborders Soil Taxonomy	Area of main soil taxa			
	High Monte[a]		Low Monte[b]	
	km^2	%	km^2	%
Aridisols				
Argids	–	–	59 877	17
Cambids	–	–	25 183	7
Calcids	–	–	57 018	16
Gypsids	–	–	11 574	4
			153 652	**44**
Entisols				
Fluvents	–	–	32 217	9
Orthents	63 529	56	32 129	9
Psamments	9348	8	96 119	27
	72 877	**64**	**160 465**	**45**
Inceptisols				
Udepts	1172	1	–	–
	1172	**1**	–	–
Mollisols				
Ustolls	–	–	179	0.06
Xerolls	–	–	143	0.04
			322	**0.10**
Undifferentiated soils	–	–	**28 816**	**8**
Miscellaneous areas	**970**	**1**	**247**	**0.1**
Rock outcrops	**38 399**	**34**	**10 055**	**3**
	113 418	**100**	**353 557**	**100**

Source: Godagnone et al. (2001).

[a] High Monte (northern Monte).

[b] Low Monte (central and southern Monte).

environmental history. These studies show that the current status of deterioration of natural resources in non-irrigated lands is due to unequal relationship with irrigated areas. They allow recognition of different eras in the process of use and occupation of space and natural resources from indigenous times to the present day.

The third stage, from the end of the 20th century to date, shows the clear predominance of systematic analyses. Contributions to the study of desertification consider the socio-economic dimensions, either in creating integral systems of desertification assessment (Abraham, 2003; Abraham et al., 2006), evaluating the relationship between complex social variables (Adamo, 2003) or developing strategies of local development (Pastor et al., 2005).

Non-irrigated areas have a rural profile and the people organize themselves in "*puestos*" (production units) according to a sparse or minimally grouped settlement pattern. Production activities are basically devoted to subsistence: livestock breeding for producing manure and meat, production of handicrafts, and collection and sale of *jonquil*. At the social level there is an indication of high poverty rates and of a constant migration into urban centres or other rural areas in the oases. Production is organized around the breeding of goats at the family scale, with predominance of low efficiency management (excessive number of goats, extensive grazing techniques, lands affected by desertification and having land tenure problems, flock sanitation issues, scarce drinking water with chronic arsenic problems). Finally, there are serious difficulties in commercializing local products and mean income is below the indigence line (INDEC, 2008).

Although studies promoting descriptions of the socio-economic dimensions are not lacking, especially because of the need to account for disturbances to natural resources, their approach to human dimensions overlooks a series of variables (political, economic, cultural and social). Most of them point out that the strategies of natural resource use adopted by the locals are neither appropriate nor rational because they lead to increased land degradation in the mid-and long term (Cony, 1995; Guevara et al., 1995; Villagra et al., 2004). Systems of land use and economic production strategies are not sufficiently considered; thus, research on the stress that human beings are exposed to is still needed. It is well known that the major land degradation issues are due to overgrazing and logging (Cony, 1995; Villagra et al., 2004), however no attempt is made to explain the causes to which these strategies respond. Finally, the suggested proposals to reverse these processes are restricted to recommending diverse examples of awareness raising, environmental education, and even cultural change in the people (Roig et al., 1991).

5. Ecological-economic issues, inter-generational transfer of Natural Capital

As similar pastoral lands, the Monte desert displays conflicts of resource use (Jones and Dowling, 2005). Some of them arise from the dependence of these systems on stochastic climate variations (Le Houérou et al., 1988). Although climate variations are difficult to predict, they require adaptive management policies able to cope with characteristic response time lags, due to the slow rates of restoration of the soil and forage sustaining these systems.

Domestic grazers, forage and soils constitute renewable Natural Capital (NC) (Costanza and Daly, 1992), with typical turnover times in the order of 5–10 years (sheep, cattle), several years to decades (forage plants) and centuries (soils). Vegetation and soil degradation, however, may occur after a few years because of anthropogenic activities (inadequate cropping, overgrazing, etc.).

In semiarid grazing lands, conventional economic approaches used to value and regulate resource uses do not seem appropriate to warrant modern community values and inter-generational transfers of NC (MacLeod and McIvor, 2006). Concepts pertaining to the sustainable (economic, ecological) management of production systems at the Monte will be presented in this section. The focus is on wool production systems in the Patagonian Monte.

Wool production systems in this section of the Monte started at the beginning of the 20th century (Defossé et al., 1992) and are currently carried out in large '*estancias*' (10 000–50 000 ha or more) usually consisting of a few paddocks around a shared watering place. Flock management has been extensive, with limited human intervention, and native vegetation has been almost the only source of forage for sheep, with flocks behaving as "semi-natural" populations (Golluscio et al., 1998; Paruelo et al., 1998b). Wool reaches the market once a year and growers make decisions about their business depending on the price obtained for their production. As in other regions of the world, the wool economy of the Patagonian Monte has had deep economic, environmental, and social regional impacts.

