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ORIGINAL PAPER

Effect of cattle grazing on soil salinity and vegetation composition along an elevation gradient in a temperate coastal salt marsh of Samborombón Bay (Argentina)

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Abstract Salt marshes of Samborombón Bay (Argentina) have been grazed sporadically at very low stocking rates, but in the last decade, grazing intensity increased due to agriculture expansion. We investigated the effect of cattle grazing on vegetation and soil salinity on the most extended *Spartina densiflora* community. This community develops along an elevation gradient where the frequency and duration of tidal flooding and soil salinity increased as elevation decreased. Vegetation and soil data were collected from a national park excluded to cattle grazing for 30 years and from an adjacent commercial livestock farm continuously grazed by cattle. As elevation level decreased, plant cover, richness and diversity of functional groups and species decreased. As we expected, grazing altered soil salinity and vegetation composition in different extent along the elevation gradient. Grazing changed vegetation structure more intensively in the high elevation level because it reduced the competitive exclusion exerted by *S. densiflora*, allowing the increase in floristic richness. Grazing increased soil salinity and the contribution of salt-tolerant species only in the medium but not in the low elevation level probably because the higher frequency and duration of tidal flooding counterbalanced the increase in evaporation promoted by biomass removal in the low respect to the medium elevation level. While grazing may cause positive impacts for plant conservation in the high elevation level, it may cause negative consequence for livestock production because of the reduction in forage quality along the entire elevation gradient.

Keywords *Spartina densiflora* · Species diversity · Forage quality · Conservation · Cattle production

Introduction

Coastal salt marshes represent a unique habitat for a wide range of organisms, are important staging areas for migratory birds and provide relevant ecosystem services (Koch et al. 2009; Barbier et al. 2011). Salt marshes are shaped by restrictive environmental factors such as soil salinity and tidal flooding (Michener et al. 1997; Bertness et al. 2002; Boorman 2003). Tidal flooding provides fine sediment deposits that form the relief and determines the elevation gradient of the salt marsh (Leendertse et al. 1997). The

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frequency and duration of tidal flooding, as well as soil salinity, increase as elevation decreases (Boorman 2003), and therefore, the elevation gradient represents an environmental gradient of stress caused by both factors. Across the elevation gradient, salt marshes exhibit a strong zonation of plant species, related to their tolerance to flooding and salinity (Bertness 1991; Castillo et al. 2000; Costa et al. 2003; Pennings et al. 2005; Isacch et al. 2006).

Anthropogenic disturbances, such as grazing of domestic ungulates, have contrasting impacts on salt marsh conservation (Boorman 2003; Gedan et al. 2009, 2011). Domestic herbivore grazing may be beneficial because it increases floristic diversity by decreasing the cover of the dominant species respect to abandoned or ungrazed salt marshes, as it occurs in Europe (Bakker 1985; Bos et al. 2002). Alternatively, grazing may be detrimental to salt marsh vegetation, as in Australian salt marshes, where selective and intense grazing and trampling are considered responsible for the reduction in rare species and the inability of vegetation to regenerate or reestablish (Laegdsgaard 2006). When grazing increased bare soil, its effect on soil salinity does not show conclusive results. While in a Canadian salt marsh, grazing increased bare soil and promoted soil salinity due to the increase in evaporation and the consequent rise of salts to the surface (Yu and Chmura 2010), in North Europe salt marshes, grazing increased bare soil but not soil salinity (Bakker 1985). The direction and extent of the responses to grazing are greatly variable along the elevation gradient. As elevation decreases, bare soil and soil salinity increase at a greater extent under grazing and favors the dominance of a small number of halophyte species. On the contrary, in the upper salt marsh, the reduction in canopy height induced by grazing promotes the occurrence of a greater number of glycophyte species (Bakker and Ruyter 1981; Andresen et al. 1990).

The effects of cattle and sheep grazing on the structure and functioning of salt marshes have been extensively studied in Europe, North America and Australia. On the contrary, in salt marshes of South America, the study of grazing effects is scarce and limited to native small herbivores, without focusing on the impact of grazing on vegetation structure and soil salinity (Jackson and Giulietti 1988; Bortolus and Iribarne 1999; Costa et al. 2003; Cardoni et al. 2007; Vila et al. 2008). Among them, the temperate salt marshes of Samborombón Bay, located in the eastern limit of Argentinean Pampas grasslands, extend along 244,000 ha and are dominated by *Spartina densiflora*, associated with different species along the elevation gradient (Vervoorst 1967; Cagnoni and Faggi 1993; Isacch et al. 2006). Since 1997, this bay has been declared a wetland of international importance (Ramsar Convention Secretariat 2011) because it is a valuable habitat for migratory birds and for the conservation of the seriously endangered Pampas deer (*Ozotocerus bezoarticus celer*) (Fernandez et al. 2004; Miñaro and Bilenca 2008). These salt marshes have been sporadically grazed by cattle at low stocking rates (Isacch et al. 2004; Vila et al. 2008), but in the last decade, agriculture expansion in the temperate humid region of Argentina has led to a displacement of livestock to more marginal areas, such as the Samborombón Bay. Consequently, these salt marshes are currently subjected to higher grazing pressure than the historically applied, with the increasing risk of ecosystem degradation.

