Journal of Arid Environments 74 (2010) 1525–1533

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Soil–vegetation relationships in semi-arid Mediterranean old fields (SE Spain): Implications for management

E.M. Cañadas[a,*], M.N. Jiménez[b], F. Valle[a], E. Fernández-Ondoño[c], F. Martín-Peinado[c], F.B. Navarro[b]

[a] Departamento de Botánica, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain
[b] Grupo de Sistemas y Recursos Forestales, Área de Recursos Naturales, IFAPA Centro Camino de Purchil (Junta de Andalucía), Camino de Purchil s/no., Aptdo. 2027, 18080 Granada, Spain
[c] Departamento de Edafología y Química Agrícola, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain

ARTICLE INFO

Article history:
Received 12 December 2009
Received in revised form
14 June 2010
Accepted 14 June 2010

Keywords:
Edaphic variables
Environmental gradients
Floristic variables
Plant community
Soil salinity

ABSTRACT

In recent decades a large proportion of agricultural lands have been abandoned in European countries, mainly in semi-arid or mountain Mediterranean areas. Environmental processes in old fields have attracted the attention of many scientists, but several issues remain unanswered. This study seeks to identify the edaphic factors determining changes in perennial-plant communities in old fields of a Mediterranean semi-arid area (Baza Basin, SE Spain) and elucidate the main relationships between these communities. For this goal, we mapped all old fields in this study area and calculated the surface area occupied by each community (single and mixed). Floristic data and soil samples were collected for all the communities, through a stratified sampling, and the data were subjected to several statistical treatments (ANOVA, DCA, CCA, Spearman correlation). The joint study of floristic and edaphic variables confirmed that the soil determines mainly the establishment of vegetation in old fields of this area. Specifically, salinity, moisture, and gravel content accounted for most of the floristic variation. The results may be useful for old-field management, for example, to identify areas that should not be cultivated due to salinity or to the high ecological value.

1. Introduction

Land-use change constitutes one of the most important causes of global-change phenomena (Dunjó et al., 2003). In particular, farmland abandonment is a major land-use change in the Mediterranean region (Rey-Benayas et al., 2007). Historically, the surface area devoted to crops and pastures gradually increased until the last century, but the process has been reversed and now abandonment processes predominate (Burel and Baudry, 2002). This trend has been particularly pronounced since the 1950s (Baudry, 1991). As a result, today a large proportion of farmlands is not cultivated and is devoid of the ancestral vegetation.

In this context, farmland abandonment exerts not only environmental but also socio-economic impact. Many scientists argue that the abandonment process is causing biodiversity loss, water and soil-quality loss, increased fire risk, landscape alteration, etc. However, the consequences of farmland abandonment, analysed under different scenarios, constitute a complex issue that is not always negative (for more information see Hobbs and Cramer, 2007).

The analysis of vegetation colonizing old fields and of the plant-succession processes involved are vital in order to understand the scope of these changes, as reflected in numerous studies (Debussche et al., 1996; Pugnaire et al., 2006). Plant succession after crop abandonment begins with the spontaneous recovery of the land by plant communities, in which colonization and progress depend on local climatic conditions, soil quality, human activity, etc. (Arbelo et al., 2006). However, in semi-arid environments, plant colonization and succession is slow (Fowler, 1986). In fact, some studies confirm that perennial species that settle in old fields of semi-arid areas may remain for several decades after abandonment (e.g. Haase et al., 1997). Time since abandonment is a decisive factor to explain vegetation change in some areas, especially in early stages of the succession (Bonet, 2004). However, it has recently been shown that the time factor explains only a small proportion of compositional variation on specialized Mediterranean soils (Martínez-Duro et al., 2010). Nevertheless, the composition and the functioning of these systems are still poorly understood (Martínez-Duro et al., 2010).

The influence of environmental factors in vegetation of these areas has aroused great interest in recent decades, and there are many studies that delve into the relations between edaphic and floristic factors (Cayuela et al., 2008; Hedlund et al., 2003). These

* Corresponding author. Tel.: +34 958241000x20223; fax: +34 958243254.
E-mail address: ecanadas@ugr.es (E.M. Cañadas).

0140-1963/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaridenv.2010.06.007

studies reveal the close relationship established between plants and soil. Even in apparently homogeneous terrain, there are complex mosaics of microhabitats, many related to edaphic variations, as well as to interactions among the microtopography and climate, selective animal predation, local perturbation of the landscape, and redistribution of the nutrients by fauna and the flora itself (Grime, 1982). Furthermore, it is well known that soil heterogeneity is a basic element for competitive and/or facilitative interactions between plants, mainly in stressed environments such as semi-arid habitats (Fowler, 1986), and consequently may determine distribution patterns of plants and communities (Rubio and Escudero, 2000). However, few studies have been conducted in arid and semi-arid Mediterranean old fields (Bonet, 2004; Pugnaire et al., 2004).

In this study, we analyse how the soil influences the establishment of perennial-plant communities and the relationships between them in old fields of a semi-arid area. The study area (Baza Basin, SE Spain) is particularly apt for such research because of the high number of old fields located in areas that are quite homogeneous in terms of geology, topography, climate, and prior crops.

2. Methods

2.1. Site description

The study area (Appendix A, Supplementary material) occupies 23 992 ha of the central Baza Basin (Granada province, SE Spain). We chose this territory for the high concentration of old fields observed. Although this is still a predominantly agricultural area, many of the cultivated lands have been abandoned due to socioeconomic as well as environmental problems. The drastic population decline undergone by this territory from the 1950s to the 1970s has resulted in the cessation of farming in certain areas, but also the diversification of activities in recent decades. At present, around 20% of the population is involved in agriculture, whereas in the 1980s this figure was over 50% and in previous decades much higher still (González Moreno et al., 2007). The environmental characteristics of the area (low rainfall, extended frost period, soil salinity, etc.) also contributed to the abandonment of farmland. This process is a major issue in Mediterranean countries and other European mountain areas, in the sense that Spain, for example, has lost some 12% of its agricultural land since 1980 (CIHEAM, 2009).

From a biogeographical standpoint, the study area is in Guadiciano-Bastetano district (Baetic province) (Rivas-Martínez et al., 1997) at an altitude ranging from 670 m to 900 m. According to Rivas-Martínez et al. (2002) the area is in the Mediterranean macroclimate, Xeric-oceanic bioclimate and Mesomediterranean semi-arid bioclimatic belt. Mean annual precipitation rarely exceeds 350 mm. Winter temperatures may drop to −10 °C and exceed 40 °C in summer, with large daily fluctuations. The dominant geological substrates are gypsum-rich marls and calcareous bedrock. The native vegetation mosaic of the overall area is dominated by *Stipa tenacissima* L. steppes, and heliophilous woody scrub rich in gypsophilous species (*Ononis tridentata* L., *Helianthemum squamatum* (L.) Dum. Cours., *Gypsophila struthium* Loefl., *Lepidium subulatum* L., etc.). Endorreic zones, where salts accumulate, have halophilous shrublands dominated by *Sarcocornia fruticosa* (L.) A.J. Scott and *Arthrocnemum macrostachyum* (Moric.) K. Koch.

2.2. Cartography

Seven perennial-plant communities were determined in a previous phytosociological study on old fields in the Baza Basin (Cañadas, 2008) (see Appendix B, Supplementary material). For the present work, the abandoned farmlands in this area were mapped using ESRI ArcMap, and old fields were outlined by photointerpretation, using orthoimages of 1997 at a scale of 1:10000 (Anon, 1997). In the field, we identified the perennial community or communities that had colonized each old field. The total abandoned surface area and that occupied by each community were calculated using the same GIS software. In addition, a query builder of this software facilitated the interpretation of the spatial relationships between communities, determining which communities occupied the same fields and what area they shared.

