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Impact of cattle grazing on temperate coastal salt marsh soils

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Abstract

Over the last two decades, grazing intensity has increased in the temperate salt marshes of Samborombón Bay (Argentina) due to agricultural expansion and the displacement of domestic livestock to these areas. We investigated the effect of cattle grazing on soil chemical and physical properties in the higher (HE), medium (ME) and lower (LE) elevation levels of this temperate salt marsh. Soil data were collected from both a National Park, where cattle grazing has been excluded for more than 35 yrs, and an adjacent commercial livestock farm continuously grazed by cattle. We found that soil salinity was greater on the grazed than on the ungrazed sites, especially those in the ME and LE. This could be related to the upward flow of salts from the saline groundwater, driven by the increase in the proportion of bare soil on grazed sites. The increase in soil salinity changed the plant community structure through the increase of salt-tolerant and non-palatable species and the decrease of palatable species. Soil physical variables (soil bulk density and soil bearing capacity) were also higher on the grazed than on the ungrazed sites, which can be related to the decrease in soil organic matter (SOM), and suggest an incipient compaction process; however, the values were still lower than those considered critical for plant growth in clay soils. These results suggest that continuous grazing management in this temperate salt marsh might have negative consequences for animal production and ecosystem conservation, mainly related to the increased soil salinity. Further research will be necessary to evaluate the suitability of switching to intermittent grazing management.

Keywords: Compaction, salinity, soil bulk density, bearing capacity, cattle grazing, salt marsh soils

Introduction

Coastal salt marshes are important intertidal grassland ecosystems that provide ecosystem services such as coastal protection, erosion control, carbon sequestration and habitat for a wide range of organisms (Barbier *et al*., 2011). Given their intertidal position, they are regulated by sea water intrusions and salinity (Mitsch & Gosselink, 2008). Both the frequency and duration of tidal flooding increase as ground elevation decreases (Boorman, 2003). Soil salinity varies according to the topographic gradient, air temperature and evaporation dynamics, which generally depend on the salt marsh latitude (Pennings *et al*., 2005). In relation to other types of wetlands and coastal ecosystems (e.g. mangroves, coral reefs, seagrass beds, etc.), salt marshes are those most affected by human activity. In fact, almost 50% of salt marshes in the world are lost or degraded due to the increasing intensity of human activity (MEA, 2005).

Livestock grazing effects on salt marshes are expected to differ from those observed in other environments, because livestock treads on the soil under quasi-permanent wet conditions and the shallow saline groundwater is a potential source of salt rising to topsoil. The magnitude of physical–mechanical grazing impacts depends on soil water content, which will be more detrimental when soil moisture and stocking rates are greater. When moist, animal trampling compresses the soft soil beneath the hoof (Scholefield *et al*., 1985), destroying macropores (Taboada & Lavado, 1993), thus increasing topsoil bulk density (Greenwood & McKenzie, 2001; Taboada *et al*., 2011). In contrast, livestock trampling on saturated soils damage topsoil structure by poaching or kneading, because of plastic flow around hooves. Furthermore, under repeated trampling, deep footprints are produced (Mulholland & Fullen, 1991).

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Beside these soil physical properties, grazing might change soil chemistry. The occurrence of a shallow saline water table promotes salt rising to topsoil in grazed grassland communities (Lavado & Taboada, 1987, 1988). This process is driven by greater evaporation rates from bare soil surfaces, which facilitate the upward flow of soluble salts from deep layers with saline groundwater, thus increasing soil electrical conductivity (Lavado & Taboada, 1987, 1988; Dreccer & Lavado, 1993). Soil organic matter (SOM) can also be affected by grazing, although studies addressing this topic showed contradictory results. On the one hand, grazing can decrease SOM, because it may reduce the quantity and quality of plant material entering the soil, change the grassland structure and modify driving factors such as topsoil temperature and moisture (Parton *et al*., 1987). On the other hand, dung and urine may activate C- and N-cycles, leading to younger organic fractions in topsoil (Taboada *et al*., 2011). Therefore, literature on the effects of grazing on SOM shows negative (Frank *et al*., 1995; Altesor *et al*., 2006), neutral (Henderson *et al*., 2004) and positive (Schuman *et al*., 1999) impacts, depending on the geographical area soil type and grazing management.