The aim of this study was to evaluate the effect of cattle grazing on vegetation and soil traits along the environmental gradient of stress of this temperate salt marsh, in order to provide original and useful information to design proper livestock management strategies, which simultaneously achieve conservation and animal production goals. We analyzed soil salinity and vegetation cover, plant species abundance, floristic composition, species diversity and forage quality. Vegetation and soil data were collected from a national park where cattle grazing was excluded 30 years ago and from paddocks of a neighboring commercial livestock farm, where cow–calf operation is carried out. As 30 years ago the whole area, including the site where the national park was located, was only sporadically grazed at very low stocking rates, we assume that our results reflect the impact of grazing on this native ecosystem. We hypothesize that the biomass removal caused by grazing alters the salinity level of the topsoil and shifts the floristic composition in a different extent along the elevation gradient, depending on the salt content of the soil and the frequency and duration of tidal flooding. Therefore, we expect that grazing increases soil salinity and consequently the relative contribution of salt-tolerant species, in a greater extent in the medium and low elevation levels than in the high elevation level. We also expect a greater shift in species composition in the high elevation level because a higher number of species can exploit the relaxation of competition induced by grazing in this lower stress site than in the other, most stressful sites.

Materials and methods

Study area

Samborombón Bay is located on the west margin of the Rio de la Plata estuary and extends for about 2,440 km^2, from Punta Piedra (35°27′S, 56°45′W) to Punta Rasa (36°17′S, 56°46′W). The climate is subhumid to humid, and mesothermal, with scarce to null water deficiency. The annual average temperature and precipitation of the last 30 years are 15.2 °C and 982 mm, respectively. The relief is plain, with a slope of 0.01 % and an average altitude of 1.6 m above mean sea level (Carol et al. 2008). Soils belong to the Vertisols order (US Soil Taxonomy) with clay texture, smectite expansible clays and low permeability and remain wet almost all the year (INTA 1974–1975). The depth of the top horizon is about 15 cm along the entire gradient, followed by a strong clay textural horizon. Tides are mixed (two high and two low tides per tidal day) predominantly semidiurnal, with tidal ranges less than 2 m (Naval Hydrographic Service 2008). The tidal wave coming from the southern Atlantic enters the Ajó River, and the numerous tidal channels distributed all over the area (Carol et al. 2009). Floods are caused by the periodic movements of the tides (Fernandez et al. 2004), and the frequency of flooding is variable along the elevation gradient. Floods occur daily in the low elevation level, while in the middle and high elevation levels, they are less frequent (Cagnoni 1999). Soil salinity along the elevation gradient also depends on the depth of the water table and on salt concentration of the groundwater, resulting from salt dissolution and accumulation processes (Carol et al. 2009).

The most extended community of these salt marshes is the *S. densiflora* community, which covers more than 50 % of the area. This community is dominated by *S. densiflora* in association with *Sarcocornia perennis, Juncus acutus*, *Cortaderia selloana* and other species in minor proportions as *Apium sellowianum*, *Limonium brasiliense*, *Distichlis spicata* and *Malvella leprosa* (Cagnoni and Faggi 1993). *Spartina densiflora* communities occupy the high, middle and low intertidal zones (Bortolus 2006), but the change of floristic composition and relative cover of associated species along this elevation gradient has not been precisely described yet. Two other communities well represented in these salt marshes are monospecific: the *S. alterniflora* and the *S. perennis* communities, in the lowest intertidal zones, commonly exposed to extended flooding periods (Cagnoni 1999).