2.3. Vegetation sampling

A stratified sampling was made in order to perform a quantitative study of the perennial-plant communities that had settled in old fields of the region. We randomly selected 36 old fields (based on the mapping done), five samples per stratum (plant communities), with some exceptions (see Table 1). The surface area of the quadrat was 5 × 5 m, this size being common in sampling perennial sub-shrub thickets (Bullock, 1996). Since farmland use can have significant impact on the development of the vegetation (Bonet, 2004; Pausas, 1999), all the quadrats selected had been previously cereals, which are the dominant old-field crops in this territory. Moreover, all the quadrats sampled were situated in flat areas or gentle slopes at similar altitudes. Data were recorded in the second half of 2003.

Richness (number of species), abundance (number of individuals), and species cover (%) were measured in each quadrat. The measure of cover was determined by linear metric transects of 20 m long, by the sum of the horizontal projection intercepted by each individual of each species. Only perennial species (chamaephytes, nanophanerophytes, and graminoid hemicryptophytes) were measured. These groups show a clear trend to replace therophytic species and provide greater cover and thus better soil protection (Debussche et al., 1996; Navarro et al., 2006). On the other hand, perennial species constitute more or less stable communities that could be managed as proposed for other semi-arid zones with a Mediterranean climate (Bonet, 2004; Leishman and Westoby, 1992). Nomenclature followed *Flora iberica* (Castroviejo, 1986–2009), *Flora Europaea* (Tutin et al., 1964–1980), and *Flora de Andalucía Occidental* (Valdés et al., 1987).

2.4. Soil sampling and analysis

Composite soil samples were randomly collected from three points of each quadrat at 0–30 cm deep in order to evaluate the soil parameters that might have influenced the vegetation changes identified. These parameters included pH, electrical conductivity (EC), available-water content (AWC), soluble gypsum, CaCO3, gravel content, and the ionic concentration (Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^- and $NO_2{}^-$; and sum of anions and cations).

The pH was measured in a soil suspension in distilled water (1:2.5). The calcium carbonate of the soil (measured as $CaCO_3$ equivalent) (%) was determined by the method proposed by Barahona et al. (1984). The available-water content (%) was calculated by the difference between the moisture content at field capacity extracted in a pressure plate at −33 kPa (M1/3) and the moisture at the withering point (M15), measured at −1500 kPa (Cassel and Nielsen, 1986). We prepared a saturation extract from each sample at 25 °C Soil Survey Staff, 1951 to determine its electrical conductivity (ds/m) and soluble ions (meq/l). Calcium and magnesium were determined by atomic-absorption spectroscopy, and potassium and sodium by flame photometry. The anions were determined by liquid chromatography using Dionex DS120 equipment. Soluble gypsum (%) was measured by acetone precipitation (Bower and Huss, 1948).

Table 1
Mean values (±standard error), and ANOVA *F* and *P* values of the floristic and edaphic variables of the plant communities studied.

	Plant communities							*F*	*P*
	SA (*n* = 6)	HA (*n* = 5)	AS (*n* = 6)	AH (*n* = 5)	CS (*n* = 5)	AF (*n* = 4)	AA (*n* = 5)		
Abundance	254.83 (99.81) abc	143.40 (75.07) cd	146.50 (26.55) bcd	76.60 (26.34) d	116 (21.10) cd	262.25 (25.80) ab	381.00 (79.09) a	4.34	0.0031
Cover	40.25 (4.23) b	53.24 (5.59) b	45.52 (4.58) b	93.83 (8.06) a	92.51 (4.90) a	42.00 (7.41) b	47.31 (4.75) b	10.4	0.0000
Richness	5.33 (1.09) b	4.20 (0.58) b	3.67 (0.56) b	5.00 (0.31) b	3.80 (0.66) b	4.25 (0.48) b	7.40 (0.24) a	3.34	0.0126
Gravel	8.03 (4.03) ab	1.20 (0.93) ab	1.03 (0.50) ab	19.60 (10.91) ab	0.00 (0.00) b	2.82 (1.62) ab	25.90 (6.98) a	7.46	0.0001
pH	8.35 (0.13) a	8.39 (0.14) a	8.60 (0.09) a	8.45 (0.15) a	8.57 (0.11) a	8.11 (0.07) a	8.67 (0.07) a	2.09	0.0852
$CaCO_3$	47.00 (2.37) a	54.82 (4.97) a	41.90(2.50) a	41.12 (5.44) a	34.90 (5.26) a	34.58 (6.06) a	39.48 (8.12) a	1.90	0.1149
M1/3	26.50 (2.76) c	26.47(2.46) c	30.17 (0.86) bc	33.75 (1.81) ab	38.03 (3.62) a	32.58 (0.77) abc	18.35 (1.52) d	7.80	0.0000
M15	10.85 (1.31) cd	11.18(0.47) bc	13.79 (0.92) b	14.41 (1.15) b	20.57 (2.76) a	15.03 (0.68) ab	8.43 (0.85) c	7.87	0.0000
AWC	15.65 (1.63) a	15.29 (2.51) a	16.38 (0.55) a	19.34 (1.84) a	17.46 (1.28) a	17.55 (1.41) a	9.92 (0.91) b	3.60	0.0087
EC	1.76 (0.27) bc	1.73 (0.48) abc	10.90 (2.00) ab	7.08 (2.72) abc	11.96 (2.42) a	2.31 (0.08) abc	0.99 (0.29) c	14.3	0.0000
Gypsum	2.60 (0.88) ab	0.37 (0.29) b	2.68 (0.48) ab	3.34 (0.54) ab	3.88 (0.82) a	3.28 (0.62) ab	1.05 (0.98) ab	3.05	0.0193
Na^+	0.06 (0.02) c	0.10 (0.06) bc	6.27 (1.84) ab	2.98 (1.73) abc	10.40 (3.11) a	0.08 (0.01) abc	0.06 (0.01) bc	12.1	0.0000
K^+	0.01 (0.00) b	0.02 (0.01) ab	0.45 (0.18) a	0.15 (0.06) ab	0.62 (0.19) a	0.02 (0.00) ab	0.01 (0.01) b	12.1	0.0000
Mg^{2+}	0.11 (0.02) c	0.13 (0.04) bc	8.92 (2.65) ab	4.59 (2.66) abc	24.90 (7.99) a	0.18 (0.04) abc	0.09 (0.02) c	18.7	0.0000
Ca^{2+}	0.93 (0.20) b	1.20 (0.46) ab	3.84 (0.33) a	2.80 (0.59) ab	4.25 (0.30) a	1.47 (0.07) ab	0.49 (0.25) b	16.0	0.0000
SO_4^-	1.09 (0.33) bc	0.91 (0.35) bc	10.12 (2.13) ab	6.22 (2.72) abc	30.28 (9.49) a	1.90 (0.16) abc	0.38 (0.33) c	15.4	0.0000
Cl^-	0.09 (0.05) ab	0.15 (0.11) b	8.23 (3.10) ab	2.70 (1.59) ab	10.29 (3.41) a	0.05 (0.00) ab	0.04 (0.01) b	9.13	0.0000
NO_3^-	0.00 (0.00) a	0.03 (0.01) a	0.00 (0.00) a	0.02 (0.01) a	0.02 (0.02) a	0.03 (0.01) a	0.02 (0.02) a	0.96	0.4692
NO_2^-	0.01 (0.00) b	0.02 (0.01) a	0.01 (0.00) b	0.01 (0.00) b	0.00 (0.00) b	0.01 (0.00) b	0.00 (0.00) b	3.09	0.0184
Sumcat	1.12 (0.21) c	1.45 (0.55) bc	19.49 (4.55) ab	10.51 (4.86) abc	40.17(10.60) a	1.75 (0.10) abc	0.65 (0.28) c	19.1	0.0000
Suman	1.19 (0.31) bc	1.11 (0.42) bc	18.36 (4.66) ab	8.94 (4.30) abc	40.59(11.29) a	1.98 (0.17) abc	0.44 (0.33) c	15.0	0.0000
Smj10	6.76 (1.16) bc	4.15 (0.54) c	9.17 (1.71) b	11.42 (2.27) ab	27.44(10.14) a	9.55 (1.26) b	6.96 (1.82) bc	5.68	0.0005
Smj20	11.23 (2.18) ab	8.26 (0.18) b	14.65 (1.88) ab	16.07 (2.68) ab	31.20 (7.29) a	14.68 (1.23) ab	9.57 (1.87) b	6.28	0.0003
Smj30	10.27 (1.49) bc	9.56 (0.27) c	19.04 (1.43) b	18.18 (2.70) b	33.40 (5.70) a	18.55 (1.24) b	12.23 (2.30) bc	10.5	0.0000
Sma10	3.88 (0.91) bcd	1.82 (0.19) d	6.75 (1.43) bc	7.32 (2.28) b	13.74 (4.23) a	5.90 (0.72) bc	1.99 (1.08) cd	6.66	0.0002
Sma20	4.93 (1.05) c	3.03 (0.33) c	13.67 (1.84) ab	11.12 (2.50) b	23.85 (4.17) a	10.09 (0.80) b	3.11 (1.18) c	13.6	0.0000
Sma30	6.31 (1.36) b	4.48 (0.42) b	17.47(1.64) ab	13.77 (2.69) ab	26.17 (4.04) a	14.46 (1.18) ab	4.94 (1.97) b	17.6	0.0000

