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Gradients of soil salinity and moisture, and plant distribution, in a Mediterranean semiarid saline watershed: a model of soil–plant relationships for contributing to the management

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ABSTRACT

This study reports the soil–plant relationships within a protected landscape in semiarid SE Spain that includes salt marshes and temporary streams and that is affected by agricultural water leaching. The main objective was to establish a conceptual model in order to use vegetation as bioindicator of soil conditions. With this model, environmental changes – based on the observation of vegetation – could be detectable, allowing the prevention of environmental impacts and the improvement of the environmental management of the studied area. Eight sampling stations with a total of 39 plots were established for the sampling of vegetation (floristic composition and species abundance) and soil (moisture, pH, redox potential, electrical conductivity and soluble ions). Multivariate analysis showed that vegetation was closely related to soil moisture and salinity. The soils colonised by steppe grasses (dominated by *Lygeum spartum*) and halophilus and halonitrophilus shrubs (dominated by *Suaeda vera* and *Limonium* spp.) were the driest (moisture < ~20%) and least saline (EC < ~30 dS m^{-1}). *Phragmites australis*, *Sarcocornia fruticosa* and *Arthrocnemum macrostachyum* dominated in the most saline and wettest soils. *P. australis* reached maximum cover at EC values ~40 dS m^{-1} and soil moisture ~30% and consistently appeared on those soils with lower seasonal contrasts of moisture and salinity. Between 30 and 80 dS m^{-1} of soil salinity, *S. fruticosa* reached maximum cover (~100%) while *A. macrostachyum* did not exceed ~80%. Outside this range of salinity *S. fruticosa* declined (cover <10%), while the other species maintained cover > ~40%. In addition, *A. macrostachyum* grew in soils with stronger seasonal changes of moisture and salinity. Based on the model established, if an expansion of *P. australis* is detected, an increase in soil moisture and a decrease in soil salinity during the year could be inferred. These changes could be due to an increased entry of effluents of fresh and/or brackish water from agricultural areas. In turn, an increase in the cover of *A. macrostachyum* would indicate higher soil salinity, which could be a consequence of an increase in the evaporation rates (due to rising temperatures) and a decrease in rainfall (predicted consequences of global warming). The expansion of *S. fruticosa* would be favoured under relatively high soil salinity conditions (which limit *P. australis* expansion) jointly with high soil moisture, without strong seasonal changes (which limit *A. macrostachyum* expansion). Our results support the role of vegetation as bioindicator of disturbances and the use of soil–plant relationships models to improve the environmental management of saline ecosystems.

1. Introduction

Wetlands are among the landscapes and ecosystems most endangered on a worldwide scale due to urban, agricultural and industrial activities (IPCC, 2007). However, these environments host specifically adapted species and hence are hot-spots for biodiversity conservation (Ramsar, 2007). In addition, wetlands have an important role in the preservation of environmental quality due to their high capacity for retention and/or inactivation of harmful substances (Mitsch and Gosselink, 2007) and for carbon sequestration (Reddy and DeLaune, 2008). Denitrification, oxidation-reduction reactions, adsorption onto soil particles, absorption by vegetation and others are processes implicated in the capacity of wetlands to remove pollutants (Reddy and DeLaune, 2008). All these functions depend, ultimately, on the correct management and preservation of the soil–water–plant system and, therefore, studies involving soil–plant relationships might contribute to the improvement of management practices.

In wetlands there is a close relationship between the vegetation and the soil and water conditions. Numerous studies have reported

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relationships between plant communities and elevation, moisture and salinity (e.g. Piernik, 2012). In fact, the identification of plant communities is a classical tool for mapping and classifying wetlands (Tiner, 1999). Plant distribution responds to changes in the soil–water conditions and hence monitoring of vegetation has been proposed as an effective tool to detect environmental impacts in wetlands (Álvarez-Rogel et al., 2006). Nutrient enrichment, desiccation and grazing are among the disturbances affecting wetlands which have been studied most (e.g. Odland and del Moral, 2002).

Changes in land use have important consequences for natural resources and are key aspects in the context of global change, affecting biodiversity (Sala et al., 2000) and contributing to global warming (Foley et al., 2005). Habitat fragmentation is one of the main threats to wetlands in areas with high human pressure (Mitsch and Gosselink, 2007). Hence, studies including quantitative and qualitative environmental data of these habitats are needed if they are to be restored and preserved.

An important aspect in the design of monitoring programmes is that they must be based on useful, simple indicators from a practical viewpoint, for local management purposes (Hellawell, 1986). Thus, indicators that are easily observable and/or measurable must be identified (Finlayson, 1996) in order to relate them to plant distribution on a local scale. In this context, the elaboration of models relating plant distribution and soil conditions can help to detect environmental impacts; hence, governmental administrations might implement management strategies with the objective of better conservation of the environment. If the capacity for detecting the impacts is improved, the amount of funds invested in restoration can be decreased and the conservation of these ecosystems improved.

