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Flooding effects on grassland species composition in the Azul creek basin, Argentina

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Abstract. From a hydrological point of view, the characteristic of the water behaviour in catchments so depressed as the Azul creek basin (centre of Buenos Aires province, Argentina) is water accumulation above the land surface. Thus, water on the ground does not have a single runoff direction, but moves in a disorderly, indefinite and unpredictable way. Considering that periodic floods are a typical disturbance of the region, the objective of this study is to analyse, under field conditions, the transformative effect of prolonged flooding on floristic composition, taking into account the different vegetation patches and their relative position over the relief, the chemical characteristics and the groundwater fluctuation, and some edaphic properties in each site.

Vegetation samplings were performed during three consecutive springs, when the grassland was on different hydrological conditions due to very different rainfall precedent histories. A digital terrain model of the study area was built and a flow accumulation map was created from it. Pits were dug to describe edaphic variables and shallow wells were drilled for monitoring the groundwater characteristics. Flooding, in relation with surface and groundwater dynamics and soil characteristics, is the factor that determines and promotes the differentiation among sites that are relatively close, contiguous and even topographically in almost identical positions. So, some patches of vegetation get their differentiation through the limiting conditions of their soils, while others receive greater influence from the hydrodynamics to which they are subject. Thus, in this study it becomes evident how certain stands are floristically homogenised or differentiated over time according to their flooding conditions and, hence, according to the area from which they receive surface and groundwater flow. Also, results corroborate the way the water regime determines the structure and heterogeneity of plant communities in such environments.

Additional keywords: grasslands, floodplain ecosystems, plant spatial patterns, vegetation dynamics.

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Introduction

The southern cone of South America is covered by over 100 million hectares of temperate grasslands, which are surrounding the de la Plata river and its vast watershed (Herrera *et al.* 2014). Within this area, the Flooding Pampas occupy ~9 million hectares in Buenos Aires province, Argentina. This region is a wide aggradational plain located to the north-east of the Tandilia hills, and it is part of the tectonic basin of the Salado river. Its landscape is extremely flat, with regional slopes close to 0.5% on the footslopes up to scarcely 0.025% near the watercourse of the Salado river (Tricart 1973).

The raising of livestock has been the main activity in the Argentine Flooding Pampas. During the last three decades the area of land devoted to crops has experienced a strong increase in the Argentine Pampas in general (Manuel-Navarrete *et al.* 2009; Bilello *et al.* 2010). This implied a reduction in the grasslands area due to the cultivation of lands suitable for occasional crops. Because flooding is a disturbance of variable frequency in this region, and may imply an additional reduction of the livestock rising area, it is important to go into detail about the role of water as a modeller of the dynamics of plant communities with strategic importance for this region of South America.

Periodically important floods occur in the area and they evidence the most significant behaviour of water in plains, which is accumulation and very slow movement as sheet flow. This is a consequence of the low morphological energy content of this hydrological system, due to the low regional slopes (Kovács 1983). Given a rainfall, the mild slope surface does not promote runoff to relatively lower areas, and a large accumulation of water in depressions occurs. Water remains for long periods on the surface with high chances to infiltrate and evapotranspirate, and these processes are closely related to water content in soil. The relative increased infiltration causes groundwater levels to be very close to the surface, connected to the air phase by materials of relatively fine texture (sandy loam, clayey silt), which determines the presence of a powerful capillary fringe (Usunoff *et al*. 1999). Most of the water (85–90%) is discharged by evapotranspiration, which is very difficult to estimate with precision (Varni and Usunoff 1999). Therefore, substantial uncertainties arise whenever a basin or a soil water budget is estimated.

