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Aboriginal settlements of arid Patagonia: Preserving bio- or sociodiversity? The case of the Mapuche pastoral Cushamen Reserve☆

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ABSTRACT

Preservation of biodiversity can be at odds with preservation of sociodiversity, i.e., human groups with different cultures, social organization and economic activities coexisting within a region. We analyzed this problem in the Cushamen Reserve, a pastoralist Mapuche aboriginal settlement in Patagonia, Argentina. We found that the current stocking rate of domestic herbivores is twice the rangeland carrying capacity, and this overstocking has resulted in a 20–30% reduction in plant cover, productivity, floristic richness and pastoral value compared to similar sites located on neighboring capitalist farms. The potential economic income of a generic Cushamen farm (625 ha) under the current stocking rate (0.27 sheep units $\cdot$ ha^{-1}) and productive parameters (wool and number of lambs produced per sheep each year and the number of sheep that died or were discarded per year) is above the family poverty line, but this potential may be only rarely achieved due to interannual variability of productive parameters. However, under the carrying capacity, only an improbable combination of 0.84 lambs $\cdot$ sheep^{-1} yr^{-1}, 5.5 kg wool $\cdot$ sheep^{-1} yr^{-1} and a 16% rate of annual sheep discarding would equal the present potential income. Active policies aimed at increasing carrying capacity of the Cushamen Reserve are needed to preserve both bio- and sociodiversity.

1. Introduction

The concept of biodiversity includes all living organisms, each with its own individual survivorship strategies, coexisting within different levels of biological organization: populations, communities, landscapes or biomes (Díaz and Cabido, 2001; Ehrlich and Ehrlich, 1992; Sala et al., 2000). Its preservation is recognized as an ethical imperative for the current generations in order to prevent the extinction of genetic traits evolved over millennia (Chapin et al., 2000; Lubchenco et al., 1991). However, the methods for preserving biodiversity are the subject of increasing debate because different preservation strategies would differentially affect the lifestyles of different human groups (Escobar, 1998). By analogy with the biodiversity concept, sociodiversity encompasses all human groups with different cultures, social organization and economic activities coexisting within different geographic levels of aggregation: towns, regions, countries or continents. The term sociodiversity was first used by Neves (1995), although without a formal definition, when analyzing four aspects of the dialectical co-evolutionary relationship between socio- and biodiversity in the Amazonian region. He showed that (a) different biodiversities generate different social organizations, cultures and economic activities, but at the same time, different human groups differentially (b) affect biodiversity and (c) understand and make use of biodiversity. Finally, he proposed that the actual genetic diversity of the human species itself depends on the maintenance of genes selected due to interactions with very diverse habitats that have occurred over millennia. Therefore, the maintenance of sociodiversity may be another ethical imperative for current generations in order to prevent the extinction of cultural traits that have developed over long periods of time.

The most arid zones of the world are subjected to desertification processes of variable intensity, which severely affect biodiversity.

☆ Spanish version available upon request.

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Pastoralism is the production system that uses animals as capital resources (Lane, 2006; Salzman, 1996). The alteration of traditional pastoralist systems (Bates, 1998) by human population growth and the restriction of mobility (Abule et al., 2005) is one of the most accepted causes of these desertification processes in Australia (Letnic, 2000; Morton et al., 1995; Pickup and Stafford Smith, 1993), Asia (Li et al., 2007), Africa (Ellis and Swift, 1988; Fratkin, 1997) and South America (Buttolph and Coppock, 2004). However, pastoralism promotes the social embeddedness of aboriginal cultures (Gill, 2005), and several other studies did not find pastoralist land use to negatively affect biodiversity and land cover (Davis, 2005; Mc Cabe, 1990; Ward et al., 1998). On the other hand, some of the deterioration problems attributed to pastoralist land use may be avoided by respecting ancestral indigenous norms, which are indiscriminately discarded by non-indigenous landowners and policymakers in both Australia (Gill, 2005) and Africa (Davis, 2005; Mc Cabe, 1990). In addition, it has recently been recognized that there is a need for integrative answers to several urgent problems, not only safeguarding biodiversity and reversing land degradation in arid zones but also simultaneously alleviating poverty and protecting the cultures of human populations native to these arid zones (Reynolds et al., 2007).

Most studies on pastoralist production systems were performed in Africa, followed by Australia and Asia (77.2, 10.6 and 10%, respectively, of 451 references found in the Scopus database, under the "pastoralis*" search criterion). Most studies on aboriginal people were performed in Australia (86.4% of 3450 references found in Scopus, under the "aborigin*" searching criterion). We found very few antecedents on pastoralism or aboriginal peoples coming from America (2.4 and 7.8% of references, respectively). In this paper, we analyze the potential conflict between the preservation of bio- and sociodiversity in a pastoralist aboriginal settlement of Patagonia (southern South America).

The biodiversity of Patagonian ecosystems is highly fragile because of the confluence of severe aridity (Soriano, 1983), intense grazing use (Anchorena, 1985; Ares et al., 1990; León and Aguiar, 1985; Perelman et al., 1997), short evolutionary history of grazing (Markgraf, 1985; Milchunas et al., 1988, but see also Adler et al., 2004 and Lauenroth, 1998), and a very low economic profitability constraining the adoption of sustainable range management strategies (Golluscio et al., 1998). The extensive sheep colonization of Patagonia began in the late 19th century (Golluscio et al., 1998; Helman, 1965; Soriano and Paruelo, 1990) after the compulsory expulsion of aboriginal human populations by the "Desert Campaign", a war driven by the Argentinean government to take over the regions inhabited by aboriginal populations (Giberti, 1986; Golluscio, 1990). Some aboriginal populations who survived the "Desert Campaign" were deported to other Argentinean regions, and the rest were confined to reserves, colonies or isolated settlements (Briones and Delrio, 2002). In most cases, the settlements were located in the most arid regions (Golluscio, 2006), and their productive capacity was clearly insufficient to satisfy the needs of their inhabitants (UCA, 2004). In addition, the subsequent growth of human populations and that of animal populations supporting them increased grazing pressure on the scarce natural resources of the settlements, leading to an aggravation of the desertification and biodiversity loss processes. As a consequence, desertification and biodiversity loss was more dramatic in most of the aboriginal settlements than in the rest of the region.

The loss of biodiversity in aboriginal settlements could be conceived of as a consequence of their pastoralist form of production, but it may also be conceived of as a consequence of the change in aboriginal lifestyle and production system after the Desert Campaign. In this paper, we will focus on the Mapuche case. The Mapuche make up the most numerous aboriginal population in Patagonia and were the last people to fiercely fight against the Argentinean army until their final defeat in the 1880s. According to their leaders, "the Mapuche People constitute a political, linguistic, cultural and historical unit. This conjunction is intimately linked to the territorial unity located on both sides of the Andes and in what is today central-southern Argentina and Chile (*Puel Mapu* 'eastern land' and *Gulu Mapu* 'western land', respectively)" (Mellico and Pereyra, 1997, our translation). This conjunction is also reflected in the lexical chain that links the land (*mapu*) where they live and the language that they speak (*Mapudungun* "language of the land") with the community and individuals who make it up (*Mapuche* "people of the land") (Golluscio, 2006).