Significance ($p < 0.05$) of between-group *post hoc* comparisons (LSD test) is indicated by different letters. DF = 6.
Variables and units: abundance (no. individuals), cover (%), richness (no. species), gravel content (%), pH, $CaCO_3$ contents (%), M1/3: moisture content at field capacity extracted in a pressure plate at 33 kPa (%), M15: moisture at the withering point at 1500 kPa(%), AWC: available-water content (%), EC: electrical conductivity (dS m^{-1} a 25 °C), soluble gypsum (%), ionic concentration (meq/l): Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^-, NO_2^-, Sum cat: sum of cations, Sum an: sum of anions, Smj10: soil moisture June 0–10 cm (%), Smj20: soil moisture June 10–20 cm (%), Smj30: soil moisture June 20–30 cm (%), Sma10: soil moisture August 0–10 cm (%), Sma20: soil moisture August 10–20 cm (%), Sma30: soil moisture August 20–30 cm (%).
Plant communities: SA (*Salsolo vermiculatae–Artemisietum herbae-albae*), HA (*Hammado articulatae–Atriplicetum glaucae*), AS (*Atriplici glaucae–Suaedetum verae*), AH (*Atriplicetum glauco–halimi*), CS (*Cistancho phelypaeae–Sarcocornietum fruticosae*), AF (*Artemisio herbae-albae–Frankenietum thymifoliae*), AA (*Andryalo ragusinae–Artemisietum barrelieri*).

Direct soil moisture (%) was measured by the gravimetric method (Soil Conservation Service, 1972). Two sampling campaigns were undertaken, one at the end of spring (June) after a rainy period, and another at the end of summer (the end of August), after two months without precipitation and with high temperatures. For this analysis, we selected 3 points at random within each quadrat and with a split-barrel sampler extracted soil from the uppermost 30 cm. Each sample was divided into three parts (0–10 cm, 10–20 cm, and 20–30 cm) and weighed with a field-precision digital scale; after drying in an oven (105 °C for 24 h) the samples were weighed again with the same scale. The mass reduction due to drying was considered water loss. The content in soil moisture (*w*) was calculated as the relationship between water mass (wm) and the mass of the dry soil sample (ds). Therefore, in each quadrat, 3 mean values for moisture were calculated for June (Smj10 = Soil moisture June 0–10 cm, Smj20 = Soil moisture June 10–20 cm, Smj30 = Soil moisture June 20–30 cm) and three for August (Sma10 = Soil moisture August 0–10 cm, Sma20 = Soil moisture August 10–20 cm, Sma30 = Soil moisture August 20–30 cm).

2.5. Data analysis

In the initial step, species and environmental data were analysed using ordination techniques, by means of CANOCO for Windows v 4.5® (Microcomputer Power, Ithaca, New York, USA), following the recommendations proposed by ter Braak and Smilauer (2002) and Lepš and Šmilauer (2003). In this sense, preliminary analyses were made using Detrended Correspondence Analysis (DCA) to check the magnitude of change in species composition between different communities. The gradient length value of the first DCA axis (greater than 4 SD units) suggested that use of unimodal ordination method was appropriate (Lepš and Šmilauer, 2003). This analysis was detrended by segments, with log-data transformation and down-weighting to the rare species to reduce distortion of the analysis.

Subsequently, we used a Canonical Correspondence Analysis (CCA) to analyse the relationships between floristic data and edaphic variables. This constrained ordination method was used to determine the variation that is directly explainable by the environmental variables measured (previously standarized; Lepš and Šmilauer, 2003). This analysis was detrended by 2nd-order polynomials, focus scaling on inter-sample distances, Hill's scaling type, log-transformed species data, and down-weighting to rare species. An automatic forward-selection procedure was used to identify the variables best related to the floristic data while non-significant ones were removed. The Monte Carlo test with the significant variables was performed with an unrestricted and randomized permutation test to assess the significance of the first and all of the canonical axes. Species abundance and cover data were used in both analyses (DCA and CCA), but only abundance-data results are shown because very similar results were found.

In the second step, we employed different one-way ANOVAs, at a confidence level of 95%, to determine the differences between the floristic and edaphic data (dependent variables) in relation to the communities studied (independent variables). The software used was STATISTIX 8.0.® (Analytical Software, Tallahassee, Florida, USA). These variables were tested to the normalized Shapiro–Wilk normality test and to Bartlett's homogeneity test of variance.

The differences between pairs of means of the variables that exceeded these tests were compared by the Least Significant Difference (LSD) test. Some of these dependent variables had to be logarithmically transformed previously (M15, Smj10, Smj20, Smj30, Sma10, Sma20). The variables which even after being transformed did not fulfil the ANOVA requirements were analysed by the nonparametric Kruskal-Wallis test (EC, gypsum and gravel contents, as well as the concentration in different ions: Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, and NO_2^-, sum of anions, sum of cations, Smj20, and Sma30). Throughout the text, means are followed by ±SE.

Finally, Spearman correlation was used to determine the degree of dependence between the edaphic and floristic variables.

3. Results

3.1. Area analysis

In the zone analysed, 1304 plots (old fields) were mapped, these occupying 2258.8 ha. The size of the minimum surface area mapped was 0.03 ha, while the largest plot measured 45.07 ha, the mean surface area per plot being 1.73 ± 2.96 ha. It was confirmed that in 2003, 48.6% of the abandoned surface area mapped on the basis of the orthoimages made in 1997 (1097.4 ha) had been cultivated again. In addition, 22 ha (0.97%) had been occupied by industrial and infrastructure activities and 7% had been included in the Afforestation Scheme of the Community Agrarian Policy (Regulation 2080/1992). In total, 43.44% of the surface area mapped (981.2 ha) continued to be abandoned in the confirmation period in the field (2003, six years after the orthoimage was made).

As mentioned above, seven perennial-plant communities (phytosociological associations) were studied: *Andryalo ragusinae–Artemisietum barrelieri* (AA), *Artemisio herbae-albae–Frankenietum thymifoliae* (AF), *Atriplicetum glauco–halimi* (AH), *Atriplici glaucae–Suaedetum verae* (AS), *Cistancho phelypaeae–Sarcocornietum fruticosae* (CS), *Hammado articulatae–Atriplicetum glaucae* (HA), and *Salsolo vermiculatae–Artemisietum herbae-albae* (SA).