Sampling sites

The study was carried out in General Lavalle (Samborombón Bay, Province of Buenos Aires, Argentina, 36°40′S, 56°96′W). The ungrazed sites (UG) were selected in the “Campos del Tuyú” National Park (3,000 ha, 36°19′S, 56°50′W) where domestic grazing was excluded since 1979. The grazed sites (G) were selected in an adjacent commercial livestock farm (1,650 ha), where continuous grazing is performed at a stocking rate that has been increasing in the last decade and reaches nowadays 0.6 animals ha^{-1}. As the whole area, including the site where the national park is located, was sporadically grazing at very low stocking rates (Fernandez et al. 2004), vegetation description shortly after cattle exclusion showed high similarity with the neighboring commercial farms (Cagnoni and Faggi 1993). Therefore, we assume that our results reflect the impact of cattle grazing on this native ecosystem. Respect to wild herbivores such as Pampa deer and ñandú (*Rhea americana*) and their population size were too small to cause any impact on vegetation or soil traits (Fernandez et al. 2004; Vila et al. 2008).

Three replicates per elevation level were located in the ungrazed (UG) “Campos del Tuyú” National Park and in the grazed (G) adjacent commercial farm. The high elevation level (HE) was at 0.80 m amsl, the medium elevation level (ME) at 0.70 m amsl and the low elevation level (LE) at 0.60 m amsl. This altitudinal range provided us three different frequencies of flooding: The LE is flooded one or two times a day; the ME is flooded one or two times per month, at the time of the new or full moon, and the HE is flooded only two times per year, during the vernal and autumnal equinoxes. We also measured the depth of the groundwater, which was around 0.50 m depth in the HE, 0.40 m depth in the ME and 0.30 m depth in the LE.

Soil salinity and bare soil measurements

Composite soil samples were extracted from each site, with ten cores of 6.5 cm diameter and 15 cm depth on December 2010 (spring). Soil salinity was estimated as electrical conductivity (EC) of saturation extracts (Rhoades 1982) and expressed in deci-Siemen per meter (dS/m). As soil salinity frequently has a positive relationship with bare soil, we plotted EC data as a function of bare soil recorded on each site.

Vegetation survey

Vegetation was surveyed in each site in December 2010 (spring), when the largest number of species could be identified. Plant basal cover (%) of each species was estimated by the step-point method (Mueller-Dombois and Ellemberg 1974) along a 10-m-long transect (100 points per transect) randomly placed within each site. Species with basal cover lower than 0.1 % were considered as rare and excluded from the species list, but they were included to calculate species diversity indices. Nomenclature and naming authorities follow Flora del Cono Sur Database, from Instituto de Botánica Darwinion (2011).

Species diversity indices

Species richness (S) was estimated as the total number of species per site. Species diversity was estimated using the Simpson's index: $1{-}D = 1{-}\sum p_{\mathrm{i}}^2$, where p_{i} is the proportion of total plant basal cover found on ith species. This index provides a good estimate of diversity at relatively small sample sizes and is easily interpretable because its values range between 0 and 1, increasing as the vegetation assemblage becomes more even and rich (Magurran 2004). Evenness ($E_{1/D}$) was estimated from the equation: $E_{1/D} = (1/D)/S$, which is recommended when a response to an intuitive gradient is expected (Smith and Wilson 1996; Magurran 2004).

Forage quality

The forage quality index (FQI) was estimated for each site to analyze differences in forage quality. The FQI was calculated as the average of each species-specific quality value (q_{i}) weighted by its relative contribution in the site (p_{i}): $\mathrm{FQI} = \sum p_{\mathrm{i}} * q_{\mathrm{i}}$. Q_{i} values for Flooding Pampa grassland species were proposed by Cahuepé et al. (1985), ranging from 0 (without any forage quality) to 5 (excellent forage quality).

Statistical analysis

In order to describe the major sources of variation in species composition between sites, ordination and classification multivariate techniques were performed. We carried out correspondence analysis (CA, Greenacre 1984) using frequency data (relative basal cover of each species). CA preserves chi-square distance (ter Braak 1985), which is the appropriate distance measure for variables expressed as samples weighted by their totals. To avoid giving too much emphasis on species whose abundance in data matrix was low, we excluded species with constancy lower than 5 %. We performed a multiresponse permutation procedure (MRPP) (Biondini et al. 1988) to test multivariate differences between G and UG for each topographic position. To identify particular species responsible for differences between G and UG, indicator species analysis and Monte Carlo test (Dufrene and Legendre 1997) were performed. Multivariate analysis CA, MRPP and indicator species analysis were performed using PC-ORD TM version 4 (McCune and Mefford 1998).

Factorial analysis of variance was performed to determine the effect of grazing (two levels), elevation level (three levels) and its interaction on bare soil (BS), EC, S, diversity ($1{-}D$), evenness ($E_{1/\mathrm{D}}$) and forage quality (FQI). Before carrying out each analysis, the percentage data (BS) was arcsine square-root transformed ($y = \text{arcsine}\sqrt{x}$) to obtain homogenous variances. We checked that all data included in analysis of variance were normally distributed performing the Shapiro–Wilks test for normality, modified by Mahibbur and Govindarajulu (1997). Significant differences were determined by HSD Tukey's test. Factorial analysis of variance was performed using STATISTICA 1999 Edition (StatSoft Inc 2007).