The Mapuche common identity embraces some degree of heterogeneity in social practices and lifestyles. These differences are closely related to the concept of *territorialidad* (territoriality), the sense of belonging to the land where one lives (Fresia Mellico, personal communication). Hence, Mapuche culture manifests a strong relationship between the space in which the people live and how they envision life (Golluscio, in press; Zúñiga, 2006). East of the Andes and before the creation of the national settlements, the Mapuche were organized in lineages with a lifestyle based on agriculture and animal breeding, hunting of *guanaco (Lama guanicoe)* and other terrestrial and aquatic wild animals, harvesting of edible and medicinal plants, and trading with other indigenous groups and European people (Ladio and Lozada, 2004a; Mandrini, 1994; Palermo, 1989). Like the rest of Patagonia's and Pampa's populations, their production systems were not pastoralist (Baied, 1988). However, starting after the Desert Campaign and continuing until the present time, they have been organized in pastoralist extended families with a sedentary lifestyle based on sheep and/or goat breeding and shepherding and a diverse spectrum of activities, including some irrigated agriculture (Delrio, 1998; Golluscio, 2006).

In spite of the undeniable loss of carrying capacity experienced by the aboriginal settlements, most of them did not disappear. This trait is characteristic of several pastoralist cultures around the world (Illius et al., 1998; Lamprey, 1983; Letnic, 2000; Roe et al., 1998). Neither orthodox classical economic calculations nor classical biological population models can explain the persistence of human communities in areas of such scarce and impoverished natural resources. This feedback between impoverished natural resources and impoverished human populations undermines the preservation of both socio- and biodiversity. The characterization of the current economic strategies of aboriginal communities and their impact on natural resources may provide some clues to aid in the understanding of the potentially conflicting relationship between the preservation of bio- and sociodiversity. In this work, we contribute to this understanding specifically by (1) comparing the carrying capacity and the actual stocking rate of the Mapuche pastoral Cushamen Reserve (Argentinean Patagonia), (2) comparing the primary production, pastoral value and biodiversity of plant communities of the reserve with those of capitalist neighboring ranches with lower stocking rates and resource deterioration, and (3) calculating short-term economic income resulting from the fitting of the stocking rate to carrying capacity at the scale of the individual farm. As we cannot escape the unconscious restrictions imposed by our own Western cultural framework, we apologize for any involuntary misunderstandings of Mapuche expectations and their lifestyle that this paper may contain.

2. Study site

The "Colonia Pastoril Cushamen" (now, pastoral Cushamen Reserve), located in NW Patagonia (NW corner of Chubut province, approximately 42° 30′, 70° 30′ W; Fig. 1), has 2700 inhabitants

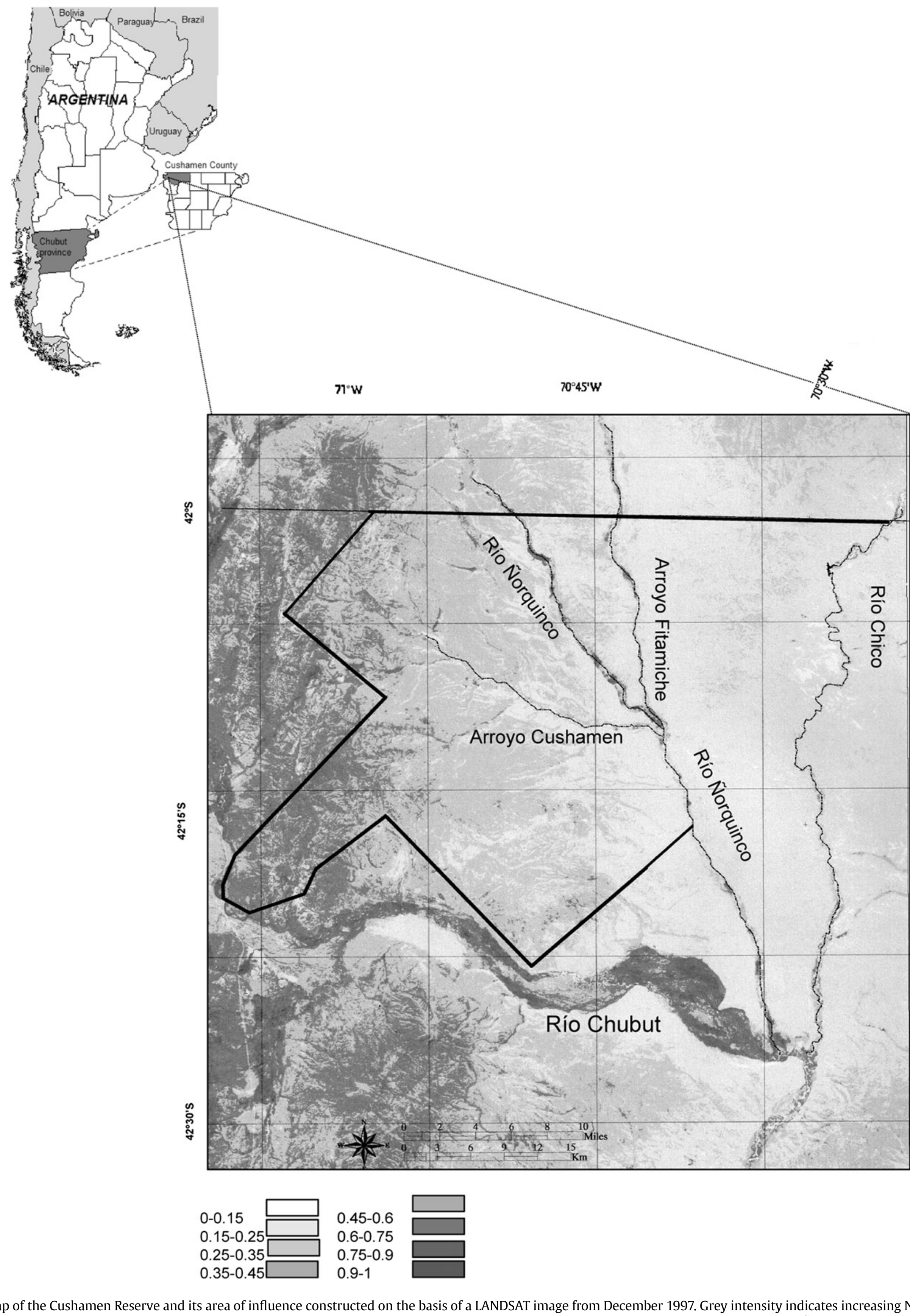

Fig. 1. Map of the Cushamen Reserve and its area of influence constructed on the basis of a LANDSAT image from December 1997. Grey intensity indicates increasing NDVI (see scale at bottom). Continuous coarse lines indicate the political western, northern and part of the southern boundaries of the Cushamen Reserve. The Río Ñorquinco and Río Chubut rivers complete the southern boundary. The Río Chico river forms the eastern boundary. The fine grid on the map corresponds to the Gauss Krüger system of geographic coordinates, whereas the numbers on the left and upper margins correspond to the latitude/longitude coordinate system.