These soils have surface and/or subsurface alkalinity and show the presence of calcrete, a hard carbonate crust of variable depth and continuity, between 0.5 and 1 m depth, locally known as ‘tosca’. Drainage conditions are poor, related to the low slopes and to the presence of a frequently shallow watertable. According to their properties these lands, in general, are suitable for grazing, and in some cases for cultivated crops. Soils have an intimately mixed spatial arrangement, and the main mapping soil unit in this region is the soil complex (Imbellone *et al.* 2010). In this regard, the grasslands of the Flooding Pampas, show a heterogeneous physiognomy, in relation with the spatial variability of geomorphology, topography, soils or water storage (Martín *et al*. 2007), and constitutes a mosaic of plant communities (Burkart *et al*. 1990). Perelman *et al*. (2001) synthetised the floristic heterogeneity, and defined five vegetation units for this area: I-mesophytic meadows; II-humid mesophytic meadows; III-humid prairies; IV-halophytic steppes and V-humid halophytic steppes. These communities may be considered ‘water-controlled ecosystems’ in which plants play a special role in water use (Rodríguez-Iturbe *et al*. 2001), and flooding is a prolonged phenomenon that shapes the community structure. The influence of flooding on plant communities has been analysed in other regions of the world (Holberg and Bischoff 1980; Jackson and Drew 1984; Pezeshki 1994; Maltchik *et al*. 2007; Gerard *et al*. 2008; Reid *et al*. 2011) and also in the Argentine Flooding Pampas (Chaneton and Facelli 1991; Insausti *et al*. 1995; Insausti 1996), where some studies have been carried out focussed on the dynamics of a particular species of plant (Insausti and Soriano 1987), a certain group of plant communities (Insausti and Soriano 1987; Chaneton *et al.* 1988; León and Burkart 1998), or using a mesocosm experimental approach (Insausti *et al.* 2005; Striker *et al.* 2011). However, studies which consider the effect of this natural disturbance on the dynamics of specific vegetation patches simultaneously *in situ*, together with the analysis of hydrological variables (groundwater depth, surface water accumulation) and physical and chemical soil properties, are not frequently carried out. Thus, considering that periodic floods are a typical disturbance of this region, the objective of this study is to analyse, under field conditions, the transformative effect of prolonged flooding on floristic composition, taking into account the different vegetation patches and their relative position over the relief, the chemical characteristics and the groundwater fluctuation, and some edaphic properties in each site.

Changes in plant communities’ composition in response to disturbances may result in changes of grassland nutritional value. In the same sense, Leauthaud *et al*. (2014) said that regular flooding is a critical property in maintaining the grassland productivity and resulting services. Thus, the results of this manuscript may help to improve the management of this natural ecosystem. In addition, this study may contribute to value vegetation heterogeneity as an important management tool, often not recognised by livestock producers or agronomists (Oesterheld *et al.* 2005).

Materials and methods

The study was carried out in a parcel of ~0.7 km^2 that belongs to a livestock property located 20 km from Azul city, in the plain environment of the Azul Creek basin that is located in the central area of Buenos Aires province (Fig. 1). It is a floodplain rangeland with vegetation patches dominated by *Distichlis spicata* (L.) Greene var. *spicata* (A), *Paspalum dilatatum* Poir. subsp. *dilatatum* (B) and *Nassella formicarum* (Delile) Barkworth (C) that were considered as vegetation stands. Based on the phytosociological analyses of Burkart *et al*. (1990, 1998) and Perelman *et al*. (2001), our stand A may be considered a halophytic steppe (small depressions in flat areas with alkaline soils and high proportion of bare soil), stand B a humid mesophytic meadow (flat areas in intermediate topographic position), and stand C a humid prairie (lowlands, subjected to frequent flooding).

To take the vegetation samples, a frame of 4 m^2 was defined based on the concept of minimum area of the community (Matteucci and Colma 1982). Then, the specimens were determined using a stereoscopic microscope (Olympus SZH10) and traditional literature (Cabrera 1963–1970; Burkart 1969–2005; Correa 1969–1999) at the Laboratory of Systematic Botany (Facultad de Agronomía, Universidad Nacional del Centro de la Provincia de Buenos Aires). The scientific nomenclature was updated according to the Catalogue of Vascular Plants of the Southern Cone (Zuloaga and Morrone 1996, 1999; Zuloaga *et al*. 1994, 2008). During samplings, plant specimens were specifically extracted to be preserved at the Herbarium of the Facultad de Agronomía (acronym FAA under Index Herbarium).