The salt marshes of Samborombón Bay (Argentina) are located on the eastern limit of the Argentinean Pampas grasslands and extend across 244 000 ha. 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 (*Ozotoceros bezoarticus celer*) (Vila *et al*., 2008). These salt marshes have been sporadically grazed by cattle at low stocking rates, but over the last two decades, the expansion of agriculture has caused domestic livestock to be displaced to marginal areas (e.g. salt marshes), thus raising stocking rates and grazing intensity over those historically recorded, with the increasing risk of ecosystem degradation. Therefore, the aim of this work was to study the impact of cattle grazing on soil physical and chemical properties in the salt marshes of Samborombón Bay. As these ecosystems are characterized by an elevation gradient in which the frequency and duration of tidal flooding increase as elevation decreases, more severe soil physical and chemical damage is expected as ground elevation decreases, due to the greater soil moisture and the proximity of the saline water table.

Materials and methods

Study area

The study was carried out in a temperate salt marsh (Samborombón Bay, Province of Buenos Aires, Argentina, 36°40′S, 56°96′W; Figure 1). Mean annual rainfall reaches 982 mm, and the average temperature is 15.2 °C. The relief is flat, with a slope of 0.01% and an average altitude of 1.6 m above mean sea level (Carol *et al*., 2008). Dominant soils are vertisols, which have an aquic regime (US Soil Taxonomy), remaining wet almost all year round and also with clay texture and smectite expansible clay mineralogy (INTA, 2014). Tides are mixed (two high and two low tides per tidal day), predominantly semi-diurnal, with tidal ranges lower than 2 m. Floods are caused by the periodic movements of tides. Soil salinity depends on the depth of the water table and on the salt concentration of groundwater, resulting from salt dissolution and accumulation processes (Carol *et al*., 2009). In this salt marsh, tidal water (surface water) receives the contribution of inland freshwater through artificial channels, and therefore, the salt content is lower than that of the groundwater (Carol *et al*., 2009). In this study, tidal water had an average electrical conductivity of 26 ± 0.3 dS/m (data not shown) and groundwater could reach 44 dS/m (Carol *et al*., 2009).

Sampling sites

In this salt marsh, neighbouring grazed and ungrazed sites were compared. Ungrazed sites (UG) were selected in the National Park 'Campos del Tuyú' (3000 ha, 36°19′S, 56°50′W), where domestic grazing has been excluded since 1979. The grazed sites (G) were selected on an adjacent commercial livestock farm (1650 ha), where the stocking rate has been increased over the last decade to 0.6 animals per ha (Figure 1). Grazing takes place in autumn, winter and early spring, when rainwater collects on the surface forming natural ponds for animals to drink from. In both UG and G sites, three different ground elevation levels were identified and sampled: (i) higher elevation level (HE) at 0.80 m above sea level (masl), flooded only twice a year, during the vernal and autumnal equinoxes; (ii) medium elevation level (ME) at 0.70 masl, flooded once or twice a month, when there is a new or full moon; and (iii) lower elevation level (LE) at 0.60 masl, flooded once or twice a day. Thus, elevation levels also represent distance from the low water level and are part of a transect. Groundwater depth is around 0.50, 0.40 and 0.30 m in the HE, ME and LE, respectively. The proportion of each elevation level over the salt marsh area is approximately the same.

Bare soil measurement

Bare soil (%) was measured on each site in December 2010 (spring). It was estimated by the step-point method (Mueller-Dombois & Ellenberg, 1974) along a 10-m-long transect (100 points per transect) randomly placed within each site.

Soil physical properties

Soil was sampled in April 2010 (fall), October 2010 (spring) and March 2011 (summer), to study soil physical properties