SA was found in more than 48.6% of the abandoned surface area (Table 2), in 390.6 ha as single or predominant community, and 86.4 ha as the subordinate community (being in smaller surface area). CS predominated in 201.5 ha, representing 20.5% of the abandoned area. Also, 141 ha were occupied by AS and a similar surface area (148 ha) by HA. The AA and AH communities were scattered throughout the study area. Meanwhile, in 86.6 ha, no perennial community was found, presumably due to the short time period since the last ploughing.

Of the spatial relations among communities (Table 2), it bears mentioning that SA coexisted with four of the communities studied, although mainly with AS (73.3 ha) and HA (69.1 ha), whether dominant or subordinate. Other communities that showed a certain trend to develop in the same old fields were AS and CS (48.86 ha). Of the community dominated by *Suaeda vera* Forssk. ex J.F. Gmel. (AS), it is worth pointing out its development in contact or mixed with AF (in 25.2 ha) and AH (in 25.4 ha).

3.2. Ordination of the vegetation

In the DCA ordination diagram drawn from species-abundance data (Fig. 1), the 36 samples tended to be grouped into the seven plant communities previously identified. The points symbolize the centroids of quadrats and species, in which proximity means similarity. This interpretation is called the centroid principle (see Lepš and Šmilauer, 2003, for more details). Thus, *S. fruticosa*, *Gypsophila tomentosa* Moench and several species of *Limonium* genus were located next to samples of CS; *Atriplex halimus* is arranged near the triangles representing AH; AF samples include species as *Frankenia thymifolia* Desf., *Suaeda pruinosa* Lange and *Limonium supinum* (Girard) Pignatti; around SA samples are *Artemisia herba-alba* Asso and *Salsola vermiculata* L.; the points corresponding to *Hammada articulata* (Moq.) O. Bolòs and Vigo, *Marrubium vulgare* L. and *Retama sphaerocarpa* (L.) Boiss. appear with HA samples, and numerous species [*Artemisia barrelieri* Besser, *Artemisia campestris* L. subsp. *glutinosa* (J. Gay ex DC.) Batt, *Helichrysum italicum* (Roth.) G. Don fil. subsp. *serotinum* (Boiss.) P. Fourn., *Santolina canescens* Lag., *Andryala ragusina* L., etc.] are found around AA.

The first axis explained the greatest part of the floristic variation (eigenvalue = 0.802, gradient length of the first axis = 6.028 SD units), indicating high variation in the composition and abundance of the species of different communities and a clear unimodal response of the species to the underlying environmental gradients. The second DCA axis explained a smaller percentage of data variance (eigenvalue = 0.411). These first two axes together explained 26.5% of the cumulative variance (Appendix C, Supplementary material). Moreover, the first axis was well correlated with the environmental data ($r = 0.96$), and to a lesser extent the second ($r = 0.79$).

3.3. Floristic and edaphic differences between communities

Numerous significant differences ($p < 0.05$) were found between the plant communities with respect to the floristic and edaphic variables analysed (Table 1). The communities offering the greatest cover were AH (93.83 ± 8.06%) and CS (92.51 ± 4.90%), SA being the community registering the least mean cover (40.25 ± 4.23%). Species abundance in community AA was higher (381.00 ± 79.09 ind.) than in most of the others, especially as compared to CS and AH. Species richness was also significantly higher in AA (7.40 ± 0.24 sp) than in the rest of the communities.

Significant differences were also found between communities with respect to all the edaphic parameters analysed except for pH

Table 2
Surface area occupied by plant communities in old fields of the study area (ha).

	Total	Sing.	Domi.	Plant communities being in smaller surface						
				SA	AS	AH	HA	AF	AA	CS
SA	477.0 ha (48.6%)	314.2	76.4	–	33.3	0.9	25.0	17.2	0	0
AS	219.4 ha (22.4%)	46.3	94.7	40.0	–	23.9	0	21.5	0	9.3
AH	29.0 ha (3.0%)	2.7	1.5	0	1.5	–	0	0	0	0
HA	173.0 ha (17.6%)	101.8	46.2	44.1	0.3	0	–	1.8	0	0
AF	50.13 ha (5.1%)	0.6	6.0	2.3	3.7	0	0	–	0	0
AA	2.7 ha (0.3%)	2.7	0	0	0	0	0	0	–	0
CS	210.8 ha (20.5%)	158.9	42.6	0	39.6	0	0	3.0	0	–
	TOTAL	627.2	267.4	86.4	78.4	24.8	25.0	43.5	0	9.3

Data indicate area occupied by each community (Total), area occupied by each community where single (Sing.) appears, and the area where two communities were mixed, both acting as predominant (Domi.) or subordinate (being in smaller surface area). Abbreviations of plant communities are given in Table 1.

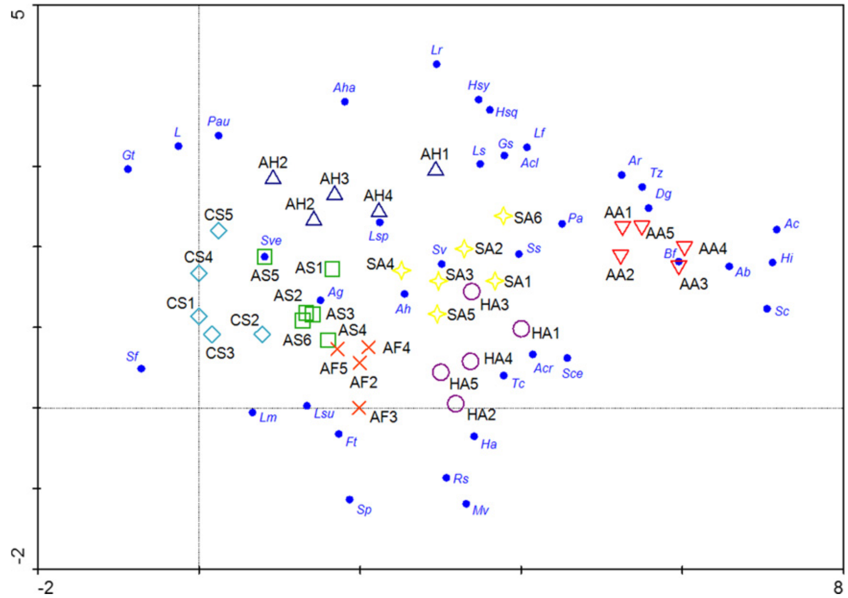

Fig. 1. DCA two-dimensional ordination diagram of the first two axes showing the distribution of 36 samples (squares, circles, diamonds, upright triangles, inverted triangles, X marks, stars) and species (points). Abbreviations of plant communities are given in Table 1. Species: Ab (*A. barrelieri*), Ac (*A. campestris*), Acl (*Astragalus clusianus*), Acr (*Allium chrysonemum*), Ah (*A. herba-alba*), Ag (*Atriplex glauca*), Aha (*A. halimus*), Ar (*A. ragusina*), Bf (*Bupleurum fruticescens*), Dg (*Dactylis glomerata*), Ft (*F. thymifolia*), Gs (*G. struthium*), Gt (*G. tomentosa*), Ha (*H. articulata*), Hi (*Helichrysum italicum*), Hsq (*H. squamatum*), Hsy (*Helianthemum syriacum*), Kv (*Koeleria vallesiana*), L (*Limonium* sp.), Lf (*Launea fragilis*), Lm (*Limonium majus*), Ls (*L. subulatum*), Lsu (*L. supinum*), Lsp (*Lygeum spartum*), Mv (*Marrubium vulgare*), Pa (*Plantago albicans*), Pau (*Phragmites australis*), Rs (*R. sphaerocarpa*), Sc (*S. canescens*), Sce (*Stipa lagascae*), Sf (*S. fruticosa*), Sp (*S. pruinosa*), Ss (*Sedum album*), Sv (*S. vermiculata*), Sve (*S. vera*), Tc (*Teucrium capitatum* subsp. *gracillimun*), Tz (*Thymus zygis*).