Results

Bare soil and soil salinity

BS was affected by elevation level ($F = 13.9$, $\mathrm{df} = 2$, $P < 0.05$). The proportion of BS recorded in the high-and medium-elevation sites was lower than 10 % and in the low elevation level was 27 % (Fig. 1). Soil salinity was affected by elevation ($F = 9.7$, df $= 2$, $P < 0.05$), grazing ($F = 21.6$, df $= 1$, $P < 0.05$) and their interaction ($F = 3.9$, df $= 2$, $P < 0.05$) (Fig. 1). Grazing greatly increased soil salinity in the medium elevation, from 14.8 to 43.6 dS/m, tended to increase salinity in the low elevation, from 19 to 35 dS/m, but did not affect salinity in the high elevation, where salinity ranges from 9.5 to 13.8 dS/m.

Vegetation composition

The first two axes of the ordination of vegetation composition (CA) accounted for 45.1 % of total variance. The first axis accounted for 27.8 % of total variance and reflected a shift in species composition of the sites along the elevation gradient. Along the first axis, the low- and medium-elevation G were located to the left side (negative values), as well as the BS and the halophytes *S. densiflora*, *S. perennis*, *L. brasiliense* and *A. sellowianum*. The medium- and high-elevation UG were located at the center of this axis, at lower positive values, while high-elevation G were located at the right side, at higher positive values. As positive values along the first axis increased, the level of salinity tolerance of the species decreased. At lower values, the halophytes *D. spicata, J. acutus, Melilotus officinalis, Melilotus albus* and *Thinopyrum ponticum* were found, while at higher values, the glycophytes *Lolium multiflorum*, *Jarava plumosa*, *Polypogon monspeliensis* and *Poa trivialis* prevailed (Fig. 2).

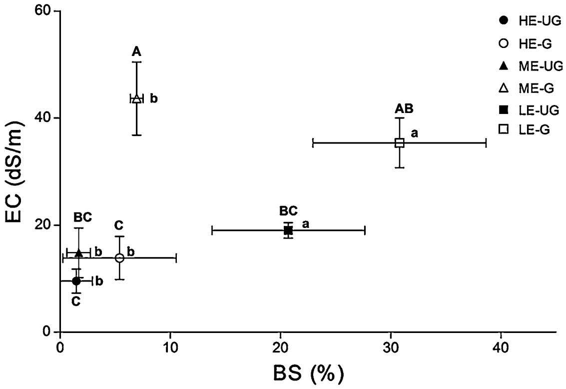

Fig. 1 EC (dS/m) and BS (%) of the HE, ME and LE elevation level under G and UG treatments. Values are means for each treatment. *Vertical and horizontal lines* indicate standard errors for EC and BS variables, respectively. *Capital letters and lowercase letters* indicate differences between treatments and elevation levels of EC and BS, respectively, derived from HSD Tukey's test ($P < 0.05$)

MRPP analysis confirmed that grazing changed floristic composition in the high ($P < 0.1$) and in the medium elevation levels ($P < 0.1$), but not in the low elevation level ($P > 0.1$) and showed that grazing increased the similarity of the vegetation within each elevation level, as the average distance among G was lower than that of UG in each elevation level (27.1 vs. 31.8, 16.8 vs. 33 and 26.3 vs. 32.9 for the high, medium and low elevation, respectively, derived from the MRPP analysis). Indicator species analysis and Monte Carlo test showed that in the high elevation level, grazing decreased the relative cover of *S. densiflora*, the dominant tall grass species in the community, and increased the relative cover of the dicotyledonous forbs *Centaurium pulchellum* and *Phyla canescens* and the warm season creeping grass *Stenotaphrum secundatum*. In the medium elevation, grazing greatly increased the relative cover of the highly salinity-resistant herb *S. perennis* and decreased the relative cover of *C. pulchellum* and the legume *M. officinalis*. In the low elevation, grazing increased the relative cover of *S. perennis* (Table 1).

Diversity indices

Richness of functional groups decreased with elevation, from nine functional groups in the high to five in the low elevation level (Table 1). Species richness (S), species diversity ($1-D$) and evenness ($E_{1/D}$) were affected by the elevation gradient (Table 2). Species richness and diversity decreased while evenness increased from the high to the low elevation level. There was a slightly significant interaction ($E \times G = 0.05$) in richness, which increased with grazing in the high elevation level, while decreased in the medium and low elevation levels under grazing. Diversity in the high and medium elevation levels was similar and higher than in the low elevation level while evenness showed an opposite response (Table 2).

