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Research article

Effects of vegetation management on plant diversity in traditional irrigation systems

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ABSTRACT

Acequias are historical community-operated water channels used for irrigating of traditional farming areas (*vegas*). They have been traditionally managed by local inhabitants, either by clearing weeds or by burning them in winter, in order to keep the channels clean of vegetation, thus avoiding their clogging. The impact of these cultural practices on vegetation has not still been studied. The aim of this paper is to show how traditional management influences floristic biodiversity in a traditional *acequia* in the *vega* of Granada (SE Spain). The *acequia* was treated following the traditional methodology used by farmers, being divided into areas that were burned, cleared, or left unchanged as control (January 2016). Afterwards, we collected soil samples and analyzed them in the lab to determine the treatment effects on soil properties. Vegetation was monitored in late spring 2016 in order to detect differences between treatments. Traditional management increased plant diversity, this effect being much more patent for the burning than for clearing treatment. Soil analyses revealed only slight differences in pH and $CaCO_3$ content, higher for the burning treatment. The increase in plant diversity found in areas treated by traditional management was due mainly to the reduction of competition, which promoted the emergence or increase of populations of non-dominant species. The results indicated that traditional management not only offers advantages to the farmers but also promotes plant diversity and ecosystem services.

1. Introduction

Agriculture is undoubtedly the main transforming agent of the landscape (Medley et al., 1995). Over the past 50 years, patterns of agricultural expansion have led to the loss of biological diversity and ecosystem services, undermining the long-term sustainability of agricultural production. Therefore, the conservation of biodiversity should become a fundamental part of agricultural landscapes to reach global conservation goals (SCDB, 2008; Martin et al., 2014). A case in point involves the traditional *vegas* of Spain, historical agricultural areas based on smallholdings irrigated through traditional channels (*acequias*), which inoculate biodiversity and its services inside the agroecosystem (*vega*), making agricultural production more sustainable and compatible with wildlife conservation. These types of agricultural systems might be considered High Nature Value Farming (EEA, 2004), which constitute the equivalent of hotspots of biological biodiversity in rural areas, and it is often characteristic of areas dominated by extensive agriculture, as in the case of traditional *vegas,* with polyculture where different species grow together in small properties (EEA, 2004).

The irrigation is vital in many places to ensure agricultural yield and, in fact, agriculture absorbs 92% of water resources consumed by mankind (Hoekstra and Mekonnen, 2012). Among the many types of irrigation systems, the traditional *acequias* are common-property irrigation ditches with the function to carry water from the source (e.g. mountains) to the agriculture areas (floodplains or valleys), simply by gravity. They are usually constituted by a principal channel (*acequia principal* or *canal principal*), secondary branches (*ramales*), and tertiary branches (*hijuelas*), arranged like a net. They are spatially organized separating farm properties and have associated right of way, usually 1 m at both sides from the center of the channel, which cannot be invaded, plowed, built, fenced, etc., for private use. *Acequia*, a word recognized by the Royal Academy of Spanish Language, derives from the Arabic (*as-sāqiya*) and means water-bearer, irrigation canal, or conduit. Spanish settlers inherited this Roman and mainly Islamic irrigation system in southern Spain, coming from North Africa and Middle East, and later brought that technology to the Southwest of the United Stated as well as some semidry areas in Meso- and South America (Butzer et al., 2010; López, 1995; Mata and Fernández Muñoz, 2010; Raheem

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et al., 2015).

Acequias promote the development of riparian vegetation, which depends on the ecological conditions where the irrigation system is located and the disturbances caused by human management (Espín et al., 2010;Plaza and Guzmán, 2010). Moreover, they provide a series of ecosystem services frequently difficult to quantify (Fleming et al., 2014), the main ones being: landscape creation, food security through extensive agriculture, involvement in nutrient cycles, soil formation, and greater temporal extension of the irrigation season (Rivera, 2011). They also have hydrological, riparian, and agroecosystemic attributes similar to those provided by rivers (Fernald et al., 2007). In addition, they help prevent damage such as flooding, regulate return flows to rivers, and even recharge aquifers (Espín et al., 2010). Furthermore, they act as ecological corridors and provide a suitable place for nesting and breeding for bird species (Peña, 1999; López-Pomares et al., 2015). They are also important in preserving the traditional knowledge about agricultural practices and agrobiodiversity in the *vegas* (Chan et al., 2012). Therefore, *acequias* are not simple ditches that carry water but have many more implications, being currently a key element for biodiversity conservation (wild and cultivated) in these agroecosystems. Despite its importance, this agroecosystems are in danger of disappearing because of elements such as wastewater discharges, modernization of irrigation systems, waterproofing, and the loss of traditional *vegas* by urbanization. To gain the multiple benefits from this irrigation system, farmers must keep them free of excessive vegetation, which would impede the water flow (Ayllón Valle et al., 2010). For this, farmers traditionally use two methods:

1 Clearing banks (C): This treatment requires labor, more commonly practiced in former times when the debris cleared could be used to feed livestock. Traditionally, sickles were used, now replaced by weeding machines.
2 Burning banks (B):This is the predominant treatment in most of the *vegas* in SE Spain in order to save time and effort. Traditionally this is done in winter to minimize the risk of the firesspreading.