Samplings were performed in the centre of each kind of patch during the second week of December 2012, 2013 and 2014, when the grassland was on different hydrological conditions due to very different rainfall precedent conditions: the total rainfall occurred the previous year to each of those dates was 1312, 645 and 1142 mm, respectively. The mean annual rainfall is 914 mm (1901–2014) at the Azul-Aero station that belongs to the Servicio Meteorológico Nacional, ~20 km away. Therefore, the year before the first vegetation control can be described as very humid, the next as dry, whereas the third year was relatively wet.

In order to analyse the similarity between the stands, the Sørensen coefficient (Sørensen 1957) was estimated.

$$\mathrm{SS} = 2\mathrm{a}/(2\mathrm{a} + \mathrm{b} + \mathrm{c}) \qquad (1)$$

where SS is the Sørensen similarity coefficient, a is the number of species common to both samples, b is the number of species

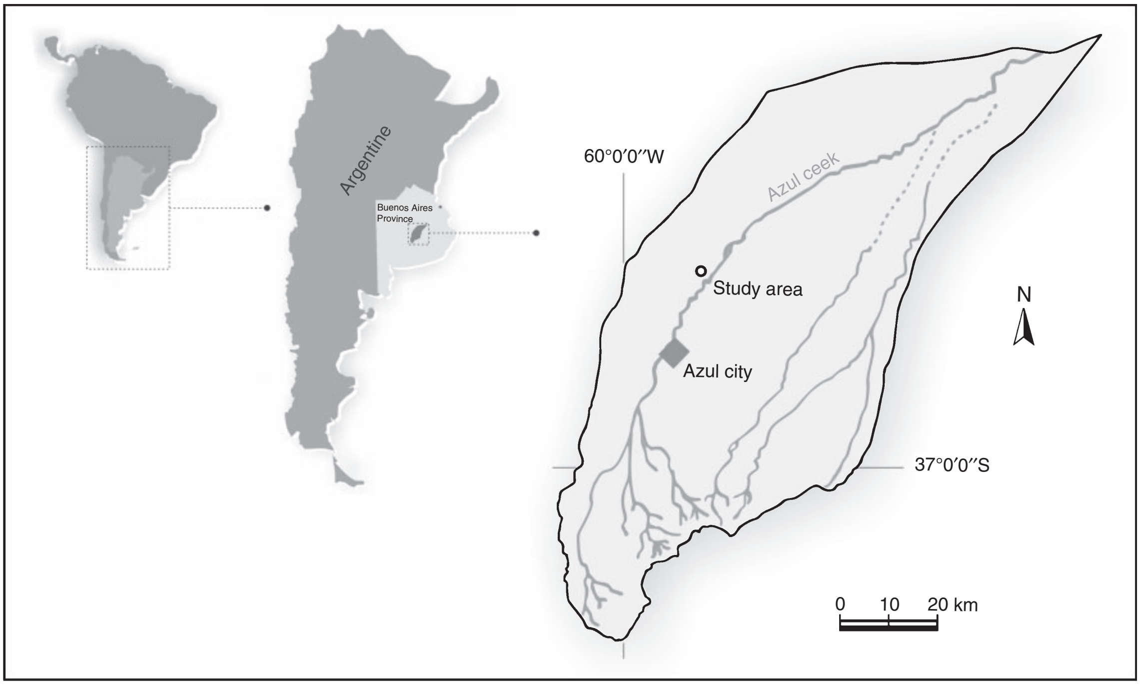

Fig. 1. Relative location of the Azul Creek basin in the Buenos Aires Province and Argentina.

unique to the first sample, and c is the number of species unique to the second sample.

Simultaneously, a digital terrain model of the study area was built from a set of points ($n = 139$) taken with a GPS ProMark 3 working in a dynamic way and a surface water flow accumulation map was created from it using a tool provided by the open geographic information system ILWIS 3.7.1 (52 North 2010). The Flow accumulation operation uses the output map of the Flow direction operation, and the resulting map contains cumulative hydrologic flow values that represent the number of input pixels which contribute any water to the outlets (or sinks if these have not been removed). At the same time as the registration of the terrain elevation using a GPS was taken, a vegetation stand (A, B or C) was assigned to each point to analyse the relationship between the presence of a particular stand of vegetation somewhere and the hydrological characteristics of the site. The flow accumulation and height values were plotted in boxplots. The Kruskal–Wallis test and multiple comparisons of mean ranks for all groups (Siegel and Castellan 1988) were performed to identify significant differences in flow accumulation and height between the stands.