(INDEC, 2001). It originally occupied 125,000 ha, but it currently has a wider area of influence due to the cultural and historical affinities of the people inhabiting it. The settlement was officially recognized by a government decree in 1899 in which Argentinean President Julio A. Roca, the leader of the Desert Campaign, accepted a petition of Mapuche chief Miguel Ñancuche Nahuelquir (Alvarez and Del Valle, 1992; Delrio, 2005; Ramos, 2004). It was created by the national government with a specific agricultural purpose as a model for future agricultural aboriginal reserves (Golluscio, 2006). The area was divided into 200 parcels of 625 ha, but they were rarely fenced. The extreme aridity makes commercial agricultural alternatives other than sheep or goat breeding ecologically unviable (Soriano and Paruelo, 1990). Continuous overgrazing has historically characterized the animal breeding systems of the Cushamen Reserve. Although some Mapuche communities developed transhuman production systems (Ladio and Lozada, 2004b), this was not the case for the Cushamen Reserve.

Geomorphology changes from highly dissected mountains (~1200 m a.s.l.) in the west to flat plateaus (~500 m a.s.l.) in the east (locally known as "mesetas"). Aridity increases from the mountains to the mesetas as the annual rainfall decreases (~400–~150 mm) and the average annual temperature increases (~8–~10 °C) from west to east (Paruelo et al., 1998). A previous phytosociological survey (Golluscio et al., 2000) included in the regional analysis by Paruelo et al. (2004) showed that the vegetation structure varies according to the climatic gradient. At the western end of the reserve there are shrub-grass steppes dominated by *Mulinum spinosum* and *Senecio filaginoides* (shrubs) and *Stipa speciosa* (grass), with some cover of *Festuca pallescens*, a grass species with a high forage quality that is dominant in the more humid grasslands of western Patagonia (Soriano, 1956). These steppes have 40–45% total cover, with a predominance of shrubs (60% of this total cover). Toward the center of the reserve, shrub-grass steppes are replaced by similar shrub steppes, including the same species except *F. pallescens*, and 30% of total cover; 75% of this cover is composed by shrubs (Paruelo et al., 2004). At the eastern end of the reserve, the shrub steppes are replaced by low-cover shrublands and semideserts dominated by the spiny shrub *Chuquiraga avellanedae*, accompanied by *Lycium chilense* in the shrublands and *Nassauvia glomerulosa* in the semideserts. In both cases, total cover rarely exceeds 20%, and the proportion of shrubs is higher than 75%.

All along the climatic gradient, intrazonal meadows occupy the river and stream valleys. These grass steppes rarely exceed 80% of total cover and are dominated by *Juncus balticus* and *Distichlis spicata* accompanied by annual grasses (*Hordeum leporinum* and *Bromus tectorum*), perennial grasses (*Poa lanuginosa* and *Stipa* spp.) and/or shrubs (*Nassauvia* spp., *S. filaginoides*, *Nardophyllum obtusifolium*, etc.). They often show evident signs of deterioration, such as desiccation and salinization, associated with the increased water depth resulting from historical overgrazing. Some of the extremely infrequent meadow patches are occupied by less degraded prairies locally known as "mallines" (Mapuche: *malliñ*), with 100% total cover. In these prairies, highly preferred perennial grasses, such as *Poa pratensis*, and naturalized valuable legumes, such as *Trifolium repens* and *Medicago polymorpha*, replace *D. spicata*.

3. Materials and methods

3.1. Carrying capacity vs. present stocking rate

We calculated the Carrying Capacity (CC, in sheep units ha^{-1}) for the Cushamen Reserve as the ratio between the available forage (expressed in kg DM ha^{-1} yr^{-1}) and the annual sheep consumption (ASC, in kg DM sheep $unit^{-1}$ yr^{-1}) (Golluscio et al., 1998). We calculated the available forage as the product between the Aboveground Net Primary Production (ANPP, in kg DM ha^{-1} yr^{-1}) and the proportion of ANPP that can be eaten by sheep (Harvest Index, HI, in kg DM kg DM^{-1}) (Golluscio et al., 1998). We estimated the ANPP for all of the pixels in the Cushamen Reserve from a LANDSAT image from December 1997. The relationship between ANPP and the Normalized Difference Vegetation Index was previously calibrated (Paruelo et al., 2004). We estimated the potential HI from the linear relationship between log Herbivore Biomass and log ANPP (both in KJ ha^{-1} yr^{-1}) found by Oesterheld et al. (1992), assuming a daily dry matter intake of 3% of living weight (Holechek et al., 1989). This analysis resulted in a linear relationship between HI and $ANPP^{0.5}$ (Golluscio et al., 1998). We assumed that ASC was 365 kg DM · sheep $unit^{-1}$ yr^{-1} (Instituto Nacional de Tecnología Agropecuaria (INTA), 2000).

We evaluated the distribution of ANPP and CC among the different NDVI classes using the Gini Index (Gini, 1912; Weiner and Solbrig, 1984). This index compares the proportion of total area occupied by an NDVI class with the proportion of CC or ANPP corresponding to the same NDVI class. The index varies from 0 (both proportions are equal and inequitability is at its lowest) to 1 (the most extended NDVI classes have null carrying capacity and inequitability is at its highest).

We compared the above calculated overall CC with the present stocking rates obtained from the Livestock Surveys made in 1991 and 2004 according to Provincial Law 4113 (*Catálogo de Señales de la Provincia del Chubut*). For practical reasons, we restricted the analysis to the original 200 parcels. We calculated stocking rates in terms of common sheep units for the different animal species following the equivalences of INTA (2000). We also analyzed the importance of the different animal species in the total animal stock of the Cushamen Reserve in both years.

3.2. Biodiversity, ANPP and pastoral value of the Cushamen reserve vs. capitalized neighboring ranches

We compared the ANPP, the Pastoral Value and the floristic diversity of 20 sites of the reserve with those of 63 sites of two capitalist ranches neighboring the reserve in the west and south. We estimated the ANPP from the NDVI for each site, as stated in the previous section, and made a phytosociological relevé in January 2000 and 2001 (included in the abovementioned regional survey of Paruelo et al., 2004). For each relevé, we calculated the Pastoral Value of the vegetation itself and that of the entire site, including microsites covered by this vegetation and those occupied by bare soil. We calculated the Pastoral Value of the vegetation (PVveg; Daget and Poissonet, 1971) as the average Specific Quality Index (SQI) of all of the species composing the community, weighed by the relative cover of each plant species (ranging from 0 to 1). The Specific Quality Index ranges between 0 (unpreferred) and 5 (highly preferred) and was established by local agricultural stations (Elissalde et al., 2002; Golluscio et al., 1999). We obtained PVveg by multiplying the weighed mean SQI by 20% (100%/5) in order to scale PVveg between 0 and 100% of the maximum forage quality (100% of plant cover with SQI = 5). The Pastoral Value of the site (PVsite) was calculated as the product of PVveg and total plant cover in order to differentiate among sites of the same mean quality of vegetation, but with different amounts of vegetation (Nakamatsu et al., 1998). From the relative cover of each species at each site, we calculated the Shannon–Wiener diversity index ($H' = -\Sigma \text{pi} \cdot \ln \text{pi}$, where pi is relative cover), floristic richness (S = number of plant species), and evenness ($E = H/\ln S$) (Begon et al., 1996). As the vegetation structure changes from west to east, the differences between the two sets of relevés were only statistically analyzed by ANOVA for those relevés with the same physiognomy and pertaining to the same floristic community. We choose the shrub-grass steppe dominated by *S. speciosa*, *M. spinosum*, and *S. filaginoides*, typical of the Occidental Phytogeographic District (Soriano, 1956), because it was the most abundant in both the reserve (14 sites) and in the neighboring ranches (27 sites).

