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Evaluating riparian vegetation in semi-arid Mediterranean watercourses in the south-eastern Iberian Peninsula

M. JACOBA SALINAS*, GABRIEL BLANCA AND ANA T. ROMERO
Departamento de Biología Vegetal, Facultad de Ciencias, Universidad de Granada, E-18071 Granada, Spain
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Summary

Riparian vegetation is vulnerable to human impact worldwide, and this is especially so in arid areas, yet there have been few quantitative studies and this is especially so in Spain. The state of the riparian vegetation along three major rivers and seasonal watercourses of south-eastern Spain was evaluated during 1992–93, using the species composition and community structure in watercourses of different sizes under different management. Reaches of the watercourses were classified using five vegetation indices, namely percentage cover, species richness, degree of connectivity between patches of the plant communities, number of exotic species, and evidence of natural regeneration. With the integration of these into one index, the degradation state of the riparian vegetation in each reach was quantified. In addition, types of human activities exerting the greatest impact were noted, and a scale to evaluate the intensity of each impact was established. The indications are that agriculture has very substantially altered the natural vegetation, and this index has served to highlight the most altered zones, and thus those in most urgent need of restoration. Less-degraded zones could serve as models and sources of plant species for future restoration. The degradation index made it possible to establish quickly, easily, and with a high degree of accuracy, the state of conservation of the riparian vegetation in the study area.

Keywords: riparian vegetation, semi-arid Mediterranean climate, conservation status, degradation levels, human activities, restoration works

Introduction

Riparian vegetation is amongst that most severely altered worldwide by human activity, particularly in semi-arid basins (Andrews *et al.* 1975; Johnson *et al.* 1976; Johnson 1979; Szaro 1989, 1990; Stromberg & Patten, 1990, 1991; Stromberg *et al.* 1991; Stromberg *et al.* 1992; Stromberg 1993). Both spatially and temporally, this vegetation forms part of a dynamic ecotone, in which there are major physical and biological interrelationships between terrestrial and aquatic environments (Gregory *et al.* 1991). Riparian ecotones also offer numerous biotopes where animals may seek refuge and food; in semi-arid riparian zones of the USA, comparatively higher species richness and density of wildlife have been reported than in upland zones (Johnson & Simpson 1971; Carothers *et al.* 1974).

In addition, the evaluation criteria derived from the Ramsar Accord (Amat *et al.* 1985; Grimmet & Jones 1989) for the protection of wet zones, when applied to the arid and semi-arid regions of the Iberian Peninsula, offer substantial discrimination of many of these ecosystems (Vidal-Abarca *et al.* 1995). The reasons are diverse, including the underestimation of seasonality and the small surface area, thereby excluding most of the biologically-rich ecosystems in these zones.

Riparian vegetation is the only type of large-scale tree or shrub community in the semi-arid Mediterranean climate; its phenology strongly differs from that of the other communities, and it contributes distinctive landscape characteristics (Salinas 1995). This vegetation partly retains eroded materials (a serious problem in this region, since the hilly slopes have low vegetation cover and the runoff can be torrential), diminishing the quantity of solids in suspension in the water and thereby improving the water quality (Pesson 1978; Manteiga 1992). In addition, the highly-developed root systems may stabilize the river banks. In recent years, various techniques have been developed to reinforce slopes and combat torrential runoff by using trees and shrubs, alone or in combination with inert materials (López 1988; Glover & Ford 1990; Glennon & Ritz 1994; Leiser *et al.* 1994). These advantages, together with the less barren quality of the landscape that this vegetation provides under the semi-arid Mediterranean climate, justify its preservation and restoration as priorities of regional management.

Most studies attempting to establish the state of conservation of riparian vegetation have been conducted on watercourses in wet climatic zones (Platts *et al.* 1983; Plafkin *et al.* 1990; Petersen 1992), where environmental conditions contrast markedly with those of the semi-arid Mediterranean, and therefore it is difficult to use the same assessment criteria. In addition, the few analyses of riparian vegetation of watercourses in semi-arid areas have been directed towards establishing the conditions of the vegetation most apt for the associated wildlife (Anderson & Ohmart 1985; Medley 1993, 1994) and not towards planning the rehabilitation of the vegetation itself.