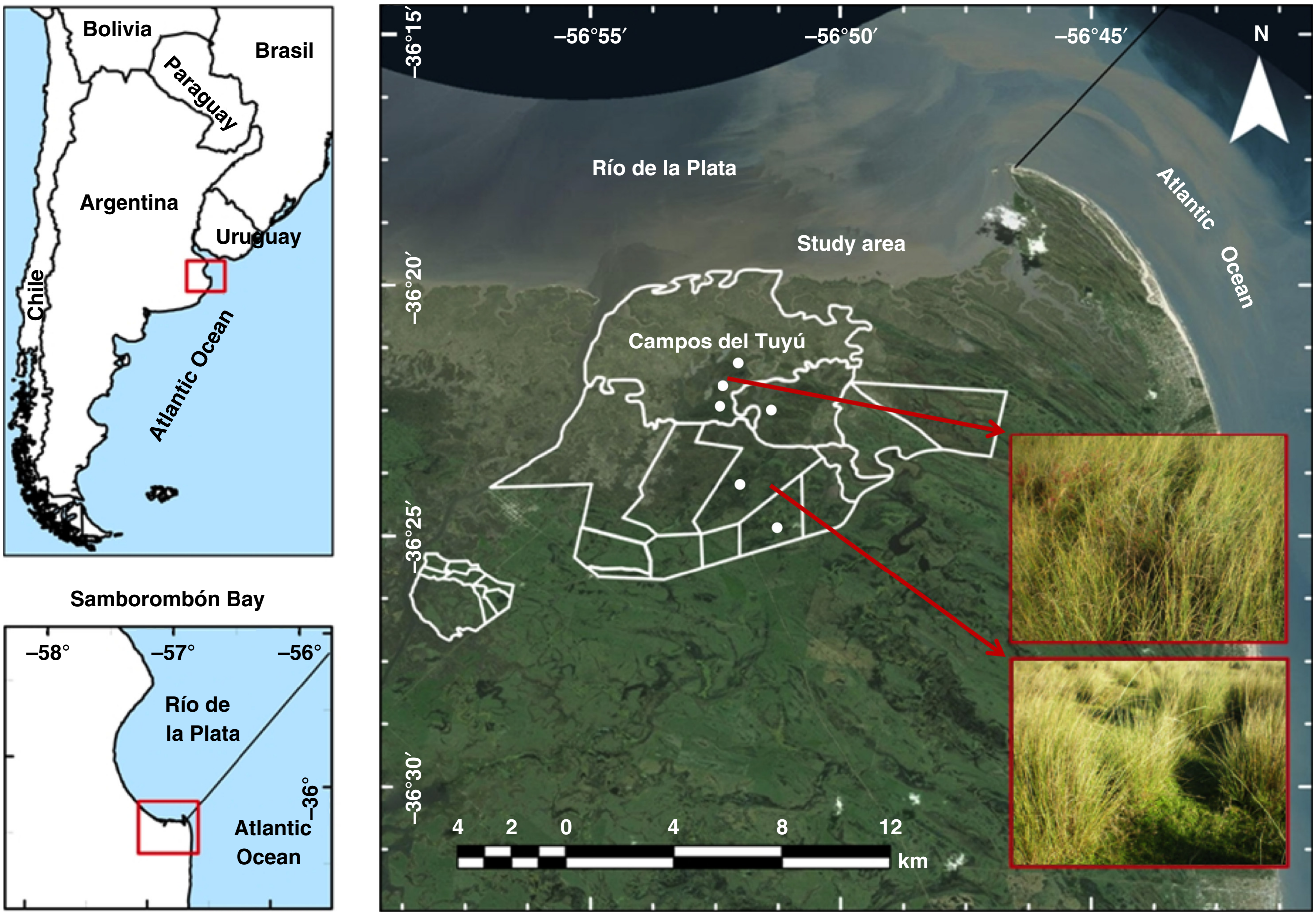

Figure 1 Location map and characteristics of the study area. The area where the transects were located are represented by dots. Photographs show the vegetation structure of the higher elevation (HE) sites of the ungrazed National Park 'Campos del Tuyú' (upper photograph) and the adjacent commercial livestock farms (lower photograph).

under contrasting soil moisture conditions. We followed this procedure as it is well documented that soil bulk density and bearing capacity are closely related to soil water content because of the wetting–drying processes typical of soils with a high content of expandable clays (Parker *et al*., 1982; Taboada *et al*., 2001). Soil gravimetric water content was determined by oven-drying soil samples from the top 15 cm at 105 °C. Soil core bulk density was determined in the 0–5 cm and 5–10 cm layers, using a cylinder of 100 cm^3 volume (5 cm diameter) (Grossman & Reinsch, 2002). Bare soil bearing capacity was determined using a static Proctor penetrometer (Davidson, 1965), with 20 replicates at each elevation and grazing treatment.

Soil chemical properties

Composite soil samples were obtained from ten cores of 6.5 cm diameter and 15 cm length at two depths (0–15 and 15–30 cm) at each ground elevation and grazing treatment. SOM content was determined by the Walkley & Black (1934) method. Soil pH was determined by potentiometry in soil suspensions (1:2.2). Both SOM and pH were measured once (in the fall), as they are quite stable over time and significant seasonal changes are not expected, especially with SOM (Chapin *et al*., 2002). Soil salinity was assessed by the electrical conductivity (EC) of saturation extracts (Rhoades, 1982). It was determined in April (fall), October (spring), December (early summer) and March (late summer), to study salinity dynamics at contrasting soil moisture and atmospheric demands. Measurements were carried out on those dates as it is well documented that EC may rise with increasing atmospheric demands because of evaporation processes and the consequent salt rise (Lavado & Taboada, 1987).