3.3. Economic assessment

Since 2001, wool has been the most important source of income for Cushamen producers because of the combination of relatively good international wool prices and Argentinean monetary devaluation. We calculated the economic income of a generic farm of 625 ha exclusively dedicated to sheep breeding. The income of a farm depends on its production level, which in turn results from the combination of the stocking rate (sheep units ha^{-1}) and productive parameters (wool and lambs produced per sheep per year and the number of sheep that died or were discarded per year). We performed the analysis under four scenarios: (1) present stocking rate and productive parameters, (2) carrying capacity and present productive parameters, (3) carrying capacity and productive parameters of the two neighboring farms with higher availability of natural and economic resources, and (4) productive parameters needed to maintain the present economic income but at carrying capacity. The information on the productive parameters was obtained from the personal communications of Cushamen producers following a protocol of qualitative interviews, including some constant queries in all cases such as lambing rate (lambs ewe^{-1} y^{-1}), adult and lamb mortality, and individual wool production in normal, wet and dry years, commercialization strategies, other economic activities, and sources of income, monetary or otherwise. The interviews were performed during six meetings in different locations of the reserve. Each meeting included 10–20 inhabitants of the reserve. We will cautiously interpret our data because they are less rigorous and complete than those obtainable by a more exhaustive and formal protocol, which was not possible in this study. All calculations were made in US dollars based on historical 1995–2004 prices. The wool price was that of the international market because it is destined for exportation, resulting in an average historical value of \$2.19 US kg^{-1} (mean wool quality obtained in the Cushamen Reserve; PROLANA 2008). The meat price was the local price (\$15 US $lamb^{-1}$) as the meat is destined for local consumption. Monthly income was compared with the monthly basic total monetary needs for two adults in December 2004 provided by Instituto Nacional de Estadísticas y Censos (INDEC, 2008). This parameter is locally accepted as the poverty line for a nuclear family, i.e., the "family poverty line".

4. Results

4.1. Carrying capacity vs. present stocking rates

The global carrying capacity of the Cushamen Reserve and its area of influence was around 41 000 sheep units, which is equivalent to 0.27 sheep units ha^{-1} (Table 1).

Both ANPP and carrying capacity were highly inequitable, but the inequitability of the carrying capacity was higher than that of the ANPP (Gini Coefficients = 0.52 and 0.32, respectively) (Fig. 2). Two-thirds (67%) of the area accounted for only 27% of the carrying capacity (NDVI < 0.25, ANPP < 700 kg DM ha^{-1} yr^{-1}). More than half of this low productivity area (38% of total) could sustain less than 0.1 sheep units ha^{-1} and accounted for only 0.3% of the total carrying capacity (NDVI < 0.215; mean carrying capacity = 0.053 sheep units ha^{-1}) (Table 1). These extremely unproductive areas predominate in the shrublands and semi-deserts that are common in the eastern areas of the reserve (Paruelo et al., 2004). At the other end of the NDVI gradient, only 5.2% of the area (NDVI > 0.35, ANPP > 1450 kg DM ha^{-1} yr^{-1}) accounted for 28.7% of the total carrying capacity, with an average CC of 1.4 sheep units ha^{-1}. These small areas corresponded to meadows of varying degrees of degradation, which are mostly located along the waterways running in the east (Paruelo et al., 2004). Between these two extremes, the shrub and shrub-grass steppes dominant in the west (0.25 < NDVI < 0.35) occupy 27.5% of the area but account for 44.2% of the total carrying capacity, with an average of 0.4 sheep units ha^{-1}.

Table 1
Carrying capacity for different NDVI classes. The Aboveground Net Primary Production (ANPP) was calculated using the Normalized Vegetation Difference Index (NDVI) from the function calibrated for the study area by Paruelo et al. (2004): ANPP (kg DM ha^{-1} yr^{-1}) = 7159.5 × NDVI − 1088.4. The Harvest Index was calculated from the ANPP using the function developed by Golluscio et al. (1998): HI (%) = −5.71 + 0.7154 × (PPNA (kg DM ha^{-1} yr^{-1}))$^{0.5}$; SU = Sheep Animal Unit.

NDVI class	Area		ANPP			Harvest Index (%)	Forage availability		Sheep carrying capacity	
	has	%	Mean (kg DM ha^{-1} yr^{-1})	Tons DM $class^{-1}$ yr^{-1}	%	Mean	Tons DM $class^{-1}$ yr^{-1}	%	SU	SU ha^{-1}
0–0.05	23	0.0	0	0	0	0	0	0	0	0.00
0.05–0.1	38	0.0	0	0	0	0	0	0	0	0.00
0.1–0.15	797	0.5	0	0	0	0	0	0	0	0.00
0.15–0.2	44 955	26.9	262	11 765	10.9	3.5	741	4.5	2029	0.05
0.2–0.25	66 524	39.8	520	34 575	32.1	10.8	3747	22.6	10 266	0.15
0.25–0.3	34 758	20.8	871	30 269	28.1	15.7	4692	28.3	12 856	0.37
0.3–0.35	11 158	6.7	1223	13 649	12.7	19.6	2644	15.9	7245	0.65
0.35–0.4	4230	2.5	1591	6729	6.2	23.0	1539	9.3	4215	1.00
0.4–0.45	2066	1.2	1952	4034	3.7	26.1	1046	6.3	2866	1.39
0.45–0.5	1038	0.6	2310	2398	2.2	28.8	688	4.1	1886	1.82
0.5–0.55	552	0.3	2673	1475	1.4	31.4	462	2.8	1265	2.29
0.55–0.6	330	0.2	3031	1001	0.9	33.8	337	2.0	924	2.80
0.6–0.65	204	0.1	3388	691	0.6	36.0	248	1.5	680	3.34
0.65–0.7	136	0.1	3749	512	0.5	38.2	195	1.2	534	3.91
0.7–0.75	87	0.1	4104	358	0.3	40.2	144	0.9	394	4.51
0.75–0.8	43	0.0	4455	191	0.2	42.2	80	0.5	220	5.13
0.8–0.85	14	0.0	4797	65	0.1	44.0	28	0.2	78	5.76
0.85–0.9	1	0.0	5055	6	0.0	45.3	3	0.0	7	6.25
Total	166 955			107 717			16 595		41 487	
Mean			645			15.4				0.272