($p = 0.085$), the calcium carbonate content ($p = 0.115$), and nitrates ($p = 0.469$) (Table 1). The highest percentage of gravel was measured in the community AA (25.9 ± 6.98%), which differed significantly from the values registered in quadrats where CS was sampled (0 ± 0%). The most marked differences with respect to EC were detected between CS (11.96 ± 2.42 ds/m) and SA (1.76 ± 0.27 ds/m), as well as AA (0.99 ± 0.29 ds/m). The soils with the highest percentage of gypsum were samples from the community CS (3.88 ± 0.82%), which differed significantly from the low content found for HA (0.37 ± 0.29%). With respect to the concentration of ions, the soils with the highest concentrations, both in cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) as well as anions (Cl^-, SO_4^{2-}) was the community CS, this being also high in AS and AH. In HA, the ionic content in NO_2^- was significantly higher than in the rest of the communities.

The soil-moisture values measured in the field in June and in August were high in the CS community, in both sampling periods and at all depths. These values were significantly higher, practically in all cases, with respect to the communities AA, SA, and HA. The available-water content (AWC), the moisture content at field capacity (M1/3), and moisture at the withering point (M15) gave similar results.

3.4. Soil–vegetation relationships

The solutions of DCA and CCA did not differ substantially (see Appendix C, Supplementary material), and thus we inferred that the environmental variables measured account for the main variation in the species data (24.2% of the cumulative variance for the first two axes). Furthermore, the correlations between species and environment axes were high, explaining 81.9% of the cumulative variance for the first three canonical axes (abundance data). These results suggest a close relationship between vegetation and soil parameters.

Of all the environmental variables included in the CCA, five were selected for their significance level ($p < 0.05$): Smj30, Sma30, M15, SO_4^{2-}, and gravels (see Appendix D, Supplementary material). The Monte Carlo permutation test (499 permutations) was significant for the first axis (eigenvalue = 0.650, $F = 4.805$, $p = 0.002$, df = 30) and for all the canonical ordination axes (trace = 1.598, $F = 3.118$, $p = 0.002$, df = 30).

The CCA ordination diagram (Fig. 2) showed the communities CS, AS, AH, and AF in the positive part of axis 1. This axis was significantly correlated with Smj30 ($r = 0.752$), Sma30 ($r = 0.918$), M15 ($r = 0.808$), SO_4^{2-} ($r = 0.684$), and gravel content ($r = -0.667$). By contrast, samples of AA, SA, and HA were in the negative section of axis 1, and therefore were related negatively with all these variables, except with the gravel content, especially AA. The importance of the five variables is similar (similar length of the vectors). These variables were positively correlated (vectors forming acute angles with each other), except gravel content, which was negatively correlated with the other variables.

The presence of species such as *S. fruticosa*, *S. vera*, *G. tomentosa*, and different species of the genus *Limonium*, are related to moisture and saline soils (Fig. 3). On the contrary, characteristic of the driest soils with lower sulphate contents are species such as *H. articulata*, *R. sphaerocarpa*, *S. vermiculata*, *A. campestris*, *A. ragusina*, *H. italicum* subsp. *serotinum*, *S. canescens*, etc., the last four, among others, being furthermore associated with soils having high gravel contents.

3.5. Correlations among edaphic and floristic variables

Both species abundance as well as richness were correlated negatively with the EC of the soil (Table 3), with the ion content (Ca^{2+}, Cl^-, Mg^{2+}, K^+, SO_4^{2-} or the sum of them), and with moisture content at field capacity (M1/3) and at the withering point (M15), in this latter case only with richness. The abundance, furthermore, was correlated negatively with the calcium carbonate content, while a positive correlation was established between species richness and gravel content ($r = 0.4441$, $p < 0.01$).

Also, positive correlations were detected between the cover and diverse edaphic parameters which measure soil moisture (M1/3, M15, Smj10, Smj20, Sma10, Sma20), electrical conductivity (EC), and the ion content in Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and Cl^-.

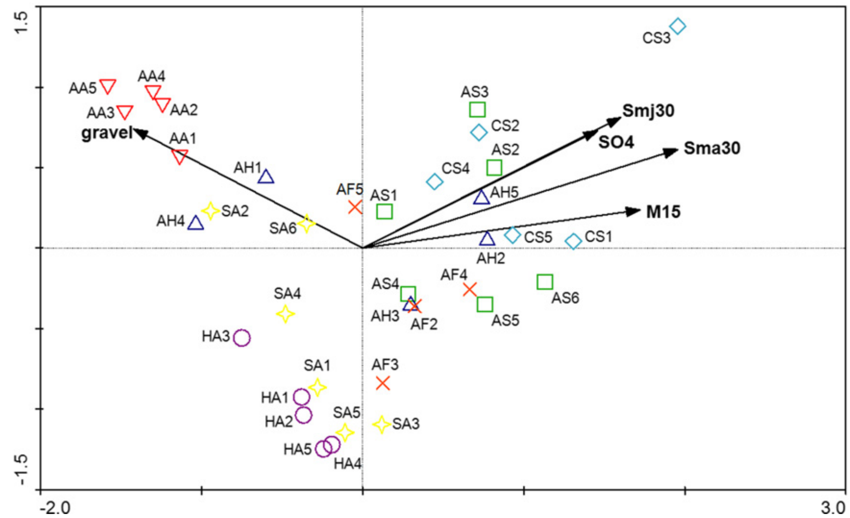

Fig. 2. CCA two-dimensional ordination diagram of the first two axes showing the distribution of 36 samples (squares, circles, diamonds, upright triangles, inverted triangles, X marks, stars) and significant environmental variables (vectors) ($p < 0.05$). The species are not represented in this diagram to provide clarity (see Fig. 3). Abbreviations of plant communities are given in Table 1 and abbreviations of edaphic variables are in Table 3.

With respect to relations between the floristic parameters themselves, it bears emphasizing the strong negative correlation between abundance and cover($r = -0.4275$, $p < 0.01$).

4. Discussion

The study highlights that the seven perennial-plant communities studied in semi-arid south-eastern Iberian old fields (AA, AF, AH, AS, CS, HA, SA) were strong groups both from a floristic and edaphic standpoint. The results confirm that the plant communities studied significantly differed and that changes in vegetation were conditioned largely by the variation in edaphic factors, mainly by soil moisture (Smj30, Sma30, M15), ion sulphate concentration, and the gravel content, according to the CCA performed.

Gravel content and edaphic variables related to salinity such as electrical conductivity or ionic content, have been found to determine vegetation changes in other arid territories (Abd El-Ghani and Amer, 2003; Moustafa and Zayed, 1996). It is well known that soil salinity is a major factor in the vegetation distribution as well as soil moisture (Pennings and Callaway, 1992), especially in arid and semi-arid regions (Maestre et al., 2003). Furthermore, their close relationship in saline environments has been demonstrated in numerous studies (Cooper, 1982; Serag and Khedr, 2001). In fact, the existence of spatial-temporal gradients of salinity and edaphic moisture has traditionally been considered one of the most important physical factors in these environments to influence plant distribution (Chapman, 1974).

Sulphates with chlorides are more directly responsible for the formation of saline soils, their properties, and salinity stress in plants (Porta et al., 2003). In the study area the sulphates predominated over chlorides (Simón, 1978); this situation may explain why only the sulphate content was selected as the salinity-associated variable that determines floristic differences between communities. Besides, the relative proportion of calcium and magnesium cations (and other ions such as Na^+ and K^+) is considered a key factor for plant growth in saline environments (Grattan and Grieve, 1992), together with the electrical conductivity (Abd El-Ghani and Amer, 2003; He et al., 2007). In any case, all the studied variables related to salinity (electrical conductivity, and ion content: SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+) were positively correlated with each other (Cañadas, 2008).

Correspondence analyses enable not only to identify main edaphic variables that influence vegetation, but also suggest that variation in the plant communities is ruled by a dominant underlying gradient (principally under axis 1, see Figs. 1 and 2). This may be interpreted as a major gradient of salinity and moisture, which indicates that changes in vegetation and soil are not sudden but gradual. This statement is also shown in the shared surface area between plant communities (Table 2).