Statistical analysis

Factorial analysis of variance (ANOVA) was performed to evaluate effects of (i) grazing (UG and G); (ii) ground elevation level (HE, ME and LE); and (iii) the interaction between both factors. Before carrying out each analysis, the percentage data (bare soil and SOM) were transformed by arcsine square root ($y = \text{arcsine } \sqrt{x}$) to obtain homogenous variances. All data included in analysis of variances were normally distributed performing the Shapiro–Wilk's test for normality, modified by Mahibbur & Govindarajulu (1997). Significant differences were determined by HSD Tukey's test.

Variations in gravimetric water content, bulk density, bearing capacity and electrical conductivity through time were evaluated by repeated measures ANOVA (rmANOVA), considering grazing and elevation level as main effects and sampling dates as within-subject effects (Von Ende, 1993). When interactions between treatments and time were significant, individual contrasts were made on each sampling date using Bonferroni's tests (Von Ende, 1993). As gravimetric water content was expressed in percentage, an arcsine square root transformation ($y = \text{arcsine } \sqrt{x}$) was performed to obtain homogenous variances. The statistical software used for both factorial analysis of variance and repeated measures was the STATISTICA package version 6.0 (Stat Soft, Tulsa, OK, USA).

Considering the expansible clay mineralogy of the soil, with slickensides and desiccation cracks, the possible occurrence of soil volume changes was assessed by bulk density–water content relationships (Taboada *et al.*, 2001). Soil bulk density (SBD) in the 0–5 cm layer of the UG and G sites did not vary with soil gravimetric water content (SWC) ($\text{SBD}_{\text{UG}} = 0.91 + 0.0021$ SWC; $r^2 = 0.23$; $n = 27$; $P = 0.01$. $\text{SBD}_{\text{G}} = 0.86 + 0.0009$ SWC; $r^2 = 0.03$; $n = 23$; $P = 0.37$). No relationship was found between SBD and SWC in the 5–10 cm soil layer ($\text{SBD}_{\text{UG,G}} = 1.04 - 0.0007$ SWC; $r^2 = 0.01$; $n = 54$; $P = 0.39$). Given the weak or nonexistent relationships between SBD and SWC on grazed and ungrazed sites, soil bulk density values were not adjusted to constant water content. Soil bearing capacity was also related by regression to SWC. Soil bearing capacity (SBC) significantly decreased with SWC (SBC = 13.06–0.18 SWC, $r^2 = 0.55$, $n = 54$, $P < 0.001$). For that reason, SBC values were also adjusted to constant gravimetric water content (52.11%) using the fitted function.

Results

Soil physical properties

Soil gravimetric water content increased from HE (47.3%) to LE (57.2%) and was 22.7% lower on grazed than on ungrazed sites in fall and spring (Table 1).

Soil bulk density of the 0–5 cm layer was significantly greater on grazed than on ungrazed sites in fall and spring (Table 1; Figure 2a–c). In the 5–10 cm layer, the grazing effect was not as significant as in the 0–5 cm layer and, interestingly, the lowest bulk density was found in summer on the HE and ME (Table 1).

Soil bearing capacity was significantly greater on grazed sites than on ungrazed sites only on the HE; the greatest bearing capacity was observed in summer on the HE and ME (Table 1; Figure 3a–c). When adjusted to constant gravimetric water content (52.11%) using the fitted function, greater bearing capacity was found on the HE than on the LE (Table 1; Figure 3d–f). Soil bearing capacity was only significantly greater on grazed than on ungrazed sites in summer; in that season, grazed top soils were harder than in fall and spring (Table 1; Figure 3d–f).