Forage quality

FQI was affected by elevation gradient and grazing, without interaction between them. FQI was highest in the high-elevation UG, reaching 1.94 from a maximum of 5.00, and decreased significantly to the

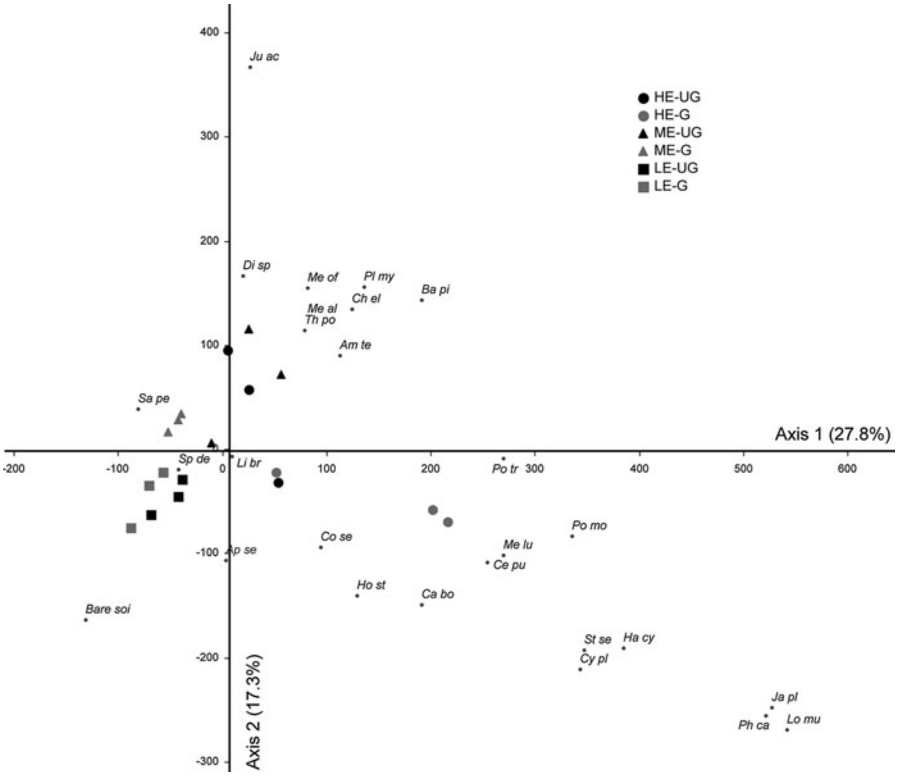

Fig. 2 Ordination (CA) of sites and species of the HE, ME and LE elevation levels under G and UG treatments. Species whose constancy was lower than 5 % were excluded from the data matrix to avoid giving too much emphasis on rare species. Species are identified by the first two letters of the genus followed by the first two letters of the epithet

medium (1.58) and the low (1.40) elevation level in UG. Grazing negatively affected FQI in a greater extent in the higher-elevation sites (~30 % decrease) than in the medium and lower-elevation sites (15 % decrease) (Fig. 3).

Discussion

As elevation level decreased, the environment became more stressful because soil salinity and frequency and duration of tidal flooding increased. Consequently, plant cover, richness of functional groups and species, and diversity decreased, resulting in species zonation, which is a general response of a wide range of salt marshes (Snow and Vince 1984; Costa et al. 2003; Pennings et al. 2005; Cui et al. 2011). Plant zonation involved a reduction in co-occurring species' and functional groups' richness from the high toward the low elevation levels. As we expected, grazing altered soil salinity and vegetation composition in different extent along the elevation gradient. Grazing changed vegetation structure more intensively in the high than in the medium and low elevation levels, as found in European salt marshes (Lefeuvre et al. 2000; Bos et al. 2002; Bouchard et al. 2003). This response may be explained because grazing reduced the competitive exclusion exerted by the dominant species in the high elevation level, allowing the increase in floristic richness. Instead, in the lower elevation levels, vegetation pattern is controlled by the tolerance of the major stressful factors such as flooding, soil salinity and soil oxygen deficiency (Snow and Vince 1984; Kleyer et al. 2003). In our experiment, grazing increased soil salinity and the contribution of salt-tolerant plant species in the medium but not in the lowest-elevation sites, as we have postulated. This probably was caused by the higher frequency, and duration of tidal flooding counterbalanced the increase in evaporation promoted by biomass removal through grazing in the lowest respect to the medium elevation level.

