

A woody plant community and tree-cacti associations change with distance to a water source in a dry Chaco forest of Argentina

Carolina B. Trigo^{A,B,E}, Andrés Tálamo^{A,B}, Mauricio M. Núñez-Regueiro^C,
Enrique J. Derlindati^A, Gustavo A. Marás^A, Alicia H. Barchuk^D and Antonio Palavecino^A

^AFacultad de Ciencias Naturales, Universidad Nacional de Salta, Avda. Bolivia 5150, Salta, Argentina.

^BInstituto de Bio y Geociencias del NOA (IBIGEO), Universidad Nacional de Salta, Consejo Nacional de Investigaciones Científicas y Técnicas, Mendoza 2, Salta, Argentina.

^CSchool of Natural Resources and the Environment and Center for Latin American Studies, University of Florida, Gainesville, FL 32601, USA.

^DFacultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Ing Agr. Felix Aldo Marrone 746 – Ciudad Universitaria, Córdoba, Argentina.

^ECorresponding author. Email: carolinatrigo88@gmail.com

Abstract. In semiarid regions, livestock is concentrated around water sources generating a piosphere pattern (gradients of woody vegetation degradation with increasing proximity to water). Close to the water source, livestock may affect the composition, structure and regeneration strategies of woody vegetation. We used the proximity from a water source as a proxy of grazing pressure. Our objectives were (1) to compare woody vegetation attributes (richness, diversity, species composition, density and basal area) and ground cover between sites at two distances to a water source: near (higher grazing pressure) and far from the water source (lower grazing pressure), and (2) to quantify and compare cases of spatial association among the columnar cacti *Stetsonia coryne* (Salm-Dyck) Britton and Rose (Cactaceae), and the dominant tree *Bulnesia sarmientoi* Lorentz ex Griseb. (Zygophyllaceae). We used a paired design with eight pairs of rectangular plots distributed along a large and representative natural water source. We found lower total species richness, plant density and soil cover near than far from water source, and more cases of spatial associations between the two species studied. Our results show evidence of increased livestock impacts around water sources. However, we found no difference in terms of species composition or basal area at near versus far sites. We conclude that grazing pressure might be changing some attributes of the woody plant community, and that the association of young trees with thorny plants (grazing refuge) could be a regeneration mechanism in this semiarid forest with high grazing pressure.

Additional keywords: grazing pressure, regeneration, water resource.

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Introduction

In many arid and semiarid areas around the world, domestic animal husbandry is the main subsistence economic activity among residents of natural ecosystems (Asner *et al.* 2004; Bedunah and Angerer 2012). In dry forests, such as the dry Chaco in Argentina, one of the main livestock systems used is ‘extensive ranching’, where animals move freely in search of forage and water (Quiroga *et al.* 2009). As a result of trampling and grazing, livestock grazing may have multiple effects on vegetation, which need to be recognised and quantified in order to evaluate the environmental sustainability of this important economic activity. Understanding the relationship between livestock and native woody vegetation is critical for future

management schemes that enhance long-term conservation of native forests.

Grazing pressure is one of the factors affecting vegetation. Increased grazing pressure on a site may cause higher herbivory rates and mechanical trampling over seeds and seedlings. As a result, the vegetation composition may be modified directly by changes in abundance of plants consumed or trampled over (Milchunas and Lauenroth 1993; Bisigato *et al.* 2005). Grazing can also catalyse indirect changes via soil compaction, which might reduce seed germination and the establishment of seedlings and saplings (Winkel and Roundy 1991; Mohseni Saravi *et al.* 2015). However, despite the very clear possible negative consequences, not all livestock effects are detrimental.

For some species, seed germination is dependent on livestock dispersal (Winkel and Roundy 1991; Carmona *et al.* 2013), and high rates of grazing and moderate trampling may lead to an increase in primary productivity and greater root or buried stem regrowth rates (Belsky 1986; Harris *et al.* 2016).

In arid and semiarid ecosystems, livestock interacts with water sources creating a unique pattern, which shapes plant communities. Here, livestock usually concentrates around water sources creating areas with bare soil and a gradient of grazing pressure that decreases with increasing distance to water; this is known as a piosphere pattern (Lange 1969; Andrew 1988; Todd 2006). Consequently, vegetation attributes such as richness, diversity and species composition, density, basal area and ground cover might change (Noy-Meir *et al.* 1989; Fleischner 1994; Pettit *et al.* 1995; Hernández Vargas *et al.* 2000; Guevara *et al.* 2006; Todd 2006; Plieninger *et al.* 2011; Macchi and Grau 2012). However, much of what we know about the piosphere pattern comes from studies focused on herbaceous communities in desert or semi-desert environments. Very few studies have considered the piosphere pattern in woody ecosystems such as subtropical dry forests. This is a true shortcoming, given that dry forests are one of the most rapidly disappearing ecosystems of the planet (Hansen *et al.* 2013). Therefore, studies that help to understand how woody plants are potentially impacted around water sources in subtropical dry forests will provide key information in the face of continued habitat degradation.