Table 1 *P*- and *F*-value for the ANOVA factors (elevation, grazing and E × G) and rmANOVA factors (elevation, grazing, E × G, time, T × E, T × G and T × E × G) for soil physical and chemical properties

	Elevation (E)		Grazing (G)		E × G		Time (T)		T × E		T × G		T × E × G	
Soil variable	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
Gravimetric water content	**0.006**	8.20	**< 0.001**	24.22	0.420	0.93	**< 0.001**	68.33	0.264	1.40	**< 0.001**	11.65	0.902	0.26
Bulk density (0–5 cm)	0.086	3.02	**< 0.001**	25.49	0.996	0.00	0.174	1.88	0.247	1.46	**0.019**	4.68	0.936	0.20
Bulk density (5–10 cm)	0.268	1.47	**0.050**	4.73	0.947	0.05	**< 0.001**	14.42	**< 0.001**	9.61	0.382	1.00	0.147	1.88
Bearing capacity	**< 0.001**	51.99	**0.002**	14.67	**0.024**	5.15	**< 0.001**	68.70	**0.004**	5.12	0.419	0.90	0.603	0.69
Bearing capacity (water content)	**0.003**	10.19	0.204	1.81	0.430	0.91	**0.014**	5.71	**0.028**	3.29	**0.001**	9.53	0.576	0.74
EC (0–15 cm)	**0.001**	26.34	**< 0.001**	61.29	**0.002**	17.36	**0.001**	8.16	0.185	1.64	0.507	0.80	0.934	0.29
EC (>15 cm)	0.217	1.91	**0.017**	9.78	0.100	3.26	**< 0.001**	12.79	0.242	1.45	0.680	0.51	0.750	0.57
Bare soil	**0.001**	13.89	0.087	3.47	0.904	0.10								
SOM (0–15 cm)	0.433	0.90	0.195	1.88	0.912	0.09								
pH (0–15 cm)	0.648	0.45	0.538	0.40	0.985	0.01								

Main effects and interactions were considered significant at $P < 0.05$ and are shown in bold type.

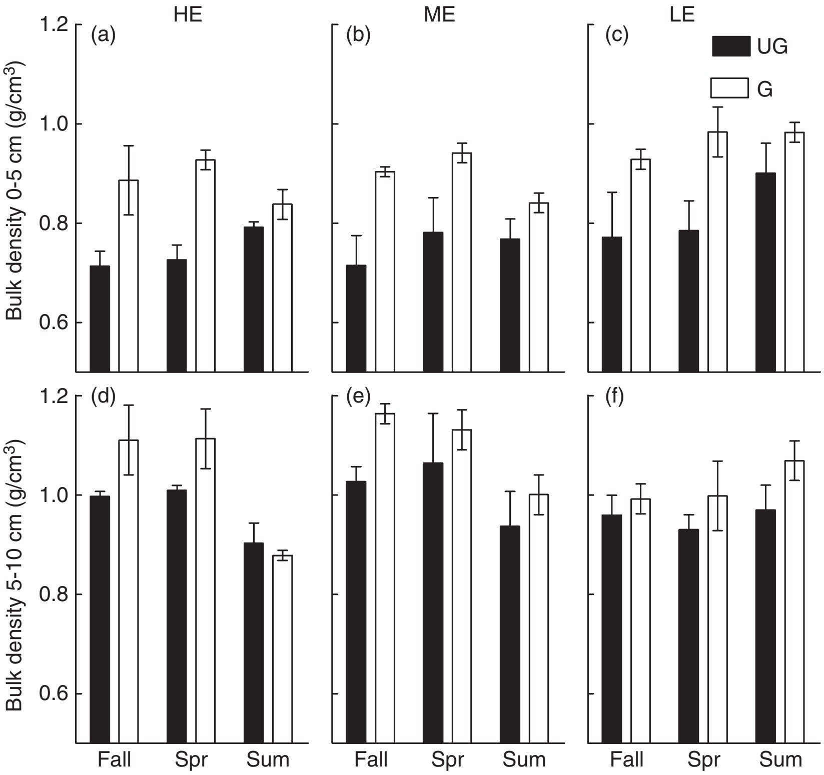

Figure 2 Soil bulk density dynamic in the 0–5 cm (a, b, c) and 5–10 cm (d, e, f) layers of the higher (HE; a, d), medium (ME; b, e) and lower (LE; c, f) elevation level of the ungrazed (UG) and grazed (G) sites of the salt marsh. Samples were taken in the fall, spring (Spr) and summer (Sum). Values are means ± SE.