* Correspondence: Dr M Jacoba Salinas Tel: +3458 243394 Fax: +3458 243254 e-mail: maria@goliat.ugr.es

In Europe, given the few watercourses of this type, very few studies have evaluated the state of conservation of this type of riparian vegetation (Salinas 1995), but where they have, a descriptive and complex phytosociological methodology has been used (Braun-Blanquet 1979), based on the floral quality of the communities without thoroughly analysing their structure. Application of such assessment is not feasible on a regional scale. The studies most similar in aim to the present study were performed in areas of California (Olson & Harris 1997; Russell *et al.* 1997) and Australia (Roberts & Ludwig 1991) which have Mediterranean climates. In accord with Olson and Harris (1997), the criteria used to evaluate the conditions of the vegetation should be defined more specifically for each region.

In the present study, the overall aim was to evaluate the conservation status of the riparian vegetation in the south-eastern Iberian Peninsula. This was done first using the natural vegetation cover, species richness, exotic species, and patch connectivity, in an approach similar to that of Olson and Harris (1997) but adapted to the particularities of the study area. The ultimate purpose was to combine these data into an assessment of degradation status, and compare this with management type and intensity, to evaluate the possible influence of management activities on the state of the plant communities concerned.

Methods

The study area

The study was conducted in south-eastern Spain (Fig. 1) along the Andarax, Aguas and Carboneras rivers and their main tributaries, and along several *ramblas* (seasonal watercourses). The total area was 4243 km^2 located between approximately 36°40′ and 37°15′N, and at altitudes varying between 0 m and 2000 m. The water flow was highly irregular, from the winter volume of the high reaches of the Andarax River to the complete absence of water in the ramblas and the lower reaches of the rivers during the dry season.

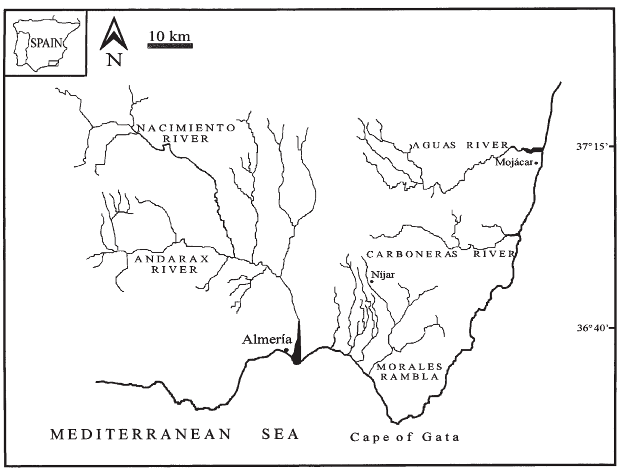

Figure 1 The study area.

The total average annual flow was approximately 2.71 m^3/s (Martín-Vivaldi 1991).

The climate is semi-arid Mediterranean (Le Houèrou 1982), with an average annual precipitation of about 365 mm (Martín-Vivaldi 1991), although the annual fluctuations are pronounced (a minimum of 63 mm in 1913, a maximum of 552 mm in 1989; Capel 1990). Precipitation occurs principally during autumn and winter, registering a maximum of 690 mm (head of the Andarax River, at 1800 m altitude) and a minimum of 217 mm (lower reaches of the Andarax River, at 80 m altitude). The winters are mild and summers hot, with a mean annual temperature of 10.1° C in the high reaches and 18.2° C in the lower reaches of the Andarax River. The geological materials are primarily Triassic schists and limestones in the highest zones of the basins, and Neogene to Quaternary in the middle and lower zones, fundamentally limestones, sandstones, conglomerates and marls, all of marine origin (Martín-Vivaldi 1991). On the river banks, hillslope vegetation is composed of diverse communities of subserial and serial scrubs, in most cases with a low percentage cover. The plants are distributed according to the degree of soil development, the nature of the substratum and the orientation; this latter factor determines the hours of direct light exposure (cf. Alcaraz *et al.* 1989; Peinado *et al.* 1992; Mota *et al.* 1997). Although there are no dams in any of the basins studied, the water is diverted and channelled all along the main courses a few kilometres below the head of each river. Practically all the zones studied have been altered with a certain degree of intensity, primarily by agricultural practices, grazing, and recreational activities.