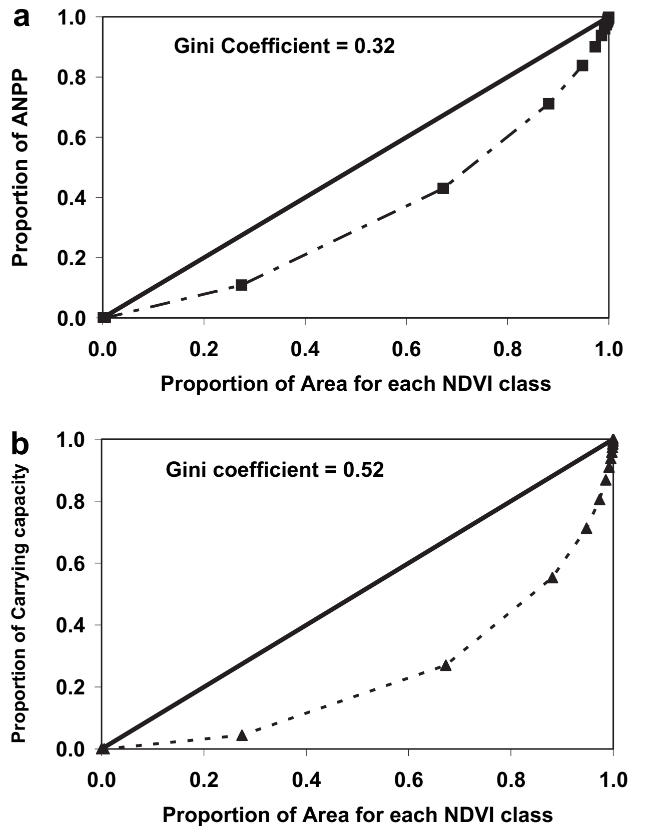

Fig. 2. Inequitability of the distribution among NDVI classes at regular intervals of 0.04 NDVI units of (a) ANPP and (b) carrying capacity (dotted lines) in comparison with the area distribution among the NDVI classes (solid lines). Gini coefficients of both variables with respect to NDVI classes are shown.

The global stocking rate of the Cushamen Reserve was almost twice the above calculated carrying capacity (0.57 and 0.51 sheep units ha^{-1} for the 1991 and 2004 surveys, respectively). Horses were the most abundant animal species, followed by sheep, goats and cows (all species transformed to sheep units; Fig. 3a). From 1991 to 2004, the proportion of total animal units corresponding to horses and goats increased (37.7–42.0% and 17.7–21.4%, respectively), whereas the proportion of sheep and cows decreased (35.5–28.0% and 9.1–8.6%, respectively). All individual producers have more than one animal species (mean = 2.68 species); 36% have three species, and 37% have four species (Fig. 3b).

4.2. Biodiversity, ANPP and pastoral value of the Cushamen Reserve vs. capitalized neighboring ranches

Under the same vegetation structure, the sites of the Cushamen Reserve have, on average, 21% less ANPP and 29% less plant cover than those of the neighboring ranches (Fig. 4b). The differences in plant cover translated into a 24% lower PVsite (Fig. 4c), although the intrinsic forage quality of vegetation (Pvveg) did not differ between the two production systems (Fig. 4a). The sites of the reserve have almost five fewer species than the sites of the neighboring ranches (−24%; Fig. 4d), but this difference disappeared when analyzing the Shannon–Wiener diversity index (Fig. 4f), because evenness showed an opposite trend. Evenness increased 8.5% in the reserve relative to the neighboring ranches, although the difference was not significant (Fig. 4e). When analyzing the entire data set and not just the data of the common community, the differences were the same, but the index of diversity was higher for the neighboring ranches than for the Cushamen Reserve (ANOVA results not shown).

4.3. Economic results

The 2004 monthly income of a 625 ha parcel occupied exclusively by sheep at the reserve's mean stocking rate (0.54 sheep units ha^{-1}) would be $185 US, 22% above the family poverty line of US $152.62 (Scenario 1; Table 2). The calculation was made based on the modal productive parameters recorded during the qualitative interviews: 30% of the animals are annually discarded because of death or aging (sheep usually have five years of useful lifespan and annual adult mortality is normally 10%), all male lambs plus the female lambs exceeding the needs for ewe replacement are sold, 4% of rams are used at mating, lambs are first sheared at one year of age, each sheep unit produces 3 kg of wool per year (2.91 and 3.07 kg $sheep^{-1}$ yr^{-1} for 1991 and 2004 surveys, respectively), and the mean lambing rate is 50% (Cushamen producers, personal communications). However, the inclusion of production expenditure (at least those of shearing and sanitary care), the size of families greater than two adults, and the high interannual variability of population parameters would make the real situation more unfavorable than this economic scenario. The lambing rate actually changes from 70% to 0–30%, and the mortality rate changes from 8% to 50–70%, in favorable and unfavorable years, respectively (Cushamen producers, personal communications).

Lowering the stocking rate to carrying capacity would increase both biological sustainability and the interannual stability of sheep breeding in the Cushamen Reserve. However, under carrying capacity, the same 625 ha parcel would obtain a monthly income of only US $93 (US $69 from wool sales and US $24 from lamb sales), which is well below the family poverty line (Scenario 2; Table 2). The increase in the lambing rate to 55% and fleece production to 4 kg per animal per year (the current productive parameters in neighboring ranches with a lower stocking rate and resource deterioration than the Cushamen Reserve) would give a monthly income of US $119, which is also clearly insufficient (Scenario 3; Table 2). To surpass the family poverty line, a parcel of 625 ha would need a lambing rate of 77% and a wool production rate of 4.65 kg animal $unit^{-1}$ yr^{-1}, both of which are rarely reached at the Cushamen Reserve. Moreover, to obtain the present potential monthly income (US $185), a 625 ha parcel would need the almost impossible combination of 84% lambing rate, 5.5 kg animal $unit^{-1}$ yr^{-1} wool production, and 16% annual sheep discard rate (which implies an increase in sheep longevity and a decrease in mortality) (Scenario 4; Table 2).