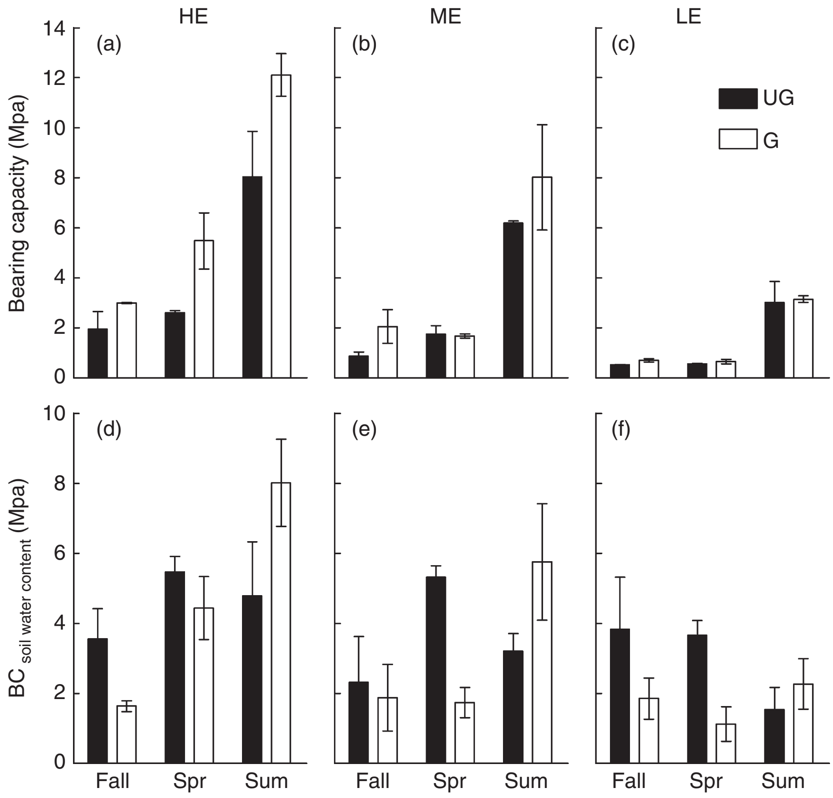

Figure 3 Soil bearing capacity dynamic (a, b, c) and soil bearing capacity dynamic according to constant soil water content ($BC_{\text{soil water content}}$, d, e, f) of the higher (HE; a, d), medium (ME; b, e) and lower (LE; c, f) elevation level of the ungrazed (UG) and grazed (G) sites of the salt marsh. Samples were taken in the fall, spring (Spr) and summer (Sum). Values are means ± SE.

Bare soil proportion and soil chemical properties

In the HE and ME, the proportion of bare soil was <10%, while in the LE bare soil surface, it was as high as 31% (Table 2). The proportion of bare soil increased from the HE to the LE of the salt marsh (Tables 1 and 2). On grazed sites, the proportion of bare soil tended to be greater than on the ungrazed sites on the ME and LE, but not on the HE; however, no interaction was found between elevation level and grazing (Tables 1 and 2).

Mean SOM contents were 8.2 ± 1.3% on ungrazed sites and only 5.8 ± 0.5% on grazed sites, showing that SOM tended to decrease on grazed sites at all elevation levels (Tables 1 and 2). Soil pH (0–15 cm) was similar across all elevation levels or grazing treatments (Table 2). Below 15 cm, no pH differences were found among treatments (data not shown).

Noticeably, soil EC (0–15 cm) was greater particularly on ME and LE grazed sites in comparison with the ungrazed sites, and no differences were found on the HE; soil EC was significantly greater in summer than in the other seasons at all elevation levels (Table 1; Figure 4a–c). Below 15 cm soil depth, EC was greater on grazed than on ungrazed sites at all elevation levels, with salinity values also greater in summer than in the other seasons (Table 1; Figure 4d–f).

Discussion

In salt marsh environments, soil salinity is one of the major composition and structure shapers of the existing grassland vegetation community (Pennings *et al*., 2005; Isacch *et al*., 2006).

In this temperate salt marsh, soil salinity was greater on grazed than on ungrazed sites. Although soil bulk density and soil bearing capacity also increased on grazed sites, suggesting an incipient compaction process, the effect was not as severe as the salinity impact.