In the high elevation level, continuous long-term grazing tended to increase floristic richness and diversity. Cattle defoliation released the competition exerted by *S. densiflora* and allowed the replacement by shorter and creeping species that avoid grazing (*P. canescens*, *S. secundatum*) and by high-growth-rate species (annual C_3 grasses and forbs). Therefore, the

Table 1 Relative cover of species (%) of the high, medium and low elevation under G and UG treatments

Species	High elevation			Medium elevation			Low elevation			Lc	O	Q
	UG	G		UG	G		UG	G				
Cool season (C_3) annual grasses												
Lolium multiflorum	–	2.8								A	E	5
Polypogon monspeliensis	0.9	1.8								A	E	3
Hainardia cylindrica	–	2.0		–	0.7					A	E	1
Cool season (C_3) perennial grasses												
Jarava plumosa	–	5.8								P	N	2
Thinopyrum ponticum	0.6	–								P	E	3
Poa trivialis	2.8	3.6		1.4	–					P	E	4
Chaetotropis elongata	1.1	0.7		0.7	0.3					P	N	3
Hordeum stenostachys	0.3	3.1		0.2	–		5.4	–		P	N	2
Warm season (C_4) tussock grasses												
Sporobolus indicus	–	0.3								P	N	3
Cortaderia selloana	1.8	–		0.6	–					P	N	1
Spartina densiflora	33.6	20.4	**	38.6	40.4		58.8	48.6		P	N	2
Warm season (C_4) creeping grasses												
Stenotaphrum secundatum	–	8.0	**							P	N	2
Cynodon plectostachyus	2.3	2.2								P	E	4
Distichlis spicata	16.0	5.1		16.2	20.1		–	6.0		P	N	1
Cool season legumes												
Melilotus officinalis	7.0	2.6		6.6	0.3	**	1.0	–		A/B	E	5
Melilotus albus	0.6	–								B	E	5
Vicia platensis				0.6	–					A/B	N	5
Warm season legumes												
Medicago lupulina	0.9	0.5								A/B	E	2
Cool season dicotyledonous forbs												
Cirsium vulgare	–	0.2								A/B	E	0
Centaurea calcitrapa	–	0.4								A/B	E	0
Senecio selloi	0.9	–								P	N	0
Sonchus asper	0.6	–								A/B	E	0
Agalinis communis	–	0.2								P	N	0
Gamochaeta pensylvanica	–	0.2								B/P	N	0
Warm season dicotyledonous forbs												
Phyla canescens	–	8.5	**							P	N	0
Symphyotrichum squamatum	0.9	–								P	N	0
Gamochaeta falcata	–	1.0								P	N	0
Ambrosia tenuifolia Spreng.	0.5	1.6		0.7	–					P	N	0
Baccharis pingraea DC.	4.1	8.3		11.6	–					P	N	0
Centaurium pulchellum	0.3	8.0	**	4.3	–	**	1.6	–		A	E	0
Sarcocornia perennis	7.0	2.7		9.3	29.4	**	8.9	14.6	*	P	E	1
Apium sellowianum	0.3	0.4		0.2	–		2.1	–		A/B	N	0
Bupleurum tenuissimum	–	0.2								A	E	0
Limonium brasiliense	–	0.2								P	N	2
Malvella leprosa	–	0.2								P	N	0

Table 1 continued

Species	High elevation		Medium elevation		Low elevation		Lc	O	Q
	UG	G	UG	G	UG	G			
Acmella decumbens	–	0.3					P	N	0
Teucrium cubense	–	0.2					P	N	0
Cotula coronopifolia	–	0.2					P	E	0
Plantago myosuros	0.6	0.5	0.3	–			A	N	2
Sedges									
Carex bonariensis	3.5	0.6					P	N	2
Cyperus eragrostis	2.3	–					P	N	0
Juncus balticus	–	0.2					P	N	2
Juncus bufonius	–	0.3					A	N	1
Juncus acutus	3.4	–	6.9	–	1.6	–	P	N	1

Values are means for each treatment. Statistical significance between grazing treatments is indicated with $^{**}P < 0.01$ and with $^{*}P < 0.05$ according to the indicator species analysis and Monte Carlo test

Lc life cycle (*A* annual, *B* biannual, *P* perennial), *O* origin (*N* native, *E* exotic), *Q* forage quality of each species are indicated

Table 2 Diversity indices of the vegetation recorded in the high, medium and low elevation under G or UG treatments