Based on this gradient, two broad sets of abandoned fields may be recognized.

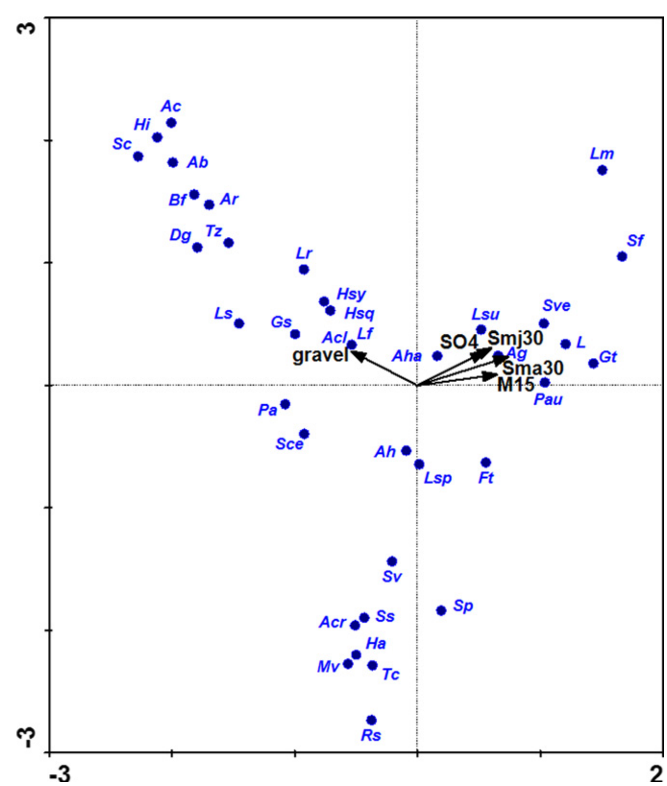

Fig. 3. CCA two-dimensional ordination diagram of the first two axes showing the distribution of species (points) and significant environmental variables (vectors) ($p < 0.05$). Samples are not represented in this diagram to provide clarity (see Fig. 3). Abbreviations of species are given in Fig. 2 and abbreviations of edaphic variables are in Table 3.

Table 3
Spearman rank correlation coefficient (r), between floristic and edaphic variables.

	Abundance	Richness	Cover
Abundance	–	0.4769**	−0.4275**
Richness	–	–	0.0456
gravel	0.2396	0.4441**	−0.2421
pH	0.1714	0.2196	0.1078
$CaCO_3$	−0.3925*	−0.0011	−0.0084
M1/3	−0.3529*	−0.4314**	0.4085*
M15	−0.2082	−0.4056*	0.3943*
EC	−0.3830*	−0.4051*	0.3434*
Gypsum	−0.1049	−0.1698	0.1607
Ca^{2+}	−0.3925*	−0.4221**	0.3265*
K^+	−0.3613*	−0.3940*	0.3403*
Mg^{2+}	−0.4127*	−0.3941*	0.4210**
Na^+	−0.3414*	−0.3948*	0.3244
Cl^-	−0.3925*	−0.4304**	0.2794
SO_4^{2-}	−0.3301*	−0.4115*	0.3586*
NO_2^-	−0.0349	0.2153	−0.0133
NO_3^-	0.0868	0.2531	0.1505
Sum an	−0.3512*	−0.4424**	0.3345*
Sum cat	−0.4209**	−0.4166*	0.3850*
Smj10	−0.0002	0.0238	0.3995*
Smj20	−0.0478	−0.1588	0.3457*
Smj30	−0.0255	−0.1147	0.3127
Sma10	−0.0002	−0.1957	0.3420*
Sma20	−0.1940	−0.3036	0.3369*
Sma30	−0.1636	−0.3199	0.3158

*($0.05 > p \leq 0.01$), **($0.01 > p > 0.001$), ***($p < 0.001$).
Abbreviations can be looked up in Table 1.

One group included plots for the plant communities HA (*Hammado articulatae–Atriplicetum glaucae*), SA (*Salsolo vermiculatae–Artemisietum herbae-albae*), and AA (*Andryalo ragusinae–Artemisietum barrelieri*), which appeared in non-saline soils (EC < 2 dS m^{-1} at 25 °C; Richards, 1954) with low soil moisture. SA was the most frequent community in the old fields studied, occupying more than 48% of the abandoned area that preserves vegetation. This community must tolerate a wide range of environmental conditions, because it lives with other communities of very different soil types. The community HA, identified in 71.2 ha, appears to be more sensitive to edaphic changes than SA, given that it shared an area almost exclusively with SA. Moreover, soils of HA stand out because they presented the lowest gypsum content, the highest percentage of carbonates and a significantly higher nitrite concentration compared to other communities. The proximity between samples in the DCA and CCA diagrams also reflects the low variability of the edaphic variables and floristic composition in this community. AA was rare in the area mapped, although it was frequent in nearby abandoned areas. Soils characteristic of this community are noted for their high gravel content.

The other set consisted of CS (*Cistancho phelypaeae–Sarcocornietum fruticosae*), AS (*Atriplici glaucae–Suaedetum verae*), and AH (*Atriplicetum glauco–halimi*) samples, the soils of which were characterized by high soil salinity and moisture. *Artemisio herbae-albae–Frankenietum thymifoliae* (AF) may also be included within this second group, because its soils had a relatively high soil moisture and gypsum content, although its salinity was lower. These four communities were also spatially related and occupied a high proportion of abandoned farmlands (more than 353 ha). Communities CS and AS were found in 342.53 ha of abandoned land. Their soils presented an EC of between 8 and 16 dS m^{-1}, with few exceptions, and thus they occupy very saline soil (Richards, 1954). In some places the EC even exceeded 16 dS m^{-1}, which corresponds to extremely saline soils according to this classification.

In any case, CS was the plant community that occupied the wettest and most saline soils. The whitish efflorescences of their soil surfaces indicated that salinity. Numerous studies have shown that the soils of this community and its most characteristic species, *S. fruticosa* (and other species of the genus) are salty and moist (Redondo et al., 2004). In fact, Salicornioideas are among the most salt-tolerant land plants (Short and Colmer, 1999). The data compiled reflect that the soils of the communities AS and CS, unlike the others, have water available to plants even in August (Sma30 and Sma20 > M15).

The soils of the AH community are characterized by lower EC and a lower ionic content, classified as moderately saline. Moisture data from AS and AH were quite similar. However, the deeper moisture recorded in the quadrats of AS, especially in August, was higher. The saline characteristics of the soils presenting such species as *S. vera*, a species that predominates in AS, are well known (e.g. Serag and Khedr, 2001). The salt tolerance of *A. halimus*, the main component of the community AH, has also been mentioned in numerous works (e.g. Zid and Boukhris, 1977).

Soil features determined not only the ordination of communities but also their floristic characteristics. The results revealed that the communities with more cover had lower plant abundance and vice versa. Greater abundance and species richness was found in *Artemisio herbae-albae–Frankenietum thymifoliae* (AA), a community noted for its high gravel content, as indicated. Some studies have demonstrated that stony soils can be more productive than those of fine texture (e.g. Unger, 1971).

The plant cover was positively correlated with variables associated with soil salinity and moisture (Table 3). In this sense, Yeo (1983) noted that plants which are able to cope with harsh conditions benefit from a high availability of water, light, and nutrients, compensating for the extra cost of tolerance and may produce a large amount of biomass (directly related to plant cover). On the other hand, in other studies made in saline environments (García et al., 1993) it was also demonstrated that the water regime and soil-nutrient content (Ca, Mg) were significant predictors of the community above-ground biomass.