In environments with high grazing pressure, woody plants spatially associate with thorny plants (e.g. cactus), which provide effective protection against herbivores and facilitate regeneration in woody plants (i.e. indirect positive interaction; Rebollo *et al.* 2002, 2005). This grazing refuge provided by a nurse plant is a type of indirect facilitation mechanism (Callaway 1995). As a result of the protection against herbivores, germination rates may increase, as well as growth and survival of protected seedlings (McAuliffe 1986; Bertness and Callaway 1994; Callaway 1995; Zamora *et al.* 2001). The positive effects of the refuge may vary with the pressure of grazing, and this association should be stronger and more common in areas with high grazing pressure (Rebollo *et al.* 2005; Tálamo *et al.* 2015a). Positive interactions can increase functional diversity in grazed ecosystems. These interactions can provide protection to grazing-sensitive species (Milchunas and Noy-Meir 2002; Rebollo *et al.* 2002; Boughton *et al.* 2011), which is very important for the restoration of native vegetation in grazed and browsed environments. Although many studies exist on this topic, the role of positive interactions or facilitation as a regeneration mechanism in the context of the piosphere pattern remains largely unexplored.

In Latin America, extensive livestock in the remaining forest patches is considered a major cause of environmental degradation of dry Chaco forest (Morello and Adámoli 1974; The Nature Conservancy *et al.* 2005; Torres *et al.* 2014). However, very few empirical studies examine possible effects of livestock on native woody vegetation in the semiarid Chaco. In this important ecoregion, water tends to accumulate around artificial dams, causing a clear piosphere pattern on the vegetation and the bird community (Macchi and Grau 2012). However, in the alluvial Chaco of Salta province, in the NW of Argentina, water is usually found in natural water bodies in areas of ancient riverbeds, locally known as 'madrejonas' (Adámoli *et al.* 1972).

In this sub-region, different vegetation units exist, characterised by their dominant tree species, such as 'Palo Santo' forests (*Bulnesia sarmientoi*), locally known as 'palosantales' (Adámoli *et al.* 1972). This species is of utmost importance from an economic and cultural point of view. For hundreds of years, local indigenous and creole communities have used its wood for several purposes such as firewood and fiber (Arenas and Suárez 2006; Suárez 2014). A second dominant species of this unit is the arboreal cactus known as 'cardón' (*Stetsonia coryne*). This is a species that might deter domestic livestock due to its typical stem and thorny branches, thus protecting other species associated to it. This system offers the possibility of conducting an observational study on the relationship between livestock grazing and woody vegetation in the context of the piosphere pattern.

Here, our objectives were (1) to compare woody vegetation attributes and ground cover at two distances to a water source (close and far away), and (2) to quantify and compare tree-cacti spatial association between both distances. Furthermore, we test the hypotheses that (1) livestock pressure alters the attributes of native woody vegetation, in the context of the piosphere pattern, and (2) spatial associations among woody and thorny plants under high livestock pressure can influence the regeneration of native woody species. We predict that woody vegetation attributes (richness, diversity, density and basal area) and ground cover will be higher, and species composition will differ in areas far away from water source (where livestock pressure is lower) in comparison to areas close to water (where livestock pressure is high). We also expect that the proportion of individuals of *Bulnesia sarmientoi* spatially associated with *Stetsonia coryne* will be higher close to the water source in comparison to sites far from the water source.

Methods

Study area

The study was conducted on the northern edge of a 5000-ha farm 'Finca el Paraíso' (23.813°S, 62.794°W), which is located in the department of San Martín, Salta Province, Argentina. The environment corresponds to the Dry Chaco ecoregion, which is composed of a xeric and semi-deciduous forest, with the overstorey dominated by *Schinopsis lorentzii* (Griseb.) Engl., *Aspidosperma quebracho-blanco* Schltdl., and *Bulnesia sarmientoi* Lorentz ex Griseb. (Adámoli *et al.* 1972). This forest is composed of other shorter trees, like *Ziziphus mistol* Griseb., *Tabebuia nodosa* (Griseb.) Griseb., *Ruprechtia triflora* Griseb., different species of genus *Prosopis* and *Acacia*. Cacti, such as *Opuntia quimilo* K. Schum., *Stetsonia coryne* (Salm-Dyck) Britton and Rose, and *Cereus haenkeanus* F.A.C. Weber ex K.Schum. (Torella and Adámoli 2006; Derlindati *et al.* 2012), are also present.