Edaphic variables were analysed by digging pits in each study site (especially those that limit infiltration): the thickness of B horizon and the depth of the soil profile to the calcrete layer (‘tosca’). Besides, soil samples of B horizon were taken to determine pH and electrical conductivity (EC) in the laboratory. It was considered that these four variables may evidence some hydrologic (e.g. water percolation facility) and chemical soil properties that determine the propitious conditions for growth and development of plant communities. B horizon’s pH was measured in a suspension of soil and water, according to Thomas (1996). The EC was measured in a saturated soil paste (Rhoades 1996).

As regards the control of the watertable level and groundwater sampling, shallow wells (4–5 m of depth) were drilled in the same sites where vegetation was observed. Approximately on a monthly basis, watertable depth was measured. A chemical analysis of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-} and HCO_3^{-}) was carried out by standard methods (APHA 2005). The analytical results were subject to several tests in order to minimise errors in the mass balance.

Results

A total of 88 different species were identified in all of the sampling dates (52 in 2012, 51 in 2013 and 56 in 2014), and only 23 species (26%) were common to the three situations. Like any typical natural grassland growing in the Flooding Pampa of Argentina, it is dominated by species of Poaceae (40%) and Asteraceae (15%) families. It is also important to emphasise that native species maintained their prominence in these grasslands, as they represented over 75% of the species found at every opportunity.

Figure 2 shows the representation of different samplings of the stands in the first two coordinates of a non-metric multidimensional scaling using the Sørensen similarity coefficient (the algorithm used is based on the proposal of Taguchi and Oono 2005). Stands A are the most similar to each other and at the same time, they are the most different from the other two types of stands. Furthermore, when comparing stands for each sampling time, the stands corresponding to sampling 2012 are the most different from the others.

The components of grassland were also analysed taking into account two functional groups, graminoids and dicots (based on the difference in the leaf angle insertion and the architecture of

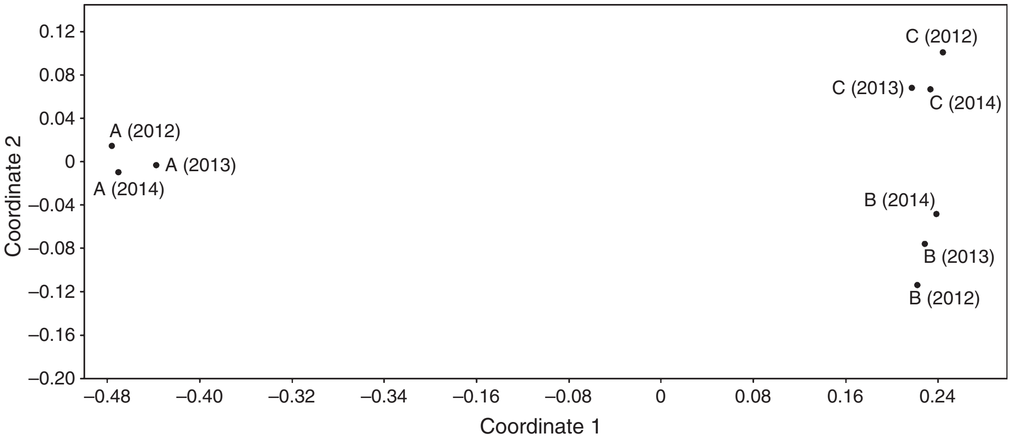

Fig. 2. Representation of the different samplings of the stands in the first two coordinates of a non-metric multidimensional scaling using the Sørensen similarity.

Table 1. Total number of species and proportion of functional groups in each sampling

		2012			2013			2013	
	A	B	C	A	B	C	A	B	C
Total number of species	10	25	27	14	31	22	16	29	25
Graminoids (%)	50.0	72.0	63.0	64.3	51.6	54.6	68.8	44.8	44.0
Dicots (%)	50.0	28.0	37.0	35.8	48.4	45.4	31.2	55.2	56.0

the canopy) because there is clear evidence that floods affect them differently (Insausti and Soriano 1987; Insausti *et al.* 2005). In this regard, it is noticeable how the percentage of plant species in the graminoids group is much higher than in the dicots during sampling 2012 when the grassland was flooded, whereas in other cases the percentages were distributed almost evenly between both functional groups (Table 1).