In fact, *Cistancho phelypaeae–Sarcocornietum fruticosae* (CS) and *Atriplicetum glauco–halimi* (AH), located in moist and saline soils, were the communities characterized by the greatest cover, their quadrats having an average cover of 93.8 ± 8.1% and 92.5 ± 4.9%, respectively. In both cases the species that provided most of the cover in the community were the large chamaephytes *A. halimus* in AH (71.9 ± 11.1%) and *S. fruticosa* in CS (74.5 ± 8.5%). The strong negative correlation detected between abundance and cover is related to these results. A reduced number of individuals provided most of the cover, the majority of them belonging furthermore to the same species in each community. Different works have shown that in highly productive communities, it is probable that competition arises, favouring a few species that can channel most of the energy available to their own benefit (Rosenzweig and Abramsky, 1993; Whittaker, 1965).

The results of the variance analysis indicate that plant cover was significantly higher in these communities. However, the rest of the plant formations were also characterized by a dominant species that provided most of the total cover (in AA this was *A. barrelieri*, in AF *F. thymifolia*, in AS *S. vera*, in HA *H. articulata*, and in SA *S. vermiculata* together with *A. herba-alba*).

The results offer useful findings for old-field management. Firstly, they indicate that most of the zones that had been cultivated in other periods must have been abandoned due to their low productivity related to their edaphic particularities. One of the parameters that may support this proposal is pH. The pH value was higher than 8.0 in all the samples analysed, although the optimal pH for a barley and wheat crop (main rainfed crops grown in the zone) is 5.5–7.0 (Young, 1976).

However, salinity appears to be the main factor determining the low profitability of the crops. The EC in the parcels studied ranged from 0.5 to 18.8, and on this basis the soils could be classified as normal to strongly saline (Richards, 1954). The EC of the quadrats of the communities CS, AS, and AH are above the yield threshold, even for very tolerant crops such as barley or wheat. The loss in crop productivity can surpass 50% in some soils of these communities, and therefore it is advisable not to use them again for cultivation. The adverse climatic conditions for the crop (e.g. markedly continental with low or irregular rainfall) in the study zone, in addition to the edaphic limitations such as the ones discussed, imply that environmental characteristics have been key in encouraging agricultural abandonment, although social factors at a larger scale have also had important repercussions (Baudry, 1991; Lasanta, 1988).

Another justification for not re-cultivating abandoned saline zones is that the communities that colonize them (*Cistancho phelypaeae–Sarcocornietum fruticosae*, *Atriplici glaucae–Suaedetum verae*, *Atriplicetum glauco–halimi*, and *Artemisio herbae-albae–Frankenietum thymifoliae*) constitute "natural habitat types of Community interest" (Directive 92/43/EEC) (see Appendix B, Supplementary material), harbouring rare, endemic, and threatened species (Lendínez et al., 2004), giving these zones particular conservational status.

In absence of disturbance, preservation of the ecological value of these areas is ensured in two ways. First, in semi-arid environments plant succession is slow. On the other hand, in saline areas without evidence of previous crops, there are more "natural habitat types of Community interest" and species of high ecological value (Lendínez et al., 2004). However, conservation of these habitats is endangered in some areas due to inappropriate agricultural practices. Sometimes, old fields are ploughed with the sole purpose of not losing the legal right to cultivate land. At other times, these areas really come into cultivation, but in this case steps must be taken in order to reduce salinity (such as construction of ditches and drains). These measures also alter the moisture and salinity regime in neighbouring fields, threatening the preservation of some habitats. Up to now, in the Baza Basin only one salt marsh is protected, the Wetlands of "El Margen" (Wetlands Inventories of Andalusia and Spain). Therefore, it is important to promote conservation measures for these sites.

Acknowledgments

This research was funded by the research group RNM-207 (University of Granada). We thank Jesús Sarabia and María Sánchez for assistance in the field. Moreover, we would like to thank David Nesbitt for the linguistic revision.

Appendix. Supplementary material

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.jaridenv.2010.06.007.

References

Abd El-Ghani, M.M., Amer, W.M., 2003. Soil vegetation relationships in a coastal desert plain of southern Sinai, Egypt. Journal of Arid Environments 55, 607–628.
Anon, 1997. Ortofotos digitales. SIG Oleícola Español. Ministerio de Agricultura, Pesca y Alimentación, Madrid.
Arbelo, C.D., Rodríguez-Rodríguez, A., Guerra, J.A., Mora, J.L., Notario, J.S., Fuentes, F., 2006. Soil degradation processes and plant colonization in abandoned terraced fields overlying pumice tuffs. Land Degradation and Development 17, 571–588.
Barahona, E., Cadahína, C., Casado, M., Chaves, M., Gárate, A., Heras, L., Lachica, M., Lasala, M., Llorca, R., Montañes, L., Pardo, M.T., Pérez, V., Prat, L., Romero, M., Sánchez, B., 1984. Determinación de carbonatos totales y caliza activa. Determinaciones analíticas en suelos. Normalización de métodos IV. In: Proceedings of the I Congreso Nacional de la Ciencia del Suelo. Madrid, pp. 53–69.
Baudry, J., 1991. Ecological consequences of grazing extensification and land abandonment: role of interactions between environment, society and techniques. Options Méditerranéennes – Série Séminaires 15, 13–19.
Bonet, A., 2004. Secondary succession of semi-arid Mediterranean old-fields in south-eastern Spain: insights for conservation and restoration of degraded lands. Journal of Arid Environments 56, 213–233.
Bower, C.A., Huss, R.B., 1948. Rapid conductometric method for estimating gypsum in soils. Soil Science 141, 199–204.
ter Braak, C.J.F., Smilauer, P., 2002. CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (Version 4). Microcomputer Power, Ithaca, NY.
Bullock, J., 1996. Plants. In: Sutherland, W.J. (Ed.), Ecological Census Techniques: A Hand Book. Cambridge University Press, Cambridge, pp. 11–138.
Burel, F., Baudry, J., 2002. Ecología del Paisaje. Conceptos, métodos y aplicaciones. Ediciones Mundi-Prensa, Madrid.
Cañadas, E.M., 2008. Estudio de tierras agrícolas abandonadas en ambiente mediterráneo semiárido: vegetación, suelo y distribución espacial. Bases para la gestión. Tesis doctoral, Universidad de Granada.
Cassel, D.K., Nielsen, D.R., 1986. Fields capacity and available water capacity. In: Klute, A. (Ed.), Methods of Soil Analysis. Part. 1: Physical and Mineralogical Methods, ASA. SSSA Monograph № 9, pp. 901–926. Madison, WI.
(Coord.) Castroviejo, S., 1986–2009. Flora Iberica. Plantas vasculares de la Península Ibérica e Islas Baleares. In: Flora Iberica, vols. I–VIII, X, XIII–XV, XVIII, XXI. Real Jardín Botánico, CSIC, Madrid.
Cayuela, L., Rey Benayas, J.M., Maestre, F.T., Escudero, A., 2008. Early environments drive diversity and floristic composition in Mediterranean old fields: insights from a long-term experiment. Acta Oecologica 34, 311–321.
Chapman, V.J., 1974. Salt Marshes and Salt Deserts of the World. Verlag Von J. Kramer, Vremerhaven.
CIHEAM, 2009. Terramed 2009, nuevas perspectivas para el desarrollo rural en el Mediterráneo. MARM, Madrid.
Cooper, A., 1982. The effects of salinity and waterlogging on the growth and cation uptake of salt marsh plants. New Phytologist 90, 263–275.
Debussche, M., Escarré, J., Lepart, J., Houssard, C., Lavorel, S., 1996. Changes in Mediterranean plant succession: old-fields revisited. Journal of Vegetation Science 7, 519–526.
Dunjó, G., Pardini, G., Gispert, M., 2003. Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain. Catena 52, 23–27.
Fowler, N., 1986. The role of competition in plant communities in arid and semiarid regions. Annual Review of Ecology and Systematics 17, 89–110.
García, L.V., Marañón, T., Moreno, A., Clemente, L., 1993. Above-ground biomass and species richness in a Mediterranean salt marsh. Journal of Vegetation Science 4, 417–424.
González Moreno, M., Genaro, D., Melchor, E., 2007. Presente y futuro del altiplano granadino: una visión económica de las comarcas de Baza y Huéscar. Fundación Caja Rural, Granada.
Grime, J.P., 1982. Estrategias de adaptación de las plantas y procesos que controlan la vegetación. Editorial Limusa, México.
Grattan, S.R., Grieve, C.M., 1992. Mineral acquisition and growth response of plants grown in saline environments. Agriculture, Ecosystems and Environment 38, 275–300.
Haase, P., Puignaire, F.I., Clark, S.C., Incoll, L.D., 1997. Spatial pattern in Anthyllis cytisoides shrubland on abandoned land in southeastern Spain. Journal of Vegetation Science 8, 627–634.
He, M.Z., Zheng, J.G., Li, X.R., Qian, Y.L., 2007. Environmental factors affecting vegetation composition in the Alxa Plateau, China. Journal of Arid Environments 69, 473–489.
Hedlund, K., Santa Regina, I., Van der Putten, W.H., Lepš, J., Díaz, T., Korthals, G.W., Lavorel, S., Brown, V.K., Gormsen, D., Mortimer, S.R., Rodríguez Barrueco, C., Roy, J., Smilauer, P., Smilauerová, M., Van Dijk, C., 2003. Plant species diversity, plant biomass and responses of the soil community on abandoned land across Europe: idiosyncracy or above-belowground time lags. Oikos 103, 45–58.
Hobbs, R.J., Cramer, V.A., 2007. Why old fields? Socioeconomic and ecological causes and consequences of land abandonment. In: Cramer, V.A., Hobbs, R.J. (Eds.), Old Fields, Dynamics and Restoration of Abandoned Farmland. Society for Ecological Restoration International, Island Press, pp. 1–14.
Lasanta, T., 1988. The process of desertion of cultivated areas in the Central Spanish Pyrenees. Pirineos 132, 15–36.
Leishman, M.R., Westoby, M., 1992. Classifying plants into groups on the basis of associations of individual traits – evidence from Australian semi-arid woodlands. Journal of Ecology 80, 417–424.
Lendínez, M.L., Marchal, F.M., Gómez Milán, F., Salazar, C., 2004. La regresión de un ecosistema de singular valor florístico y fitocenótico: los saladares de la Hoya de Baza (Granada). Propuestas para su conservación. In: Peñas de Giles, J., Gutiérrez Carretero, L. (Eds.), Biología de la Conservación. Reflexiones, propuestas y estudios desde el S.E. ibérico. Instituto de Estudios Almerienses. Diputación de Almería, Almería, pp. 207–217.
Lepš, J., Šmilauer, P., 2003. Multivariate Analysis of Ecological Data Using CANOCO. Cambridge University Press, Cambridge.
Maestre, F.T., Cortina, J., Bautista, S., Bellot, J., Vallejo, R., 2003. Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6, 630–643.
Martínez-Duro, E., Ferrandis, P., Escudero, A., Luzuriaga, A.L., Herranz, J.M., 2010. Secondary old-field succession in an ecosystem with restrictive soils: does time from abandonment matter? Applied Vegetation Science 13, 234–248.