The subtropical climate is characterised by strong seasonality, with a hot and humid season, between the months of November and April (510 mm) and warm and dry season, between the months of May and October (65 mm) (Bianchi and Yáñez 1992). Numerous water sources are used by animals in the study area; the majority of these run out of water during the dry season. For this reason, we chose one of the most prominent, permanent and representative water source to perform the study. This water

source is a large pond where the water level varies with rainfall (in summer it expands and in winter it contracts).

Sampling design

To test our hypotheses, we utilised a paired design, where the design factor (or treatment factor) evaluated was ‘distance from water source’, with two discrete levels: areas near the water source (15 m from it, where livestock-use intensity is higher) and areas far from the water source (200 m from the previous level, where livestock pressure is lower). The separation distance used between areas could not be greater than 200–300 m, because at that distance the vegetation unit changes by edaphic characteristics, regardless of the existence of livestock (i.e. a ‘quebrachal’, dominated by *A. quebracho-blanco*, was immediately beyond a ‘palosantal’, dominated by *B. sarmientoi*, see Fig. 1). Thus, by restricting our sampling to the ‘palosantal’ unit we are controlling the possible effect of an undesirable confounding factor. For the same reason, it was not possible to work with a gradient by adding an intermediate distance. Similarly, the first 15 m were not sampled, because the vegetation (species composition, identity of the species and productivity) surrounding the water bodies was very different from that of the

‘palosantal’ vegetation unit. Camera-trapping confirmed almost 6 times higher frequency of livestock near water sources in comparison to sites far away from water sources (Poisson regression parameter $\beta = 5.87$; 95% C.I. = 4.92, 6.04). For this, five camera traps were placed <150 m from the water point and eight cameras were set in areas >1 km from the water source. Camera traps were active for 16 days. We built a generalised linear model using log as the link function and the Poisson distribution as the assumed probability distribution function of the response variable (number of livestock individuals in 12 h). We used the categorical classification of near (<150 m from the water point) and far (>1 km from the water point) as predictor variables.

The design consisted in eight blocks with two plots each (one near the water source and another far from it), located parallel to the longest axis of the water source (Fig. 1). The representativeness of the sampling was increased spreading the plot pairs spatially; therefore they were separated by at least 200 m.

Each plot consisted of a rectangle, with two different sizes depending on the size categories of plants. The size categories were: (1) ‘saplings’ (individuals with height <1 m), (2) ‘adult shrubs and young trees’ (individuals with height >1 m and diameter at breast height <10 cm) and (3) ‘adult trees’ (individuals

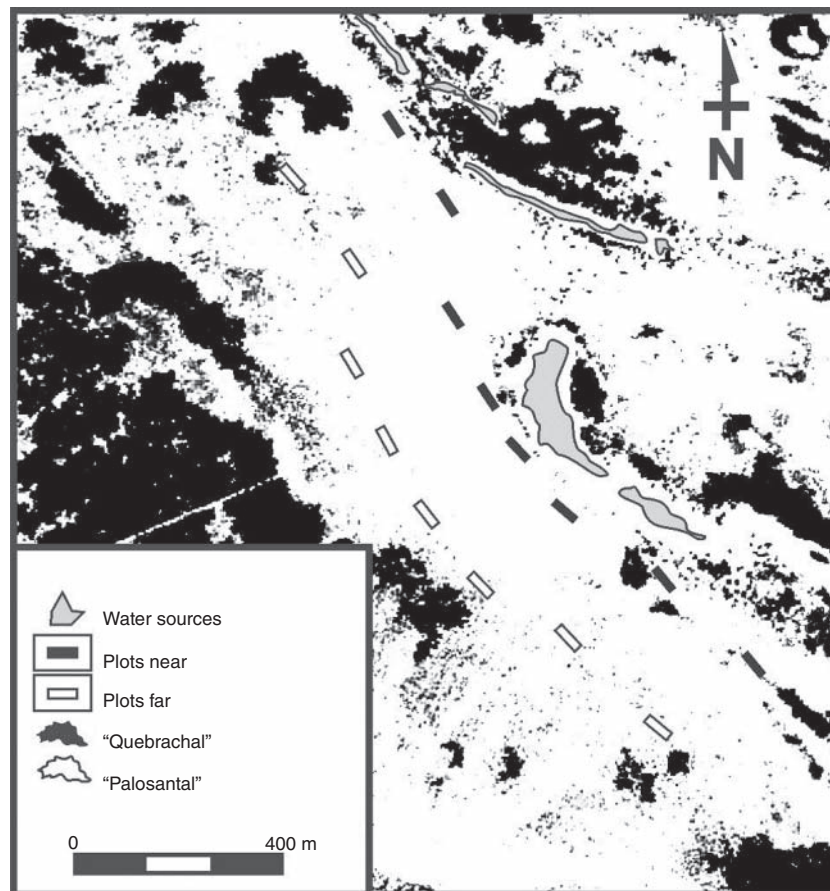


Fig. 1. Map showing the study area, the natural water source and a sketch with the sampling design. Plots are located within the vegetation unit called ‘Palosantal’. The other vegetation unit (‘Quebrachal’) was excluded of the sampling because it has a different soil type in comparison to ‘Palosantal’.