Diversity indices	High elevation		Medium elevation		Low elevation			*F* ratio	df	*P*
	UG	G	UG	G	UG	G				
Richness (S)	16 (1.1)	28 (6.6)	12 (2.3)	9 (2.6)	5 (1.2)	3 (0.3)	E	17.44	2	<0.05
							G	0.74	1	0.41
							E × G	3.85	2	0.05
		A		B		B				
Diversity (Simpson's index, 1-*D*)	0.79 (0.01)	0.88 (0.03)	0.75 (0.04)	0.66 (0.003)	0.36 (0.17)	0.44 (0.05)	E	16.91	2	<0.05
							G	0.14	1	0.71
							E × G	0.87	2	0.44
		A		A		B				
Evenness ($E_{1/D}$)	0.31 (0.02)	0.34 (0.03)	0.36 (0.08)	0.39 (0.09)	0.41 (0.11)	0.70 (0.08)	E	4.96	2	<0.05
							G	3.55	1	0.08
							E × G	1.84	2	0.20
		B		B		A				

Values are means for each treatment, and standard errors of means are shown within parenthesis. *F* ratio, degree of freedom (df) and *P* value are indicated (*E* elevation, *G* grazing treatment, *E* × *G* interaction between elevation levels and grazing treatment). Different letters indicate statistical significance at $P < 0.05$ according to HSD Tukey's test

rapid replacement of vegetation contributed to maintain high basal cover that prevented salt rise to surface (Taboada 2006; Drewry et al. 2008). These species were able to establish soon after defoliation of dominant tall species (Rusch and Oesterheld 1997; Chaneton et al. 2002), favored by the high availability of light at soil surface (Deregibus et al. 1994; Rodríguez et al. 1998; Huan et al. 2006). Most of co-occurring species are not or slightly tolerant to salinity and flooding and are components of rich humid and mesophyte prairies of the Flooding Pampa (León 1975; León et al. 1979; Perelman et al. 2001). A similar response was found in high-latitude salt marshes of North Hemisphere, where cattle and sheep grazing shifted floristic composition and increased species richness and diversity due to the reduction in the contribution of the dominant tall species (Bakker 1985; Bos et al. 2002).

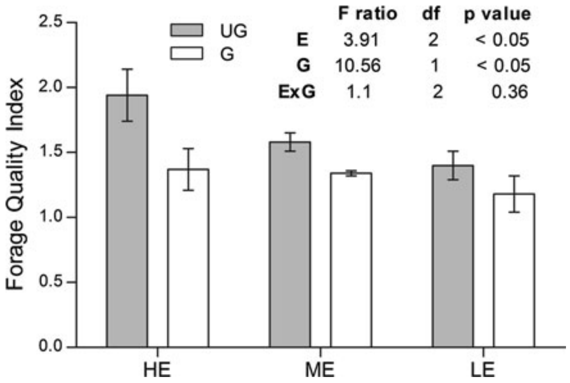

Fig. 3 FQI of the HE, ME and LE elevation levels under G and UG treatments. Values are means for each treatment. *Vertical lines* indicate standard errors of the mean. Insert: *F* ratio, degree of freedom (df) and *P* value for elevation levels (E), grazing treatment (G) and the interaction (E × G)

In the medium- and low-elevation sites, vegetation assemblage was shaped by the tolerance to the major stressful factors (Snow and Vince 1984; Kleyer et al. 2003), so it was restricted to moderate- to high-tolerant species, such as *S. densiflora* and *S. perennis* (Davy et al. 2006), determining lower covers, richness and diversity as elevation decreased. Continuous cattle grazing increased soil salinity probably due to defoliation which reduced aerial biomass and increased bare soil, promoting water evaporation and the capillary rise of salts from the lowest soil layers (Lavado and Taboada 1987; Srivastava and Jefferies 1996; Yu and Chmura 2010). These processes are magnified by the high temperatures that prevail in this temperate salt marsh respect to cold salt marshes (Pennings et al. 2005), and with the nearness of a saline groundwater (Hassan and Ghaibeh 1977), which was at a depth ≤40 cm in the medium and lower positions in our experiment. Grazing increased soil salinity three times in the medium and less than two times in the low elevation. The lower increment of salinity in the low elevation may be related to the higher frequency of tidal flooding because tidal water receives the contribution of inland freshwater through artificial channels, and therefore, the salt content is lower than that of the groundwater table (Carol et al. 2009). For this reason, the salt rise to soil surface would be lower due to a lower evaporation rate, as it was demonstrated in a saline-sodic community in this region (Alconada et al. 1993). The increase in soil salinity mediated by continuous cattle grazing favors the increase in the relative abundance of highly tolerant species to this stressful condition, such as the halophyte *S. perennis*, and the decrease in the relative abundance of dicotyledonous forbs. As in our study, *Salicornia europaea*, a species close to *S. perennis*, increased its cover in middle marsh under grazing through the increase in bare soil and soil salinity (Tessier et al. 2003). Cattle selectivity may also contribute to the vegetation shift, reducing the relative abundance of the legume *M. officinalis*, highly preferred by cattle (Kneebone 1959). This change mediated by grazing increased the similarity between the medium- and low-elevation sites of this salt marsh, as was documented for other plant communities of the Flooding Pampa grasslands (Sala et al. 1986; Chaneton et al. 2002).