This paper reports the results of a study in which plant distribution was related to soil conditions in an inland watershed with a complex system of temporary streams and saline wetlands (e.g. salt marshes), within a protected landscape in semiarid SE Spain. The aims of the study were: (1) to identify key species representative of the different vegetation groups/plant communities of the zone; (2) to identify the relationships between soil moisture and salinity and plant zonation in the zone; and (3) to establish a conceptual model to describe the relationships between soil conditions (moisture and salinity) and the main plant communities, in order to use vegetation as bioindicator of soil conditions. With this model, environmental changes – based on the observation of vegetation – could be detectable, allowing the prevention of environmental impacts and contributing to the management and conservation of this protected landscape.

2. Material and methods

2.1. Site description

The study site was the protected landscape of Ajauque-Rambla Salada (16.32 km^2), located in the sedimentary basin of Fortuna (Murcia Region, SE Spain) (Fig. S1). The area presents an irregular topography with gullies and slopes. The bottom of the gullies is occupied by temporary streams called "ramblas" (Gómez et al., 2005). A recent review has highlighted the important value of these streams and the associated environments (Millán et al., 2011). When the gullies open, flat zones appear that suffer flooding due to the overflow of the streams during events of heavy rain (Photograph S1). Two main, temporary streams cross the protected landscape: Rambla de Ajauque and Rambla Salada. The geological materials are halite-rich sedimentary marls of Miocene and Triassic origin. The most abundant soils of the zone were classified by Álvarez-Rogel et al. (2001b) as Gypsiric Hyposalic Regosols, Hypogypsid Hyposodic Gypsisols and Hypergypsic Gleyic Solonchacks, according to FAO-ISRIC-ISSS (1998), or Sodic Haplogypsids, Gypsid Aquisalids and Gypsic Haplosalids, according to Soil Survey Staff (1999).

The area is characterised by a semiarid Mediterranean climate with an annual mean precipitation of 250–350 mm, mainly concentrated in spring and autumn and with high inter-annual variability. The annual mean evapotranspiration rate is higher than 900 mm/year, with average temperatures ranging between 16 and 19 °C and long, warm, dry summers and mild winters.

The protected landscape of Ajauque–Rambla Salada is a Specially Protected Area (SPA) under the EU Wild Birds Directive and a Site of Community Importance (SCI) to be integrated into the Nature 2000 Network (EU Habitats Directive). The native vegetation of the land surrounding the zone is open Mediterranean scrub. However, many of these areas are under irrigated agricultural use that generates numerous impacts due to eutrophic water leaching (Arce et al., 2013).

2.2. Sampling stations establishment

After several field trips in the territory, eight sampling stations, distributed throughout the protected landscape, were selected (Fig. S1, Photographs S2 to S10) according the following criteria: (1) it must be representative of the physiographic variability of the zone; (2) it must have surface water flow at least in some period of the year; and (3) it must have a zonation pattern of vegetation with several plant communities (identified by the dominant species), that indicates the existence of a gradient in soil moisture and/or salinity.

Sampling station 5 (Ajauque salt marsh), having most of the vegetation groups identified in the protected landscape, was chosen for a detailed study of the seasonal gradients in soil moisture and salinity.

2.3. Collection of vegetation data

In each sampling station and according to the different plant communities recognised, a number of 4 × 4 m plots were established (39 plots in total). The number of plots in each sampling station was: seven (stations 5 and 8), six (station 2), five (stations 3 and 7), four (stations 1 and 6), and one (station 4). The floristic composition and species abundance were determined in each plot using the standard method of relevés, based on the visual estimation of species cover. The plant species were determined according to Tutin et al. (1964–1980) and Castroviejo et al. (1986–1993).

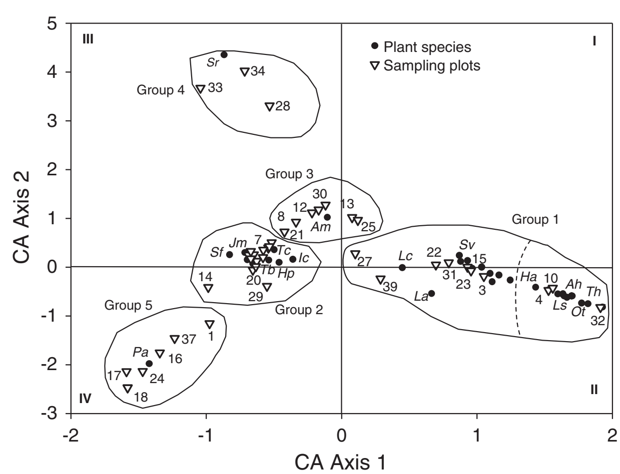

Fig. 1. Results of the Correspondence Analysis (CA) carried out with the data of the relevés taken. Cumulative percentage of variance explained by the first two axes: 86.4%. Ah: *Ananabis hispanica*, Am: *Arthrocnemum macrostachyum*, Ha: *Hammada articulata*, Hp: *Halimione portulacoides*, Ic: *Inula crithmoides*, Jm: *Juncus maritimus*, La: *Limonium angustebracteatum*, Lc: *Limonium cossonianum*, Ls: *Lygeum spartum*, Ot: *Ononis tridentata*, Pa: *Phragmites asutralis*, Sf: *Sarcocornia fruticosa*, Sr: *Salicornia ramosissina*, Sv: *Suaeda vera*, Tb: *Tamarix boveana*, Tc: *Tamarix canariensis*, Th: *Thymelaea hirsuta*.