with height >1 m and diameter at breast height >10 cm). To sample categories 1 and 2, we used plots of 2 m × 50 m. To sample adult trees (size category 3) we used plots of 10 m × 50 m because of their lower density. In plots of 2 m × 50 m we recorded species richness (number of species of all woody plants), plant density (size categories 1 and 2), and ground cover (with a rod of 1 m, we counted the number of touches of the following categories every 1 m: bryophytes, litter, bare soil, wood, dicots and Bromeliaceae). In plots of 10 m × 50 m we recorded tree density, diameter at breast height, and number of cases of spatial associations between *S. coryne* and *B. sarmientoi*. We defined a spatial association when a *B. sarmientoi* individual was found within 20 cm from the trunk of an individual of *S. coryne*.

The response variables analysed to meet the first objective (to compare woody vegetation attributes and ground cover between two distances to a water source) were: (1) Species richness, (2) Diversity, (3) Species composition, (4) Density, (5) Basal area, and (6) Ground cover in different categories. For the second objective (to quantify and compare tree-cacti association between both distances) the response variable was the percentage of spatial associations counted as number of cases of tree-cacti association in relation to the total number of individuals per plot.

Statistical analyses

Mean species richness, density, basal area, and percentage of tree-cacti associations was analysed using a paired-sampled *t*-test (Zar 1999). All component of diversity were visually compared by range-abundance curves (Feinsinger 2004). To assess whether both distances differ in their species composition, we used a

multivariate technique known as blocks multiple response permutation procedure. This technique allows assessing if the differences in species composition found between groups are greater than what might be expected by chance (McCune and Grace 2002). This analysis was performed using the PC-ORD software (McCune and Mefford 1999). To determine whether the different ground cover categories are distributed equally between both distances, we used the X^2 homogeneity test (Zar 1999).

Results

We found a total of 21 woody plant species, 14 in plots near the water source (Table 1) and 17 in plots far away from the water source (Table 1). Both near and far sectors differed in the mean number of species per plot ($|\bar{d}| = 3.63$ sps; $s.d._{(dif)} = 2.33$ sps; $T = 4.41$; $P = 0.0031$; Fig. 2). With regard to species diversity, saplings and adult shrubs and young trees assemblages had greater evenness in areas far from the water source in comparison to areas close to the water source (Fig. 3). The species composition was not different in both distances (multiple response blocked permutation (MRBP): $T = -0.25$; $P = 0.30$). We recorded a total of 243 woody plants (for the three size categories) in plots near the water source, and a total of 943 woody plants in plots far from the water source. We found the highest density of saplings in plots far from water source ($|\bar{d}| = 7413$ saplings/ha; $s.d._{(dif)} = 6028$ saplings/ha; $T = -3.48$; $P = 0.0103$; Fig. 4a). Both distances had a similar density of adult shrubs and young trees ($|\bar{d}| = 375$ adult shrubs and young trees/ha; $s.d._{(dif)} = 913$ adult shrubs and young trees/ha; $T = -1.16$; $P = 0.2834$; Fig. 4a), but more adult trees were found in plots far from the water source than in plots close to water

Table 1. List of woody plants species presents ('saplings', 'adult shrubs and young trees' and 'adult trees') in areas near and far from a water source in the northern edge of the Finca el Paraiso, Salta, Argentina

| Scientific name | Common name | Sapling | Far Adult shrubs and young trees | Adult trees | Sapling | Near Adult shrubs and young trees | Adult trees |
|--------------------------------------|--------------------|---------|----------------------------------|-------------|---------|-----------------------------------|-------------|
| <i>Acacia praecox</i> | Garabato | | | | X | | |
| <i>Aspidosperma</i> sp. | Asp sp. | X | | | | | |
| <i>Aspidosperma quebracho-blanco</i> | Quebracho blanco | X | | | | | |
| <i>Aspidosperma triternatum</i> | Quebrachillo | X | X | X | | | |
| <i>Bromelia</i> sp. | Chaguar | X | | | | | |
| <i>Bulnesia sarmientoi</i> | Palo santo | X | X | X | X | X | X |
| <i>Capparis retusa</i> | Sacha poroto | X | X | X | X | X | |
| <i>Capparis salicifolia</i> | Sacha sandía | X | X | X | X | | X |
| <i>Capparis speciosa</i> | Bola verde | | X | | X | | |
| <i>Castela coccinea</i> | Meloncillo | X | X | | X | | |
| <i>Cercidium praecox</i> | Brea | | | | X | | |
| <i>Mymozyanthus carinatus</i> | Iscayante | X | X | | | X | |
| <i>Opuntia quimilo</i> | Quimil | | | | | X | |
| <i>Prosopis elata</i> | Algarrobbillo | X | X | | X | | |
| <i>Prosopis ruscifolia</i> | Vinal | | X | X | | | X |
| <i>Prosopis sericantha</i> | Barba de tigre | X | X | | | | |
| <i>Ruprechtia triflora</i> | Duraznillo | X | X | | | | |
| <i>Schinopsis lorentzii</i> | Quebracho colorado | X | | | | | |
| <i>Stetsonia coryne</i> | Cardón | X | | X | X | X | X |
| <i>Tabebuia nodosa</i> | Palo cruz | X | X | X | | X | X |
| <i>Zizyphus mistol</i> | Mistol | | | X | | | X |