5. Discussion

This paper suggests that the carrying capacity of an "average" parcel of the pastoral Mapuche Cushamen reserve is clearly below the economic survival threshold, suggesting that sheep breeding is economically unsustainable (Morton et al., 1995). Simultaneously, the overall stocking rate of the reserve is clearly higher than its carrying capacity, suggesting that pastoral resource use is biologically unsustainable. Therefore, we suggest that economic unsustainability leads to biological unsustainability in the Cushamen Reserve. As biological unsustainability increases, economic unsustainability increases as well, generating a positive feedback between these two aspects of sustainability. The magnitude of our results suggests that our conclusions would persist even under a more exhaustive and formal economic data gathering protocol. Three symptoms reflect the fragility of an economic system which overuses the scarce forage resources: (a) the high interannual variability of sheep population parameters (Cushamen producers, personal communications), (b) the replacement of sheep and cows by more rustic goats and horses (Fig. 3a), a common trend in several pastoralist systems subjected to desertification processes around

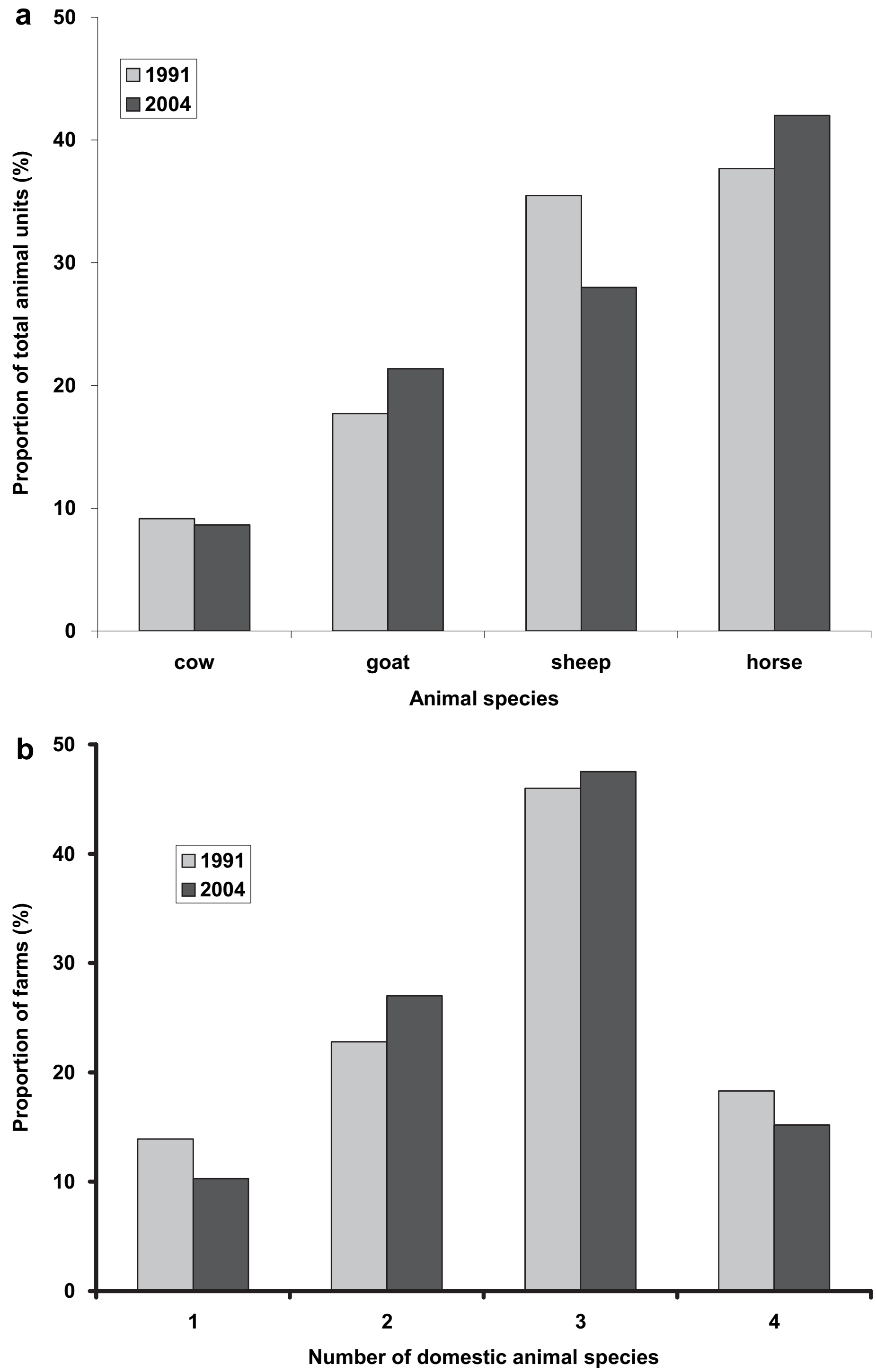

Fig. 3. Evolution of the diversity of animal species in the Cushamen Reserve from 1991 (light bars) to 2004 (dark bars): a) Proportion of different species in the entire Reserve, b) Proportion of farms with different amounts of animal species.

the world (Ellis and Swift, 1988; Kassahun et al., 2008), and (c) the low cover, richness, primary production, and pastoral value of rangelands of the reserve, compared with those of neighboring ranches (Fig. 4).

Indigenous people living in their own territory usually have a great amount of traditional ecological knowledge, which allows them to live in adverse habitats (Berkes et al., 2000). This traditional ecological knowledge includes not only a vast repertoire of practices for sustainable ecosystem management but also the social mechanisms that guarantee the generation, accumulation and transmission of knowledge. The Mapuche people are not an exception to this conceptual model. For example, they have profound knowledge about the alimentary and medicinal properties of the plants located where they actually live, either native or exotic (Houghton and Manby, 1985; Ladio et al., 2007). They also maintain some degree of knowledge about the plants located in sites inhabited by their ancestors, because they have transmitted this knowledge from generation to generation. However, it is an