In the present work, we hypothesize that traditional management of vegetation in the *acequias* (clearing and burning), both considered a disturbance, increase floristic biodiversity. We base our hypothesis on Connell's intermediate perturbation theory (Connell, 1978), which states that intermediate levels of disturbance result in the highest biodiversity values. Biodiversity analyses in traditional *acequias* have been the target of several studies. However, these studies have been based almost exclusively on the biological (less), economic, historical, or social importance of the system, whereas the management perspective has not yet been analyzed. Therefore, our objective is to show the effects of traditional management of vegetation in the *acequias* on plant diversity and soil.

2. Material and methods

2.1. Study area

This study was conducted in the south of the *vega* of Granada (Spain). The *vega* (as called by local population) is located in the heart of the Granada province (SE Iberian Peninsula), occupying the depression formed by the river Genil and its tributaries, and bordered by mountains ranges belonging to the Betic systems (García Leal, 2014). This traditional farmland is partly defined by the presence of thousands of kilometers of *acequias* which bring water mostly from Sierra Nevada mountain to the farmlands (Guzmán and Navarro Cerrillo, 2010). This agroecosystem was established mainly by the Muslims and has been maintained for more than 1000 years. At present, the *vega* is fragmented and has lost much of its agricultural surface area due to the population growth of the city of Granada and its metropolitan area (Junta de Andalucía, 2012). Field work was carried out between winter and summer of 2016 in the "*acequia*" known as "*Ramal de Porliz"* located in the town of Gójar. The *principal acequia* conducts water coming from the Dílar river and irrigation is managed by a local farmers community (*Comunidad de Regantes de Gójar*), which has water rights since immemorial times, and a board of directors selected in general assembly is in charge of guaranteeing the sustainable use of water by the community. The study area has a Mediterranean climate with strong summer drought and annual rainfall below 600 mm, with a meanannual temperature of14 °C. The soil is classified as Calcium Cambisols with Calcareous Regosols, Calcareous Fluvisols, and Calcium Luvisols (Martínez Richart, 2015). Potential vegetation of this net of *acequias* is that concerning to the near river (Dílar), which is based on communities dominated by *Salix, Populus, Ulmus*, and *Fraxinus* tree species (*Salicetum neotrichae, Rubio tinctori-Populetum albae, Hedero helicis-Ulmetum minoris*), shrublands (*Rubo ulmifolii-Coriaretum myrtifoliae*), perennial grasslands (*Mantisalco salmanticae-Brachipodietum phoenicoides*), or megaforbs communities such as *Scrophulario auriculatae-Epilobietum hirsuti*, among others (Salazar and Valle, 2004). Principal crops in this irrigation system are currently olives and almonds. Weed control is usually carried out by tilling, clearing, or herbicide application. Plant species, when present are ruderal, mainly annual species belonging to *Gramineae, Fabaceae, Compositae*, and *Cruciferae* families, some of them being non-native species.

2.2. Experimental design

The experimental design was limited to the area between the *acequia* center and 1 m outwards to the right bank. We have considered 1 m because it is usually the space that must be preserved by farmers (both ways) to let the local water manager (*acequiero*) reach the floodgates (right of way). Such area is usually occupied by typical riparian vegetation and must be kept in good conditions by farmers to facilitate the water flow. In this area, three treatments were applied: a control (0), where plants were not removed, and two treatments based on traditional management: to burn the banks (B) and to clear banks (C). Both types of management were applied in January 2016, as the vegetation becomes more susceptible to fire after the first frost events. The treatments were applied by local farmers. Four replicates were made for each treatment (4 × 3) and each replicate measured 10 m long. Therefore, the total area of experimentation was 120 m^2. Treatment assignment to each replicate was partially random, in order to avoid fire treatments in the segment where there were olive trees near the *acequia*, avoiding damage to farmland. The treatment distribution was established as follows (east-west view): B, C, 0, C, 0, B, C, 0, B, C, 0, and B (Fig. 1).

2.3. Soil analysis

To study the effect of treatments on the soil, we sampled the soil (the uppermost 10 cm) on March, two months after treatments application, to assess differences in soil variables. For each treatment replicate, one sample was chosen (12) and subjected to a natural drying process, after which the soil sample was screened (2 mm), and one part was then milled. When the samples were ready, we assessed different soil variables. All analyses used the fine-soil fraction (< 2 mm). For the pH, exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and the cation-exchange capacity (CEC), we applied the methodology proposed by the Soil Conservation Service (1972). The calcium carbonate content ($CaCO_3$ equivalent) was analyzed following Barahona et al. (1984). For soil organic carbon (SOC), we applied the methodology proposed by Tyurin (1951). The available phosphorus was analyzed as in Olsen and Sommers (1982). The total C and N was established by an NGasAnalyser using an induction furnace for thermal conductivity (LECO TruSpec CN). All soil analyses were made at the University of Granada (Department of Soil Science), Spain.