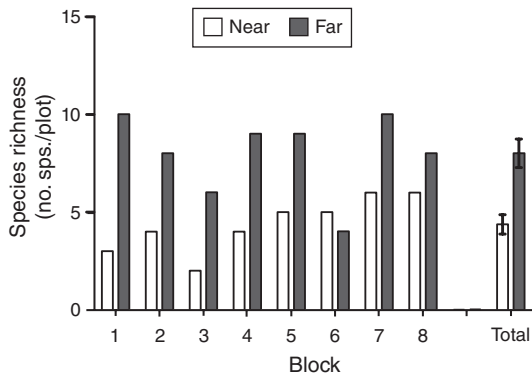


Fig. 2. Species richness per plot (2 m × 50 m) in relation to both distances to the water source (near and far) in different blocks (1–8), and mean values per plot ± 1 s.e. (Total) in the northern edge of the Finca el Paraíso, Salta, Argentina.

source ($|\bar{d}| = 167.5$ adult trees/ha; s.d._(dif) = 173.3 adult trees/ha; $T = -2.73$; $P = 0.0292$; Fig. 4c). On the contrary, both near and far sectors were similar in terms of basal area ($|\bar{d}| = 1.44$ m²/ha; s.d._(dif) = 9.79 m²/ha; $T = 0.42$; $P = 0.6892$; Fig. 4d). The proportions of ground cover categories were different between both distances ($X^2 = 42.97$; d.f. = 5; $P < 0.0001$). Near the water sources bare soil was higher and cover of dicots and Bromeliaceae was lower than areas far away from water source (Fig. 5). Finally, sectors near the water source had a higher percentage of spatial associations ($|\bar{d}| = 20.56\%$; s.d._(dif) = 17.47%; $T = 3.33$; $P = 0.0126$; Fig. 6).

Discussion

The results of this study suggest a potential effect of livestock pressure on native woody vegetation, confirming both hypotheses. In comparison to areas far from the water source, sectors near the water source showed lower total and mean species richness, lower woody plant density, higher bare soil and a greater degree of tree-cacti spatial association. Species composition and basal area were similar in sites far and near the water source.

Our study contributes to fill the gap in relation to the effect of livestock – that use water sources – on dry forest vegetation. Also, we provide baseline information on a possible positive plant–plant interaction, which could be used to design strategies for forest restoration. Here, we highlight novel results regarding an unexplored field (relationships between livestock and woody plants, while simultaneously exploring positive interactions between plants) for the Chaco forest, which is being lost and degraded as a consequence of increased farming in this region (Volante *et al.* 2012; Torres *et al.* 2014; Vallejos *et al.* 2014; Núñez-Regueiro *et al.* 2015).

This work is similar to other studies on the piosphere pattern in several arid and semiarid areas of the world. In relation to species richness, we found a lower number of species in the areas near the water source, which coincides with similar results reported in Australian grasslands (Landsberg *et al.* 2003) and in dry Chaco forest (Macchi and Grau 2012). A similar pattern was found in the community of shrubs in Nama-Karoo, where species richness decreased with increasing proximity to the water source, because of the loss of local palatable species for livestock (Todd 2006). In contrast, another study in the grasslands of southern Ethiopia