When analysing the percentage of species according to their exclusive occurrence in a given stand, a pair of stands, or in all the stands simultaneously, it is noted that during sampling of 2012, 83% were species that occurred exclusively in stand A, B or C, whereas in the other two samplings this percentage decreased, that is, the number of shared species between patches of vegetation increased (the grassland tended to be more homogeneous). Furthermore, when comparing the flora belonging to each particular stand (consisting of 20 species in A, 52 in B, and 43 in C) it is notorious that along the three sampled springs, 40% of the species in stand A are repeated over time, whereas B and C only maintain constant 17% and 19% of their species, respectively.

Based on the assumption that water is the modelling agent of the structure of the plant community of these landscapes, the relationship between each vegetation stand and its elevation in the field and the accumulation of surface flow at each sampled point was analysed. Because of the subtle nature of the relief, no significant differences were found among the positions that different stands of vegetation occupy over the ground. However, it is clear that, when these stands are analysed according to the superficial water supply area (through the accumulation of the surface flow) differences arise between them. Fig. 3 shows the box plot graph for flow accumulation relating to each stand. Significant differences were found between the flow accumulation of stands A and C, and B and C ($P < 0.05$).

That may explain why in times of prolonged flooding, the stands get to be different from one another and increase the percentage of species that appear exclusively in each one. This is especially evident between stands B and C, because in conditions of prolonged flooding (sampling 2012) hydrophytic species (*Marsilea ancylopoda* A. Braun; *Cyperus corymbosus* Rottb.; *Eleocharis bonariensis* Nees. and *Juncus pallescens* Lam. var. *pallescens*, for example) are those that appear in this last stand which accumulates surface water.

With regard to the soil variables considered in this study, stand A had the highest pH and EC values of B horizon, the thinnest B horizon and the lowest depth to the calcrete layer (Table 2). Regarding stands B and C, the pH showed the same value, whereas the EC had a difference of $31\ \mu S\ cm^{-1}$ between the stands. The thickness of B horizon showed similar values in both stands, but, in contrast, the calcrete layer was deeper in stand B than in stand C. According to the pH and EC values, B horizons of the three stands may be classified as sodic. The presence of sodium causes expansion and dispersion of clay particles, which alters pore geometry, and, as a consequence, reduces soil permeability (Brady and Weil 2008; Imbellone *et al.* 2010).

Over the 3 years of sampling, the mean groundwater depth at stand A was 1.01 m, 1.19 m in B, and 0.99 in C. The depths are similar, but we must say that the 20 cm deeper at stand B is because, in this plain relief context, this area acts as a groundwater recharge predominant area, that is, with mainly downward vertical flow in the unsaturated zone. It is easy to see that given the small depths of groundwater level and the fine-textured soils (Varni *et al*. 1999), the capillary fringe rises to almost the ground surface, which is additional contribution to the roots of the vegetation. Fig. 4 shows the temporal evolution of the groundwater depth in each stand.

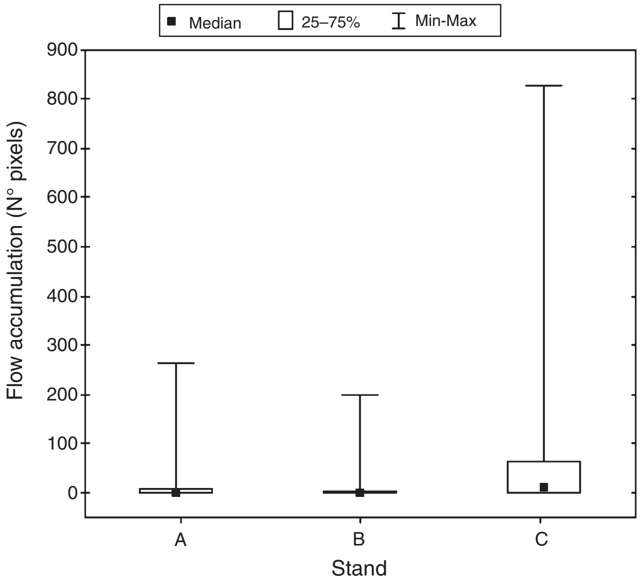

Fig. 3. Box plot for flow accumulation relating to each stand (different letters indicate significant differences between stands, $P < 0.05$).