However, some evidences indicate that these systems are not ecologically and economically sustainable, since gradual losses in the NC seem to have taken place during the last decades, as occurred in other regions of Patagonia (Golluscio et al., 1998). Sheep grazing impacted on the forage stocks of the Monte, producing structural and floristic changes that are eventually (but not always) partially reverted after releasing the grazing pressure (Bertiller and Bisigato, 1998; del Valle et al., 1998; Bertiller et al., 2004). Such recovery of preferred grasses occurs only after 20–30 years of sheep exclusion (Bisigato et al., 2002). Ecosystem modeling experiments with parameters obtained from field experiments (Parton et al., 1993) show that observed trends of vegetation dynamics under moderate grazing are compatible with a gradual diminution of the plant cover at regional scale (Carrera et al., personal communication). Evidence also indicates that the soil NC experienced reductions during recent decades under the impact of wool production systems. Ares et al. (2003) identified structural changes in vegetation cover in the sense of a progressive alignment of plant patches along the direction of predominant winds suggesting an indication of progressive wind erosion of soils.

In a recent contribution (Ares, 2007) the following questions were addressed: 1. How can investment policies be designed to achieve both ecological and economic sustainability of Patagonian wool production systems? and 2. What are the trans-generational transfers of NC stocks and how can generation equity principles about the Patagonian pastoral system be formulated?

Regarding the first question, an economic analysis of several investment policies was performed. Results showed that feasible investment policies within accepted market rules for the private sector can be devised such that economic-ecological sustainability would be attained over periods of 25–30 years. However, Net Cash Flows (NCF) values can experience wide fluctuations depending on climate and market behaviours.

With respect to the second question, the time scale at which perturbations of these processes are propagated into the wool production system is comparable to human generation times. Sheep owners are likely to avoid adaptive actions while NC losses occur during the wool production process (Kelly et al., 2005), but would nevertheless continue to experience positive NCFs; it is likely that the depletion of NC would remain unnoticed and adaptive actions would tend to be delayed or transferred to the following generation.

Analysis of the mechanisms underlying the development of Patagonian Monte wool production in non-sustainable systems reaches similar conclusions as those obtained in other pastoral areas of the world (Gardener et al., 1990; MacLeod and McIvor, 2006).

Why do ranchers in the Monte and elsewhere seem to prefer investing in increasing the flock stocks instead of the forage capital? Answers seem complex: socio-cultural traits modifying the perception of the environmental quality, reverse assurance game policies, the size of the production systems or regional conditions of access to markets have been indicated as promoters of non-sustainable policies (Lise et al., 2006; MacLeod and McIvor, 2006). Since it might be technically or more likely, economically impossible to repair NC degradation in the Monte once it has occurred, its effect on future generations raises complex issues of inter-generational equity (Common and Stagl, 2005).

6. The Monte as a macroregion in dialogue with other South and North American arid biomes

The Monte forms, together with the "Central Andean Dry Puna" and "the Atacama desert", the ecoregion of Neotropic deserts. They are located within the South American Arid Diagonal, so called by French geographers (De Martonne, 1948; Bruniard, 1982), i.e. an oblique band stretching from the Pacific coast of the Equator to 50°S on the Atlantic Patagonian shore. It is formed by a mosaic of different types of deserts: coastal hot, subtropical, rain shadowed and temperate continental. Along the southern border of the Arid Diagonal, Le Houérou (1990) locates a Mediterranean Diagonal.

The Monte dynamics depends on a higher hierarchy system: the Cordillera-Plains system. The Andean Cordillera and its secondary ranges bound the Monte to the west and have a strong influence on this biome. It runs parallel to the 70°W meridian from 18°S to 52°S and, with a total length of 7200 km, is the longest mountain range in the world. South of 23°S it marks the border between Argentina and Chile for over 3000 km.

According to Morello (1984), the N–S axis of the Andes organizes the Argentine space in a prevailing W–E direction only, since the mountain range not only creates the leeward arid climates but also determines several other topographic and hydrographic effects. The Andean-induced drylands extend over 70% of the Argentine territory (Fernández and Busso, 1997).

Morello (1984) remarks on the clear interactions between the Andes and the plains. High mountains supply energy, water, sediments, nutrients and also catastrophic events. The extra-Andean system receives the Andean influence for up to very long distances, mainly through aeolian and hydrological transport processes. At shorter distances, the Andes affect closer systems by means of seismicity, aquifers, orographic rains, etc. So, the Andes influence the nature–society relationships far beyond their specific space. For instance, in a macroscale view, the Andes condition the river systems, the rain regime and the aridity conditions, namely surface and groundwater supply, over a great extent of Argentina and the whole Monte biome. A few allochthonous rivers cross the drylands and connect to the Atlantic basins; groundwater reserves from Andean origin are the only available water source in most of the northern and central Monte, allowing the presence of leguminous woodlands in some areas. Such reachable watertables are lacking in the southernmost portion of the Monte (Roig, 1998).

There is a remarkable convergence between the arid areas of North and South America, in what Morello (1984) defines as "iso" spaces, with the same climate subtypes, the same dominant vegetation and the same combination of biological forms. Among these, the Monte and Chihuahuan and Sonoran deserts in Mexico show surprising similarities, not only in biotic conditions but also in the adaptation of the local population in relation to land uses and production systems (Morello, 1972).