Methods

To quantify spatial variation of the perennial riparian vegetation, we systematically located a total of 266 pairs of plots (one on each bank) of 120 m^2 each (30 m × 4 m), spaced some 5 km apart, along the banks of the principal watercourses. In each plot, the percentage cover of all the perennial phanerogamous plant species was measured, using the line-intercept method (Canfield 1941) for a length of 30 m. The method consisted of extending a tape measure and noting the length in centimetres along which each species was intercepted by the tape. The intercept measurements were taken at heights of 5 m for the tree stratum, 1.5 m for the shrub stratum and 50 cm for the stratum of chamaephytes and hemicryptophytes. As an estimate of the species richness, all the phanerogamous plant species present in each plot were recorded. The nomenclature used comes from Castroviejo *et al.* (1986–90, 1993*a*, 1993*b*, 1997), Valdés *et al.* (1987) and Tutin *et al.* (1964–80). The different types of vegetation along the courses were classified by a cluster analysis, using the percentage cover for each species. A matrix of similarity was constructed using Sörensen's index (1948), first employed by Motika *et al.* (1950), while the hierarchical and agglomerative clustering of the groups was performed by the weighted pair group method using arithmetic average (WPGMA). The computer programme chosen for this latter operation was IM (BMDP Statistical Software; Hartigan 1990).

In each pair of plots (left and right together) we calculated five indices. (1) Percentage of total cover (sum of the percentages of cover of all the species of the strata present) provided an index of the development of the plant biomass. The estimate of percentage of cover for each species was calculated by dividing the length of interception of this species at the transect by the total length of that transect (30 m). (2) Species richness was measured as the total number of species recorded in each pair of plots; it was expected usually to be high in strongly-dynamic stretches where new resources were being created and low in zones which had recently been altered (naturally or artificially) and niches were reduced in number (Malanson 1993). (3) The degree of connectivity between patches of riparian vegetation was evaluated by the line-intercept method measuring the cover of the community (all strata) up to 100 m on both sides of the plots; this enabled an analysis to be made of the degradation level of the community along a given stretch. (4) The number of exotic species in the plots was used to indicate human activities (Tabacchi *et al.* 1996). (5) Evidence of natural regeneration was provided by the presence or absence of seedlings and/or juvenile plants of the dominant plant species. A value of 0 was assigned to the presence or regeneration and a value of 1 when no regeneration was evident.

The categories used for each index and the values assigned for each are summarized in Table 1. Degradation level was estimated as the arithmetic mean of the sum of the values for each index in each pair of plots (Table 1). Maps were compiled assuming the same degradation level applied to the zone 2.5 km upstream and 2.5 km downstream from the plot, where field inspection indicated that the vegetation was homogeneous enough to extrapolate. Where the vegetation was too heterogeneous, 10 additional samples were taken.

In each pair of plots, we noted the presence or absence of human activity, which was identified as: agriculture (crops of table grapes, citrus, olives, and, to a lesser extent, almonds; on the lowest terrain, intensive cultivation under plastic), grazing (sheep and goats), mining, roads, urban sewage release, water channelling, and forestry. Due to the absence of quantitative data, the intensities of these activities were evaluated in three classes, namely none, medium and high. Table 2 specifies each of the activities analysed and defines the intensity levels established.