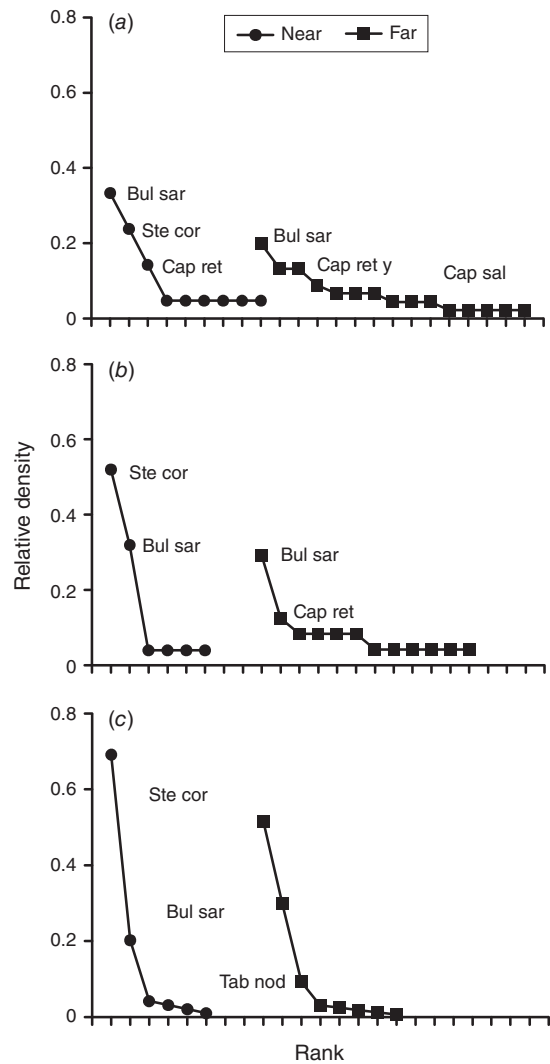


Fig. 3. Rank-abundance curves for (a) saplings, (b) adult shrubs and young trees and (c) adult trees in relation to both distances to the water source (near and far) in the northern edge of the Finca el Paraíso, Salta, Argentina. Bul sar: *Bulnesia sarmientoi*; Ste cor: *Stetsonia coryne*; Cap ret: *Capparis retusa*; Cap sal: *Capparis saliscifolia*; Tab nod: *Tabebuia nodosa*.

found that the richness of woody vegetation was higher in intermediate distances to water sources (Tefera *et al.* 2007).

In relation to woody species composition, our results present a unique pattern, which differs from what was found in other studies. In general, livestock changes the community composition of plants, especially affecting palatable species (Brits *et al.* 2002; Landsberg *et al.* 2003; Todd 2006). Contrary to these trends, our results indicate that grazing and trampling apparently did not affect species composition between near and far areas from the water source. The Chaco forest has a long history experiencing livestock pressures (Bucher 1987). Consumption of palatable species over a long period of time could result in a community composed of grazing-tolerant species (less palatable) regardless of the distance from the water source. This could explain why we found a similar community composition in near and far areas.

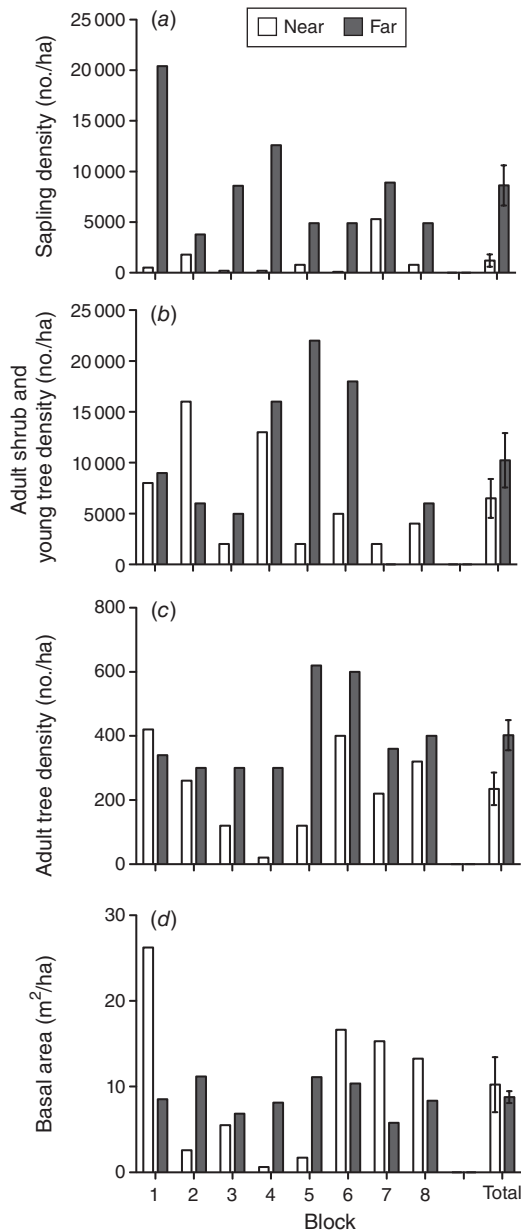


Fig. 4. (a) Density of saplings, (b) adult shrubs and young trees, (c) adult trees, and (d) basal area in relation to both distances to the water source (near and far) in different blocks (1–8), and mean values per plot ± 1 s.e. (Total) in the northern edge of the Finca el Paraíso, Salta, Argentina.