Forage quality decreased as elevation decreased, consistently with the increment of the stress level that caused the shift of co-occurring species along the gradient (Vince and Snow 1984; Cui et al. 2011). High-quality grasses and legumes were recorded only in the high elevation level, whereas lower-quality, high-salinity and flooding-tolerant species were recorded in the low elevation level. Grazing reduced the forage quality of the high and medium elevation levels due to cattle selection or taller, higher-quality grasses (*L. multiflorum, P. trivialis, P. monspeliensis, T. ponticum, Chaetotropis elongata, Sporobolus indicus*) and legumes (*M. officinalis*), allowing the invasion of short-creeping, lower-forage-quality grasses or dicotyledonous forbs (*S. secundatum*, *P. canescens*, *C. pulchellum* and *S. perennis*). Shift in species composition due to continuous grazing that favors short-creeping grasses and forbs in detriment of tall, high-nutritive-value grasses and legumes was also found in humid prairies and meadows of Flooding Pampa grasslands (Chaneton et al. 1988; Agnusdei 1991; Deregibus et al. 1995; Rusch and Oesterheld 1997; Jacobo et al. 2006). The relative increase in *S. perennis* and the relative decrease in *S. densiflora* determined the reduction in forage quality in the low-elevation G, as a consequence of the lower forage quality value of *S. perennis* respect to *S. densiflora*.

The effect of livestock grazing on biodiversity conservation is under intense debate (Cingolani et al. 2005; Lunt et al. 2007) considering that it may be harmful, relatively neutral or even desirable for these purposes (Cingolani et al. 2008; de Bello et al. 2010). The impact of grazing on plant diversity depends mainly on its intensity (de Bello et al. 2006; Cingolani et al. 2008), finding the maximum plant diversity at moderate grazing intensity (Noy-Meir et al. 1989; Noy-Meir and Kaplan 2002; Rosa García et al. 2012). This response was found in several salt marshes, where the highest plant richness and diversity occurred at moderate grazing intensity and the lowest under exclosure or at very high intensity and over-grazing (Andresen et al. 1990; Bouchard et al. 2003; Kleyer et al. 2003). Supporting this general concept, in "Campos del Tuyú" National Park, in the high elevation level, natural succession after the exclusion of grazing led *Spartina* community to a final stage dominated by a few tall grasses and with lower richness and diversity. However, the higher plant richness and diversity in this elevation level under continuous grazing occurred by the appearance of short and creeping species with low or negligible forage quality. In the medium and low elevation levels, the changes in relative cover of several species also led to the reduction in forage quality. Therefore, continuous grazing may cause a positive impact for vegetation conservation in some sites (high-elevation sites) but not in others (medium-elevation sites), while it causes a negative impact for livestock production due to the reduction in forage quality along the entire gradient.

Conclusions and implications

We found strong evidences that the effect of grazing on vegetation and soil salinity in this RAMSAR-protected Samborombón Bay salt marshes is strongly related to the elevation gradient. In effect, continuous grazing caused a shift of vegetation composition in the high elevation level, increased soil salinity in the medium elevation level and caused little changes in vegetation and soil salinity in the low elevation level, while it decreased forage quality along the entire gradient. Therefore, opposite responses arise for conservation and animal production purpose because grazing may be beneficial for conservation as it increases richness in the high elevation, but it may be negative for cattle production due to the decrease in forage value. We suggest that the current continuous grazing applied in this salt marsh may explain the negative effect on forage quality, through selective grazing. As the commercial farm of our experiment is representative of the cattle management applied in most livestock farms, a general loss of forage value could be occurring throughout the region. Moreover, the increasing stocking rate in this region because of agriculture expansion makes aware of the risk for conservation of this temperate coastal salt marsh. Further research will be necessary to evaluate whether intermittent grazing, as it was demonstrated in other grassland communities of Flooding Pampa region (Jacobo et al. 2006), increases forage quality and soil cover, decrease soil salinity and would be more suitable to reach both conservation and livestock production goals.

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