In Argentina, the Monte biome is considered as a prolongation of the Chaco ecoregion towards drier zones; it is floristically related to the zone of *Larrea* spp. (Mexico, USA) and to the Espinal from the Mediterranean zone of Chile (Mares et al., 1985); Roig and Rossi (2001) compare in Table 3 the floras of the Monte (Ñacuñán, central Monte), Central Chile, Chaco and the Mexican xerophytic flora of Mapimí. The results show a high percentage of genera and species shared in common between the flora of the Monte and the Chaco. Next in importance is the flora in Central Chile and Mapimí.

The genera present in the Chaco ecoregion (Morello, 1958) are *Prosopis*, *Capparis*, *Geoffroea*, *Bulnesia*, *Bouganvillea*, *Condalia*, *Ximenia*, *Grabowskya*, and *Flaveria*, all of them also occurring in the Ñacuñán reserve (central Monte). But the most remarkable relations occur – according to the authors mentioned – among the genera and species that Ñacuñán and the deserts of Mexico and the USA have in common. Such is the case of *Capparis atamisquea*, *Setaria leucopila*, *Trichloris crinita*, *Scleropogon brevifolius*, *Sporobolus cryptandrus*, *Verbesina encelioides*, *Bouteloua aristidoides* and *Diplachne dubia*, in addition to the genera *Prosopis*, *Cercidium* and *Larrea*. Of the 15 species shared in common, many are endemic to both South and North American amphitropical desert zones, with the most amazing similarity between these deserts being at the level of Gramineae.

Table 3
Flora of Ñacuñán and its comparison with other floras

Flora	Ñacuñán Reserve	North of Córdoba	Santiago de Chile Basin	Uspallata Range (West)	Mapimí Reserve	Uspallata Range (East)
Phytogeographic province	*Monte*	*Chacoan*	*Central Chilean*	*Puna*	*Mexican xerophytic*	*Cardonal*
Total general	95	117	427	101	197	89
Total species	136	295	942	152	313	116
Number of genera in common	–	47	46	35	23	20
Number of species in common	–	31	16	16	15	6
% of genera	–	49	48	36	24	21
% of equal species	–	33	17	17	16	6

Source: Roig and Rossi (2001).

Analyzing the divergences among plant species is also extremely interesting, with the most outstanding case being that of the Cactaceae, a family endemic to America with a high number of species. Nevertheless, the cacti of Argentina, Chile and Mexico show few relations, the similarity being reduced to the genus *Opuntia* without any coincidence with the North hemisphere.

Four theories are developed to explain the amphitropical disjunction of these dispersions between two desert areas more than 9000 km apart: (1) the existence of only one desert in the past, (2) the formation of possible ecological corridors, (3) the dispersion over great distances, and (4) the convergent evolution from common ancestors, with greater possibilities being granted to the two first theories. These theories are discussed in the work by Roig et al. (2009).

7. Concluding remarks

With this contribution we have attempted to provide an updated overview of the existing knowledge related to the Monte as an ecoregion, while searching to encompass all aspects of its diverse environmental problematic issues: from the biophysical to the socio-economic and the cultural. The most controversial topic was the regional delineation of the Monte. As with other biomes, opinions differ about the Monte boundaries and transitions (ecotones). In our discussion, we laid emphasis on vegetation, but it must not be forgotten that heterotrophs also play essential roles in the Monte. Further studies on Monte borders are deemed necessary.

Besides, we analyzed the related information generated in the Monte itself with a view to determining the state of knowledge in the light of the different theories and disciplinary bodies to which the authors subscribe. In so doing, we found a great asymmetry between the literature related to biophysical aspects and that associated with socio-cultural ones. The scientific production has privileged biophysical issues, whereas social and cultural aspects have been disregarded. The interdisciplinary approach is unusual and only partially applied, especially between naturally allied sciences and subjects, for instance relationships among water, vegetation and soils. Interdisciplinary studies addressing perspectives and links between the cultural and the natural are harder to find. The same is true for integrated, systemic studies, practically absent since Morello's works.

Sustainable investment policies in rangelands of the Patagonian Monte should consider the ecological-economic relationships and feedbacks between forage consumption by ewes and ewe natality/soil erosion controls exerted by forage and market behaviour.

Comparative studies on the similarities of the Monte desert, the Sonoran and Chihuahuan deserts in Mexico, and the deserts in the South West of the USA should be fostered, in the certainty that they could contribute new models for comprehending the structure, dynamics and evolution of drylands.

The evolution of the knowledge emerging in relation to the Monte shows a parallelism with that of environmental sciences; starting from early simple inventories of the ecosystem components – even in the cultural realm – it is only in recent times that systemic and research-action approaches have been attained. This indicates an attempt to generate processes of local development and, in this sense, the Monte is a region not yet well understood.

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Appendix A. Supplementary material

Supplementary material associated with this article can be found in the online version, at doi:10.1016/j.jaridenv.2008.09.028.

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