EC values measured in the medium and lower elevation levels were greater under grazed than under ungrazed condition. This increase in soil salinity can be explained by the upward flow of salts from saline groundwater (located at <40 cm depth at the medium and lower elevation level of our experiment), driven by the increase of bare soil on grazed sites (Lavado & Taboada, 1987). On the higher elevation, soil salinity did not increase compared with the other elevation levels, probably due to the deeper groundwater and the lower bare soil proportion. Similar results were also found in low-latitude marshes on both US coasts, where salinity levels reach a peak in the middle marsh because of evaporation processes, and salinities may reach higher levels than those found in sea water (Pennings & Bertness, 1999, 2001). In contrast, in high-latitude marshes, salinity tends to decline from the low to the high marsh, and it is rarely greater than levels found in sea water (Pennings & Bertness, 1999). Therefore, in this temperate salt marsh, the proximity of saline groundwater and the greater proportion of bare soil on grazed sites, in comparison with the ungrazed sites, would be the main factors driving soil salinity increases on the medium and lower elevations, showing a high vulnerability to soil salinization. As mention before, soil salinity is a driving factor in vegetation composition and structure, and this was reflected in the medium elevation where the increase in soil salinity promoted the cover of halophytic species, as *Sarcocornia perennis*, decreasing species richness and forage quality of the plant community (Di Bella *et al*., 2014).

Soil bulk density (0–5 cm), which is used as an indicator for soil compaction, was significantly greater on grazed than on ungrazed sites at all elevation levels. Similar results were also found in soils from different geographical areas and different intrinsic properties (Greenwood & McKenzie, 2001; Taboada *et al*., 2011) as well as in other salt marshes (Elschot *et al*., 2013; Nolte *et al*., 2013). Soils of high clay content, such as those of Samborombón Bay, are also more likely to suffer compaction than soils with greater sand content (Schrama *et al*., 2013). Although in soils with high content of expansible clays, the increase in bulk density could also be a consequence of shrinkage because of the wetting–drying processes (Taboada & Lavado, 1993), there was no relationship between bulk density and gravimetric water content in this salt marsh. It is possible that high EC values in the studied soils have prevented swelling promoted by expansible clay and exchangeable Na^+ (Gupta & Abrol,

Table 2 Bare soil (%), soil organic matter (SOM %) and pH, in the 0–15 cm layer of the higher (HE), medium (ME) and lower (LE) elevation level of the ungrazed (UG) and grazed (G) sites of the salt marsh. Values are means ± SE

	HE		ME		LE	
	UG	G	UG	G	UG	G
Bare soil (%)	1.5 ± 1.5 a	5.4 ± 5.1 a	1.7 ± 1.1 a	6.9 ± 0.6 a	20.7 ± 6.9 b	30.8 ± 7.9 b
SOM (%)	9.7 ± 0.5	6.5 ± 0.8	8.1 ± 3.5	6.0 ± 1.2	6.8 ± 2.4	4.9 ± 0.5
pH	7.2 ± 0.23	7.3 ± 0.17	7.3 ± 0.1	7.4 ± 0.09	7.4 ± 0.32	7.5 ± 0.15

Different letters indicate statistical significance at $P < 0.05$ according to HSD Tukey's test.