Livestock could change the abundance of woody plants at different distance from the water point, even when the composition of species remains the same. With regard to woody plants density, our results agree with Landsberg *et al.* (2003), who also showed lower densities of woody plants near the water source. It is noteworthy that our results show far lower adult tree densities near than far despite the short distance between these areas. In contrast, Tefera *et al.* (2007) indicated that the density of woody plants was similar at different distances from water source, because the strength of other disturbances was similar along the sampled gradient. When grazing is the dominant source of

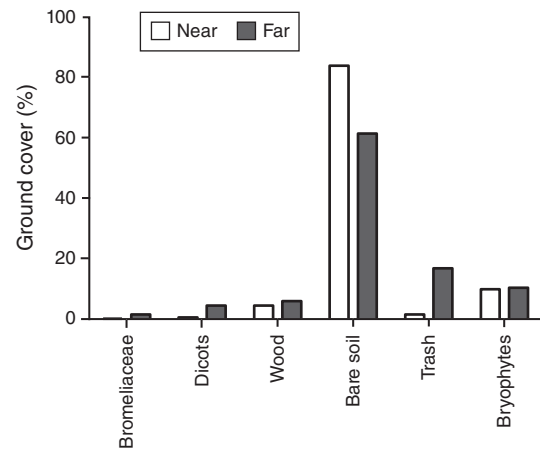


Fig. 5. Percentage of ground cover in relation to both distances to the water source (near and far), on the northern edge of the Finca el Paraíso, Salta, Argentina.

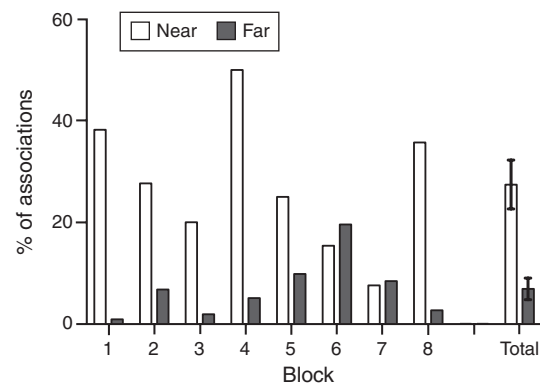


Fig. 6. Percentage of spatial associations *Stetsonia coryne* and *Bulnesia sarmientoi* for both distances from water source (near and far) in different blocks (1–8), and mean values per plot ± 1 s.e. (Total), on the northern edge of the Finca el Paraíso, Salta, Argentina.

disturbance, higher livestock pressure near a water source may be driving differences in plant density (Lange 1969). In relation to basal area (m^2/ha), we have not found differences between areas near and far from water source. These results agree with Gandiwa *et al.* (2012). They too were not able to find significant differences in basal area, except after at 2000 m from water source. Our results may be related to the density and the diameter of individuals, where although areas near water source had a lower density, individuals had a higher stem diameter. One explanation could be related to resources availability and grazing tolerance (Gao *et al.* 2008). In sites near the water source, with less plant density, plants may have more resource availability (space, light) and probably experience lower competition pressures. As a result, fewer established plants can grow faster than plants located far away from the water source (higher plant density, less resources availability, and more competition). In agreement with our results Macchi and Grau (2012) measured diameter at breast height and found decreased diameter at breast height at greater distance from the water source.

Forest regeneration is a critical aspect in grazing ecology, and we found higher sapling density in areas far from the water source. In sectors with high livestock pressure (close to the water source), regeneration of trees was lower than in areas with low stocking rates (far from the water source). In the dry Chaco, the use of a traditional livestock managing system with high stocking rates may be the main factor that inhibits installation of tree saplings, because livestock can graze directly and trample over newly germinated seedlings (Saravia Toledo 1988). In forests, ungulates tend to consume young plants and therefore may affect community dynamics, changing the species composition of the future canopy (Augustine and McNaughton 1998). In addition, the effect of higher trampling in areas near the water source can have a negative impact on the survival of saplings of woody species, favouring the growth of herbaceous vegetation (Brits *et al.* 2002).

Ground cover also changed, as seen by the proportion of bare soil that was higher near the water source in comparison to areas far away from the water source. This is consistent with results reported by Landsberg *et al.* (2003) and Guevara *et al.* (2006), where the proportion of bare soil tended to increase with the proximity to the water source. In our study we found differences in *Bromeliaceae* (one category of ground cover) between near and far areas. This differs with the results obtained by Landsberg *et al.* (2003) where the shrub cover did not vary significantly with distance from the water source. In contrast, other studies demonstrated the dominance of grass cover in highly disturbed areas near from water source (Todd 2006). Usually, presence of species resistant to grazing and trampling by livestock tend to increase near water sources, whereas the amount of more sensitive species tend to decrease (Guevara *et al.* 2006), which is an aspect that could be addressed in future studies.