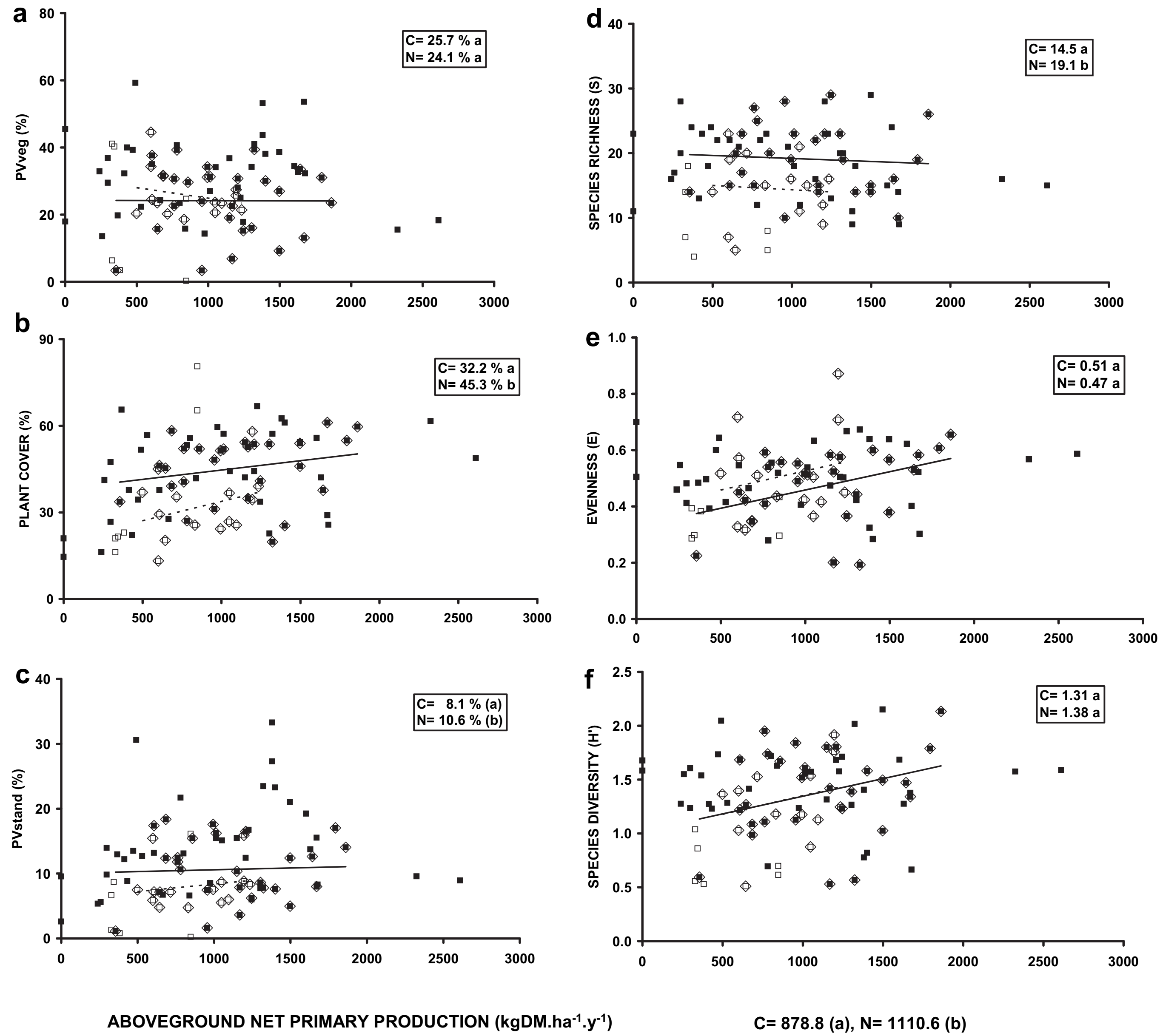

Fig. 4. Variation of a) Pastoral Value of the vegetation, b) Plant cover, c) Pastoral Value of the site, d) Species richness, e) Evenness, and d) Shannon–Wiener diversity index, as a function of Aboveground Net Primary Production in 20 sites of the Cushamen Reserve (white squares) and 63 sites of two neighboring capitalist farms (black squares). The regression lines of each variable with respect to ANPP are shown for the two production systems (Cushamen Reserve = dotted line, Neighboring farms = entire line), but only the regression of Evenness vs. ANPP in the neighboring farms was statistically significant ($r^2 = 0.15$, $p < 0.05$). On the right upper corner of each panel the means of the two production systems are shown, with different letters indicating significant differences ($p < 0.05$; $0.05 < p < 0.10$ when between brackets). Because of the floristic heterogeneity of both data sets, only data from shrub-grass steppes typical of the Occidental phytogeographic district (light rhombi overimposed over the square symbols) were included in both the regressions and the ANOVA tests ($n = 14$ for Cushamen Reserve, and $n = 27$ for neighboring farms).

urgent matter that this knowledge be preserved (Houghton and Manby, 1985) because it tends to disappear as the older members of the community die (Ladio, 2001; Ladio and Lozada, 2004a; Lozada et al., 2006). In the long term, the biological unsustainability of its production system may lead to the emigration of the human population of the Cushamen Reserve to towns. This emigration would imply the virtual loss of a culture with a profound knowledge (Golluscio, 2006; Ramos, 2004) and a friendly relationship with the environment (Ladio et al., 2007). These types of cultures may provide new insights into man's relationship with nature that could contribute to changing the predominant consumption-centered culture, which is based on wasting natural resources (Berkes et al., 2000).

The Mapuche worldview and the social practices emerging from it are not based on the modern Western definitions of society, nature and the limits between them (Ramos, 2008). The Mapuche view of the world is an integral conception based on an ordered harmony (*az mapu*) among the land, human beings, and non-human beings, who can also intervene in history (Ramos, 2008). The *Wall Mapu* is the ancestral Mapuche territory, a space closely linked to its own culture, language and origin. The humans, Mapuche or not, own neither the land nor the water. Nor do they own animals; they coexist in harmony with them as well as with the "non-humans" in the *Wall Mapu*. The non-human "forces of nature" (the *newen*) are also present in a permanent relationship with the beings and the community. There exists, then, an everyday

Table 2
Economic analysis under four scenarios: (1) Present stocking rate and productive parameters of the Cushamen Reserve; (2) Carrying capacity and present productive parameters of the Cushamen Reserve; (3) Carrying capacity and productive parameters such as those of less deteriorated neighbor farms; and (4) Carrying capacity and productive parameters needed to maintain the monthly income of scenario 1.

	Scenario	1	2	3	4
Productive parameters	Stocking rate (Sheep units ha^{-1})	0.54	0.272	0.272	0.272
	Marking rate (lambs $sheep^{-1}$; in %)	50	50	55	84
	Fleece production (kg $sheep^{-1}$ yr^{-1})	3	3	4	5.5
	Annual discarding (%)	30	30	30	16
Flock structure	Ewes (heads)	188	94	92	90
	Ewe hoggets (heads)	56	28	28	14
	Lambs (heads)	94	47	51	76
	Rams (heads)	8	4	4	4
	Total (heads)	346	173	175	184
	Total (sheep units)	338.8	169.4	169.4	170.8
Monetary income	Fleece sales (US $ $month^{-1}$)	138.0	69.0	90.5	108.4
	Lamb sales (US $ $month^{-1}$)	47.5	23.8	28.8	77.5
	Total income (US $ $month^{-1}$)	185.5	92.7	119.3	185.9

communal relationship with the "forces of nature". The *ngellipun,* a traditional ritual held annually to renew the relationship between these components of the *Wall Mapu* strengthens the bonds between the individuals, their families and communities, and their ancestors (Golluscio, 2006). The *ngellipun* constitutes, at the same time, the deepest religious and philosophical Mapuche manifestation and also a profound political act of renewing the links between the local community and the Mapuche People, thus avoiding any dichotomy between political meetings and religious rituals (Ramos, 2008). The Mapuche worldview has several points in common with those of other aboriginal groups that do not conceive of a dichotomy between man and nature (Escobar, 1998) but conceive of the world as a community of living beings, within which man is included only as another live being. Based on this common philosophical framework, several aboriginal groups have common values including sharing, reciprocity and humility (Berkes et al., 2000).