Table 2. Edaphic variables: pH, electrical conductivity (EC, μS cm^{-1}), thickness of the B horizon (cm), and depth to the calcrete layer (cm) for the stands A, B and C

Soil variable	Stand A	Stand B	Stand C
pH	9.7	8.8	8.8
EC	2016.7	348.5	379.5
Thickness of B horizon	25	45	40
Depth to the calcrete layer	40	100	65

The highest groundwater levels occurred in 2012 (0.64, 0.775 and 0.63 m for stands A, B and C), which has the highest daily precipitation for the 15 previous days to vegetation sampling (7.47 mm). During 2013 the levels were deeper (1.433, 1.6 and 1.534 m for stands A, B and C) and the previous daily precipitation was lower (1.27 mm), whereas in 2014 both groundwater levels and previous rainfall were between the values of the other 2 years (0.913, 1.061 and 0.93 m for stands A, B and C; 3.67 mm, respectively).

Major ions, EC and pH of the groundwater on the three stands are shown in Table 3. Stand A is characterised by the most saline and sodic groundwater, whereas stand C has the lowest salinity groundwater. In vegetation patches like stand A, salinity is not given by dilution-concentration processes, but by high salt content in the soil profile of these sites.

Discussion

As it was proposed several decades ago, vegetation is structurally dynamic, and dynamics is, in part, initiated by natural disturbances (White 1979). These grasslands are periodically subject to flooding events with a particular regime, and this phenomenon may be considered a disturbance process that influences directly on the structure of plant communities. This study demonstrates, on the one hand, that the graminoids and native species seem to be evolutionarily more prepared to deal with these typical disturbances of the grasslands (issue previously tested by other authors). In addition, it becomes evident how vegetation patches that are floristically homogeneous in a certain time, may become different in another one, according to the conditions of flooding that they suffer. In environments so depressed like these, flooding conditions are more feasible to be recognised through a flow accumulation map than from a digital terrain model. Consequently the responses of each kind of vegetation stand are more related to their surface and groundwater contributing area than to the topographical position they occupy.

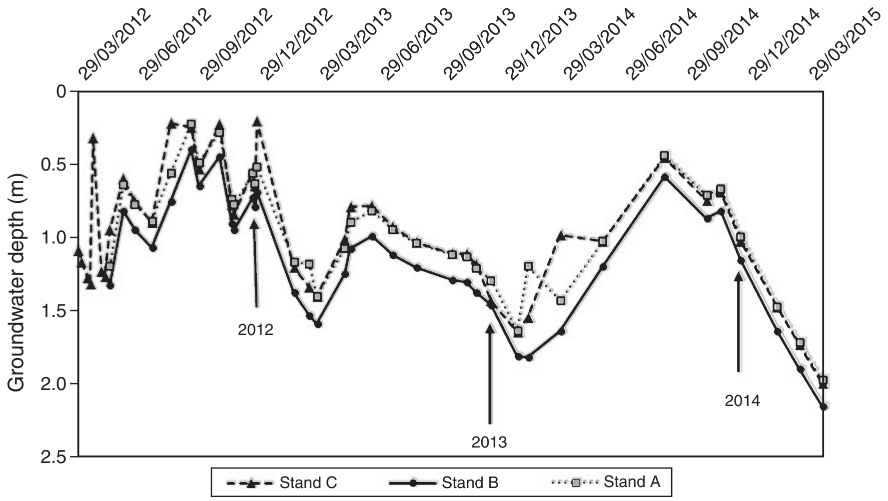

Fig. 4. Temporal evolution of the groundwater depth in each stand (arrows indicate the samplings dates).