Moustafa, A.M., Zayed, A.M., 1996. Effect of environmental factors on the flora of alluvial fans in southern Sinai. Journal of Arid Environments 32, 431–443.
Navarro, F.B., Ripoll, M.A., Jiménez, M.N., de Simón, E., Valle, F., 2006. Vegetation response to conditions caused by different soil-preparation techniques applied to afforestation in semiarid abandoned farmland. Land Degradation and Development 17, 73–87.
Pausas, J.G., 1999. Mediterranean vegetation dynamics: modelling problems and functional types. Plant Ecology 1440, 27–39.
Pennings, S.C., Callaway, R.M., 1992. Salt marsh plant zonation: the relative importance of competition and physical factors. Ecology 73, 681–690.
Porta, J., López-Acevedo, M., Roquero, C., 2003. Edafología para la agricultura y el medio ambiente. Ediciones Mundi-Prensa, Madrid.
Pugnaire, F.I., Armas, C., Valladares, F., 2004. Soil as a mediator in plant-plant interactions in a semi-arid community. Journal of Vegetation Science 15, 85–92.
Pugnaire, F.I., Luque, M.T., Armas, C., Gutiérrez, L., 2006. Colonization processes in semi-arid Mediterranean old-fields. Journal of Arid Environments 65, 591–603.
Redondo, S., Rubio-Casal, A.E., Castillo, J.M., Luque, C.J., Álvarez, A.A., Luque, T., Figueroa, M.E., 2004. Influences of salinity and light on germination of three *Sarcocornia* taxa with contrasted habitats. Aquatic Botany 78, 255–264.
Rey-Benayas, J.M., Martins, A., Nicolau, J.M., Schulz, J.J., 2007. Abandonment of agricultural land: and overview of drivers and consequences. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 57, 1–14.
Richards, L.A. (Ed.), 1954. Diagnosis and Improvement of Saline and Alkali Soils. US Department of Agriculture Handbook 60. US Salinity Lab., California.
Rivas-Martínez, S., Asensi, A., Díez, B., Molero, J., Valle, F., 1997. Biogeographical synthesis of Andalusia (southern Spain). Journal of Biogeography 24, 915–928.
Rivas-Martínez, S., Díaz, T.E., Fernández-González, F., Izco, J., Loidi, J., Lousa, M., Penas, A., 2002. Vascular plant communities of Spain and Portugal. Itinera Geobotanica 15, 5–922.
Rosenzweig, M.L., Abramsky, Z., 1993. How are diversity and productivity related? In: Ricklefs, R.E., Schluters, D. (Eds.), Species Diversity in Ecological Communities. Historical and Geographical Perspectives. The University of Chicago Press, Chicago, pp. 52–65.
Rubio, A., Escudero, A., 2000. Small-scale spatial soil–plant relationship in semiarid gypsum environments. Plant and Soil 220, 139–150.
Serag, M.S., Khedr, A.A., 2001. Vegetation–environment relationships along El-Salam Canal, Egypt. Environmetrics 12, 219–232.
Simón, M., 1978. Estudio de los suelos salinos en la provincia de Granada. Tesis doctoral. Universidad de Granada.
Short, D.C., Colmer, T.D., 1999. Salt tolerance in the halophyte *Halosarcia pergranulata* subsp. *pergranulata*. Annals of Botany 83, 207–213.
Soil Conservation Service, 1972. Methods and procedures for collecting soil samples. Soil Survey Report, 1. U.S.D.A. Soil Survey Laboratory, Washington, DC.
Soil Survey Staff, 1951. Soil Survey Manual. In: U.S. Department of Agriculture Handbook, Num 18. US Government Printing Office, Washington, D.C.
Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M., Webb, D.A. (Eds.), 1964–1980, Flora Europaea, vols. 1–5. Cambridge University Press, Cambridge.
Unger, P., 1971. Soil profile gravel layers: II. Effect on growth and water use by a hybrid forage sorghum. Soil Science Society of America Proceeding 35, 980–983.
Valdés, B., Talavera, S., Galiano, E.F., 1987. In: Ketres (Ed.), Flora vascular de Andalucía Occidental, vols. 1–3 Barcelona.
Whittaker, R.H., 1965. Dominance and diversity in land plant communities. Science 147, 250–260.
Yeo, A.R., 1983. Salinity resistance: physiology and prices. Physiologia Plantarum 58, 214–222.
Young, A., 1976. Tropical soil and soil survey. Cambridge Geografical Studies, 9. Cambridge University Press, Cambridge.
Zid, E., Boukhris, M., 1977. Some aspects of salt tolerance of *Atriplex halimus* L.: multiplication, growth, mineral composition. Oecologia Plantarum 12, 351–362.