In spite their biological unsustainability, the sheep breeding systems in the Cushamen Reserve there still persist. Several elements can explain the permanence of these economically and biologically unsustainable production systems, at least as long as resource degradation does not become more severe. The Cushamen producers have a subsistence economy, not a capitalist one. Therefore, their optimal goal is not to maximize economic benefit but to minimize risk by diversifying products. As in other pastoralist systems around the world (Abule et al., 2005), the one practiced in the Cushamen Reserve has a high number of animal species per farm (Fig. 3), which are used for self-alimentation, transport, labor, sale, or saving capital. It is not an accident that the Mapuche language has only one word (*"kullin"*) to designate "livestock", "money" and "to pay for". The capital saving function of this system is especially clear in the case of the extremely abundant horses. In this harsh environment, they have very low commercial value because they are often very thin, but they have a mortality rate markedly lower than other domestic herbivores of potentially higher commercial value. In addition, horses are closely related to social prestige and also have an important cultural role because they are crucial protagonists of religious ceremonies: (a) two sacred horses and two sacred kids symbolically preside over the *"ngellipun"*, (b) a herd of horses delimits the sacred space (*"awïn"*) by galloping around it, and (c) the direction freely chosen by another group of horses is interpreted as an augury (Ramos, personal communication). In addition to the abovementioned animal production activities, the Cushamen producers usually have other income sources, including small vegetable or alfalfa (*Medicago sativa*) plots under irrigation, vegetable production in little greenhouses, hunting, fishing, fruit gathering, egg production, wool handicraft, government welfare services and temporary employment outside the reserve (Alvarez and Del Valle, 1992). Diversification is a common strategy of pastoralist production systems, which allows them to buffer environmental or economic hazards (Berzborn, 2007; Illius et al., 1998; Roe et al., 1998). Most of these productive activities provide for the alimentary needs of the Cushamen producers, reducing their monetary needs below the theoretical family basic monetary needs. Finally, the goods and services included in this family "basket" are based on the needs of the urban population, which are not necessarily the needs of populations with a pastoralist lifestyle and culture (Stafford Smith et al., 2008).

The benefit of this high-diversity, low-risk, low-benefit economic system for the Mapuche people is the preservation of cultural traditions and healthy alimentation, both of which are difficult in the living conditions of those Mapuche people who are living as poor urban people (Ferrari et al., 2004). The preservation of the cultural traditions of the Mapuche people explains not only their subsistence economy but also their strategies for living together, which are difficult to understand under capitalist points of view. For example, the absence of wire fencings would have been a source of conflict about the use of the most productive resources, especially in regions where resources are unevenly distributed among parcels of constant size (Fig. 2). However, in the Cushamen Reserve, the lack of wire fences facilitated coexistence among inhabitants, as it allowed for the differentiation of the land into communal hunting, transit, sacred, and animal feeding areas (Ramos, personal communication). The absence of fences, for example, allowed access to water and productive forage resources to producers from very poor parcels and to the ceremonial *mallin* where the *ngellipun* takes place. Obviously, this system has been possible because the owners of the parcels do not consider themselves to be the owners of the water or prairies within them (see above). The shared and careful use of the wettest and most productive portions of the landscape is another cultural trait common to several pastoralist cultures in the arid zones of the world (Buttolph and Coppock, 2004; Ward et al., 2000).

In the specific case of the Cushamen Reserve, within the present context there exists some degree of conflict between the preservation of bio- and sociodiversity. Without state intervention, the maintenance of the present productive system would compromise biodiversity, but any extreme conservationist policy would compromise sociodiversity. The design of active state policies to improve the living conditions of their inhabitants would be the best alternative to preserve both socio- and biodiversity (Reynolds et al., 2007). The consideration of which of those policies should be adopted is a point of conflict because some could be beneficial to one social group but harmful to others. However, any policy must include the improvement of education, sanitary care, communications, roads, and commercialization channels, and it must unavoidably include an increase in the carrying capacity of each individual farm (in sheep units per farm). This change would imply an increase in the carrying capacity per unit of area and/or an increase in the area of each individual farm.

When designing agronomic strategies to increase the carrying capacity of the Cushamen Reserve, the importance of spatial heterogeneity as a factor that allows agricultural activities in sites of very low average ANPP must be appreciated (Noy-Meir, 1981). As the area explored by sheep to find food increases, the energy cost of feeding increases disproportionally more than the energy that the sheep may obtain. In the east of the reserve, the mean carrying capacity of shrublands and semideserts was 0.05 sheep unit ha^{-1}, making sheep breeding almost biologically impossible because such a value implies that an individual sheep would need to graze 20 ha to find its food. However, such carrying capacity did not come from a homogeneous region supporting 0.05 sheep units ha^{-1}, but from the coexistence of a vast region supporting less than 0.05 sheep units ha^{-1} with very small "islands" with a carrying capacity higher than 1 sheep unit ha^{-1}. Therefore, under the same low average carrying capacity, sheep breeding based on the few highly productive patches of heterogeneous landscapes becomes sustainable, while it may be unsustainable in a homogeneous landscape. As in other pastoralist arid systems around the world (Scoones, 1991), this element is crucial when designing any communal land use project for the entire Reserve: all producers must have access to highly productive patches.

Some technological tools are available to improve the carrying capacity per area unit only by assigning external financial resources to the producers of the reserve, as recommended by Reynolds et al. (2007). For example, a 28% increase in the overall carrying capacity (CC) of the reserve may increase the economic income above the family poverty line (calculated from Table 2, Scenario 3). This change may be achieved by increasing the carrying capacity of the most productive area by 20% (5.2% of the reserve with CC $>$ 1 sheep unit ha^{-1}; mean CC changes from 1.4 to 1.68 sheep units ha^{-1}) and simultaneously increasing the CC of the less productive area by 3.7% (94.8% of the reserve with present CC $<$ 1 sheep unit ha^{-1}) until the improved mean level of the most productive area is reached (calculated from Table 1). Both goals (increasing CC and the area of the most productive patches) may be attained by devoting external funds to enlarge irrigated areas and reduce the depth of river beds, by using electric fences to differentially use high productivity patches (i.e., mallines), and using rest grazing management to recover the few surviving individual plants of forage species (Golluscio et al., 1998). Cooperative or associative use of these funds is necessary because the problems that must be solved do not operate at the scale of individual farm but on the scale of river basins.

The allocation of lands outside the reserve, whether public or private, may allow for an increase in the area of each farm and a subsequent reduction of the stocking rate until it reaches carrying capacity. However, this type of political tool should be preceded by a profound discussion by the whole society, as it could have very high social and political costs. In addition, the allocation of lands outside the reserve without any regulations for use would have severe environmental costs because it may be accompanied by an increase in human population size, leading to a further increase in herbivore density to above carrying capacity. In the medium to long term, this unregulated policy may reproduce and amplify the feedback between biodiversity loss, impoverishment and sociodiversity loss. As a consequence, whatever active state policy is used to increase the carrying capacity and preserve the sociodiversity of the reserve, it must observe the central premises of preserving biodiversity and must simultaneously respect the cultural traits, social organization and specific ways that the current inhabitants appropriate nature (Aronson et al., 2007; Escobar, 1998; Morton et al., 1995; Reynolds et al., 2007). This strategy is the only way to break the positive feedback between the deterioration of biodiversity and the deterioration of sociodiversity in the Cushamen Reserve.

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