Table 3. Major ions concentration (mg L^{-1}), electrical conductivity (EC) (μS cm^{-1}) and pH of the groundwater on the three stands

Stand	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	CO_3^{2-}	HCO_3^{-}	EC	pH
A	20.4	2.78	216.7	8.56	34.4	42.2	0	590.5	950	8.06
B	51.3	19.81	110.2	7.75	24.8	36.4	0	466.2	751	7.58
C	32.8	7.60	77.6	7.69	4.4	11.8	0	337.6	477	7.60

These grasslands that are apparently so homogeneous actually possess a great internal heterogeneity, which is displayed by the physiognomy given by the different communities and that is the result of soil–water–vegetation interaction. This mosaic consists of patches of vegetation that are expressions of several key conditions.

In this way, stand A seems to be a consequence specifically of soil limitations (poor soil cover, greater evaporation – salt concentration, higher pH and EC values, thinner B horizon, lowest depth to the calcrete layer) so the plant community is highly specialised in these limiting conditions. In fact, these stands are the ones that deeply differ about their botanic composition from the remaining stands. Moreover, those soil characteristics are constant over time and, therefore, so is the botanical composition (40% of species remain constant over the three samplings). Groundwater in these sites reflects what happens on the soil, as it shows the highest salt concentration. From the hydrological point of view, it is an area of combined recharge-discharge of groundwater, with predominance of discharge (upward flux through capillary fringe that supply water for direct evaporation).

Stands B and C, in turn, develop into sites that share, in general, their soil properties but differ with regard to their ability to receive water from neighbouring sites. Stand B works as a recharge site where rainwater falls, infiltrates and percolates faster comparatively to the other stands. Stand C develops on sites that have a big surface water contribution area, which added to the rainwater that falls directly on them, receive a large supply of water that infiltrates into a less developed profile, with a calcrete layer at 65 cm depth. This layer has high microporosity, which reduces water percolation velocity. Moreover, in comparison with stand B, this layer is nearer to the surface, and, therefore, this site has lower storage capacity. In addition, stand C works as a groundwater discharge site. Consequently, water stays during a longer period of time in this stand, and leads to groundwater dilution. Thus, under flooded conditions, both stands are clearly differentiated and therefore they differ in their botanical composition (a greater number of hydrophytes in stand C than in B).

Trying to describe these grasslands dynamics without recognising the modelling role of water in the conformation of the mosaic of plant communities is as useless as trying to understand the water cycle in these systems without regarding vegetation as an indicator factor of all these processes.

As many authors have remarked, flooding constitutes an essential part of the system that would be appropriate to be considered as a driving force (White 1979; Vogl 1980; Rapport *et al*. 1985; Chaneton *et al*. 1988) and a key driver of the ecological balance of riparian and wetland ecosystems (Insausti *et al*. 1999; Kuppel *et al*. 2015). But the results of this work corroborate that in these particular grasslands of the Flooding Pampas, where an intricate mosaic of different vegetation patches exists, the way water dynamics determines the structure and heterogeneity of plant communities is very particular. Flooding, in relation with surface and groundwater dynamics and soil characteristics, is the factor that determines and promotes the differentiation among sites that are relatively close, contiguous and even topographically in almost identical positions.

In these water-controlled ecosystems, vegetation is the biotic component of the landscape that best represents the interactions between the complex matrix of environmental factors and the information and energy subsidies incorporated by anthropic intervention. It is necessary to deepen research related to the causes of vegetation patterns, aspect that would simplify the studies of land evaluation and productive capacity of vegetation systems. In landscapes affected by prolonged flooding, their structure, functioning and dynamics interact in a complex way with technological resources, influencing the responses to their intervention. That is why we believe that in this particular case knowing the responses of natural grasslands to floods will provide criteria for the adoption of livestock practices based on the appreciation of the internal heterogeneity of these ecosystems.

Conclusions

Vegetation patches that are floristically homogeneous at a certain time may become different in another time, according to the conditions of flooding they suffer. The responses of each kind of vegetation stand are more related to its surface and groundwater contributing area than to the topographical position it occupies. Some patches of vegetation get their particularities through the characteristics of the soils, whereas others receive greater influence from the hydrodynamics to which they are subject. In grasslands that are periodically subject to flooding events, with an intricate mosaic of plant communities, it is evident that their structure can only be understood through the analysis of the plant–soil–water interaction.

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