Finally, in this arid environment with domestic livestock grazing, tree saplings may be protected against the effects of grazing by associating with thorny plants, which could be a regeneration strategy for some tree species like *B. sarmientoi*. Additionally, this positive effect was more marked in sectors with higher herbivory pressure. Surprisingly, despite a large literature on grazing refuges, we have not found studies that analysed plant–plant interaction in the context of piosphere. However, compared with studies of grazing refuges, our results agree with patterns found by others. In grazed ecosystems of Swiss Jura Mountains (France and Switzerland) unpalatable plant species act as nurse plants, protecting young trees from livestock grazing (Smit *et al.* 2006, 2007). Olf *et al.* (1999) also described how the thorny bushes protected tree seedlings of large herbivores in the floodplain forests in Western Europe. Rebollo *et al.* (2002, 2005) observed that the cactus *Opuntia polycantha* provides refuge for some plant functional groups, maintaining production of inflorescences, seeds and sustaining abundance of some species sensitive to grazing. In the mountainous Chaco forests of central Córdoba, the regeneration of different tree species in the presence of exotic livestock can depend on the shelter provided by shrubs (Torres and Renison 2015, 2016). Similarly, in the semiarid Chaco forests (dominated by *Schinopsis lorentzii* and *Aspidosperma quebracho-blanco*) the regeneration of key tree species in the presence of exotic livestock might be related to the presence of shelter provided by thorny shrubs (Táalamo *et al.* 2015a, 2015b). Our study supports the hypothesis that in arid and

semiarid environments with high herbivore pressure, indirect facilitation would be a common interaction between some plant species, and its effect would be more important with increasing grazing pressure (i.e. near the water source).

Here we present results from an observational study (not manipulative) and therefore the trends we report could be explained, at least in part, by factors other than livestock pressure. For example, the humidity gradient, soil differences, or different disturbance frequencies (e.g. fire) could also vary at different distance from the water source. Observational studies are abundant in the piosphere literature and have limited ability to untangle the effects of the factors mentioned above. However, such factors will likely have a weaker effect than the potential effect of livestock. It is unlikely that areas near the water source have a higher frequency of wildfires because they lack fine woody debris that could fuel a wildfire (A. Táalamo, pers. obs.). Furthermore, informal interviews with local people who live in the vicinity of the water source report that this area never experienced an intentional or wildfire. The soil and environmental humidity gradient could be an important factor, albeit only at short distances from the water source. The satellite image from our site (Fig. 1) shows a clear vegetation difference on the first 15 m from the water source in comparison with areas far from the water source. For this reason, our sampling did not consider sites located <15 m from the water source. Finally, we did not consider soil variables because the soil type remains constant throughout all our sites (A. Táalamo, pers. obs.). However, it might be interesting for future studies to explore if other soil variables, besides soil type, vary at different distances from the water source. Thus, we firmly believe that the stronger factor potentially impacting the observed trends is livestock pressure.

Although our study was conducted in only one water source, we believe that the same trends might be taking place in other similar water sources (large and permanent water) of this region. Satellite imaging can reveal the same piosphere pattern in many other water sources in the area. Thus, we strongly suggest conducting similar studies in the area, covering more water sources with the aim of getting a better understanding of the relationship between livestock and the vegetation of the region, considering other response variables such as the browsing rate.

Implications for management and conservation

The study of the piosphere provides a framework for basic ecological research, as well as for rangeland management (Andrew 1988). The dry Chaco forest provides food and fuel resources to indigenous and peasant families that rely on the many sources grouped surrounding water where cattle focus, exerting a piosphere pattern (Macchi and Grau 2012). Understanding how woody plant communities respond in forested lands that are managed for livestock will help preserve these natural habitats and ensure continued provision of vital ecosystem services. For example, according to our study a possible management recommendation could be to reduce the livestock load or to promote the exclusion of sectors near the water source in order to allow the natural regeneration of some species. We plan to experimentally test the effectiveness of this recommendation in future studies.

In general, understanding the drivers of spatial associations in plants at the community level is essential to design restoration and management strategies for natural environments. For example on intensively grazed pastures, some managers have increased survival and growth of seedlings by transplanting seedlings of trees under natural bush nurses (Smit *et al.* 2006). Moreover, Rebollo *et al.* (2002) argued that the ecological role of cactus *O. polycantha* should be considered for management practices, acting as a nurse plant for seedlings by protecting them from herbivores. Similarly, the cactus *S. coryne* in our study site could be used as a possible tool for reforestation and management in grazed and degraded areas in this dry forest. This can be particularly important for some woody plant species that are heavily used, such as *B. sarmientoi*, which is extensively used throughout the region (Arenas and Suárez 2006; Suárez 2014). In cases where these techniques are expensive, we recommend protecting shrubs and cacti as potential nurses to promote spontaneous regenerations.

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