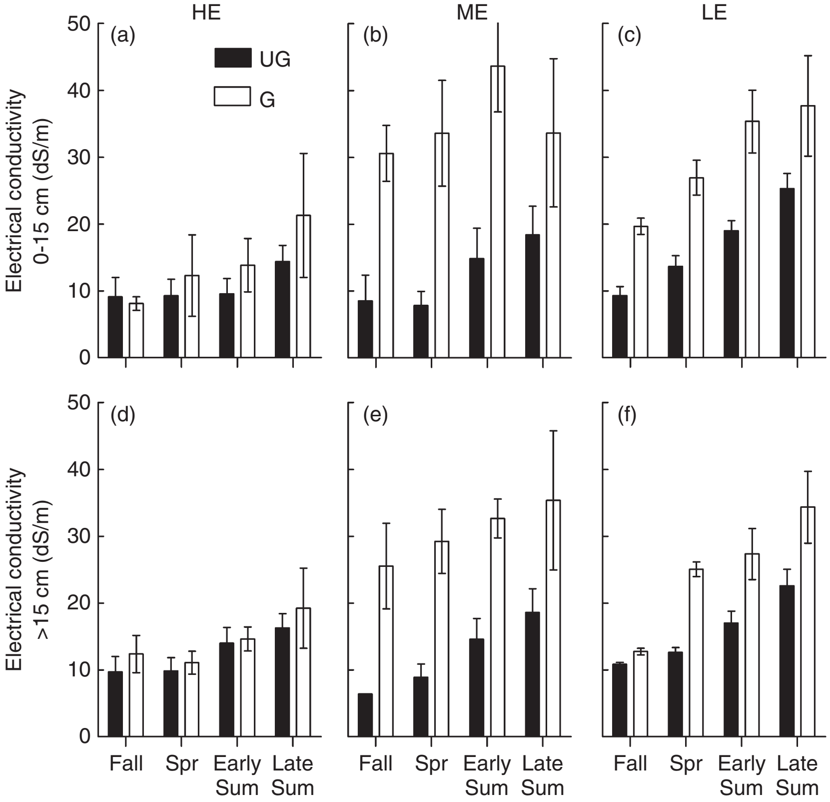

Figure 4 Soil electrical conductivity in the 0–15 cm (a, b, c) and >15 cm (d, e, f) layers of the higher (HE; a, d), medium (ME; b, e) and lower (LE; c, f) elevation level of the ungrazed (UG) and grazed (G) sites of the salt marsh. Samples were taken in the fall, spring (Spr), early summer (Early Sum) and late summer (Late Sum). Values are means ± SE.

1990), as soil dispersion effects could be counteracted by high EC values of the soils under study. This suggests that the increase in soil bulk density is only a consequence of animal trampling and not of wetting–drying processes. However, despite the significant increase in soil bulk density on the grazed sites of this study, the values obtained were lower than those considered critical for plant growth in clay soils (>1.2–1.4 g/cm^3; Hazelton & Murphy, 2007), when root penetration is likely to be severely restricted.

Soil bearing capacity was greater on the higher elevation of grazed sites than in the other treatments. On these sites, both a lower percentage of bare soil and the presence of a much denser sward were found in comparison with the other elevation sites (see Figure 1; Di Bella *et al*., 2014), a fact which could have increased bearing capacity due to the presence of a greater number of roots and rhizomes. As differences in soil bearing capacity persisted even when data were adjusted to constant water content, the greater bearing capacity during summer on the higher and medium grazed sites may be attributed to grazing compaction and not to drier soil conditions. In this humid environment, high bearing capacity probably facilitates animal traffic, as its values exceed 0.098–0.19 MPa, which is the static pressure range exerted by cattle on the ground (Greenwood & McKenzie, 2001).

Despite livestock treading on soil under wet conditions, especially on the medium and lower elevation sites, no structural damage by poaching was observed in the study area, as neither soil bulk density nor bearing capacity was decreased by swelling and weakening, respectively (Scholefield *et al*., 1985; Taboada *et al*., 2011). This can firstly be explained by the lack of poaching damages to the sward which can be attributed to the relatively low stocking rates (0.6 cow/ha/yr) in this salt marsh. These results agree with Taboada & Lavado (1993) who did not find poaching damage in the nearby Flooding Pampa because the low stocking rate (<1 cow/ha/yr) was probably insufficient to create a repeated stress. Secondly, the distribution of treading along the elevation gradient might not be uniform, affecting the soil in a different way (Adler *et al*., 2001). Even though animals tread and graze on the three elevation sites studied (data not shown), it is probable that animals spend more time on the higher drier elevation, attenuating grazing impacts on the medium and lower wetter elevation.

Although grazing tended to decrease SOM in this salt marsh, the magnitude of the impact was not as significant as the negative impacts found in other studies (Frank *et al*., 1995; Altesor *et al*., 2006). However, an incipient ongoing C loss from grazed soils should not be disregarded as it could be a consequence of drier condition, favouring a greater mineralization rate of soil organic matter (Chapin *et al*., 2002). These processes would be more evident in the medium and lower elevation, which are more prone to be under anaerobic conditions caused by flooding and tidal movements. Furthermore, the greater soil bulk density on grazed than on ungrazed sites discussed above could be related to this incipient decrease in SOM (Keller & Håkansson, 2010).

Conclusions

According to our results, current cattle management (continuous grazing) of this temperate salt marsh might be leading the system to an undesirable situation, mainly due to the increase in soil salinity. This process is decreasing species richness and forage quality of the grassland plant community, with negative consequences for management (increase in salt-tolerant and non-palatable species and decrease of nontolerant and palatable species). Continuous cattle grazing also promotes soil compaction; however, the magnitude of the impact is small, as soil bulk density values were still lower than those values considered critical for plants growth in clay soils.

Further research will be necessary to evaluate whether switching to an intermittent grazing management will be more suitable, as has been demonstrated in other grassland communities of the Flooding Pampa region where soil cover increased and soil salinity decreased with intermittent grazing management. This would allow the sustainable use of the salt marsh avoiding soil changes that can damage the system and the management.

Our results are also applicable to other temperate (low-latitude) salt marshes in Argentina and worldwide, where the increase in bare soil could promote evaporation processes, increasing soil salinity with a consequent negative change in floristic composition for cattle production.

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