To evaluate the influence of human activities on the state of the riparian vegetation, we used a one-way analysis of variance (ANOVA), comparing the degradation indices formulated for each pair of plots with the intensity of each of the human activities considered. In human activities where significant differences were detected between the different intensities, pairwise comparison of means was performed using Tukey's method (or HDS). The computer programme used was SYSTAT VERSION 7.0 (© 1997, SPSS INC).

Results

Four plant communities were identified (Fig. 2), each dominated respectively by the following species (Table 3): *Tamarix canariensis* and *T. africana* (group 1); *Nerium oleander* (group 2); *Salix atrocinerea* (group 3); and *Alnus glutinosa* and *Populus* ssp. (group 4). The first three groups comprised shrubs, while the last was composed of a tree overstory with a poorly-developed shrub understory in which *S. atrocinerea* was the most representative constituent. In the lower stratum (chamaephytes and hemicryptophytes), the total number of species in all the communities was very high (53), but both the percentages cover and frequency values were small. *Atriplex halimus* and *Dittrichia viscosa* registered the highest mean values of cover in group 1, *Hyparrhenia hirta* and *D. viscosa*, and *Anthyllis cytisoides* in group 2, and *D. viscosa* in group 3. Group 4 showed a poor third stratum, lacking any species with substantial cover.

There was a natural gradient (Fig. 3) in the most mesic plant communities (*Alnus* and *Populus*, and *Salix* communities) of replacement by communities adapted to more severe climatic conditions, in terms both of the hydrological regime (which becomes more irregular downstream of the principal watercourses), as well as of macroclimatic conditions, such as temperature, evaporation, and insolation, which reach values characteristic of semi-arid zones. In addition, the altitude, morphology of the watercourse, and the nature and texture of the substratum influenced the distribution of the different communities (Table 4).

Only 4.8% of the plots studied presented a degradation level of 1 (Fig. 4). This vegetation was represented by communities dominated by *Salix* ssp. (group 3 of the cluster; Fig. 2) located along the highest reaches of the Andarax River (Fig. 3). A degradation level of 2 was recorded in

Table 1 Ranges of the categories established for each index, values assigned to each category, and levels of degradation assigned.

Plot total coverage	*Plot species richness*	*Degree of patch connectivity*	*Exotic species*	*Assigned values*	*Degradation levels*
100%	> 8	Continuous (100%)	0	1	1 (0.8–1)
76–99%	7–8	Very high (76–99%)	1	2	2 (1.01–2)
51–75%	5–6	High (51–75%)	2	3	3 (2.01–3)
26–50%	3–4	Low (26–50%)	3	4	4 (3.01–4)
< 25%	1–2	Very low (< 25%)	4	5	5 (4.01–4.2)

Table 2 Human activities as degradation factors together with the intensity of their effect on the riparian vegetation and watercourses.

Factor	*Intensity*	*Definition*
Agriculture	None	No physical effects evident in the riparian vegetation.
	Medium	Partial destruction of the riparian vegetation and slight alteration of the watercourse.
	High	Substantial reduction or replacement of riparian vegetation by cultivation and notable alteration in the watercourse (generally by regulating flow).
Livestock	None	No physical effects evident in the riparian vegetation.
	Medium	Partial destruction of the riparian vegetation and slight alteration of the watercourse (generally used as crossing or passage).
	High	Substantial destruction of riparian vegetation (to facilitate passage or resting area for flocks or herds) and notable alteration of the watercourse (abundant excrement).
Mining	None	No physical effects evident in the riparian vegetation.
	Medium	Partial destruction of riparian vegetation (localized dredging).
	High	Substantial destruction of riparian vegetation, drastic alteration of the watercourse and heavy evaporation of water (massive dredging).
Roads	None	No physical effects evident in the riparian vegetation.
	Medium	Presence of trails and lanes on the ground that eliminate part of the riparian vegetation and open passage to the most inaccessible zones.
	High	Roads follow the river, often constructed on the riverbank, destroying riparian vegetation.
Sewage release	None	No physical effects evident in the riparian vegetation.
	Medium	Discharges localized and limited in time without apparent alteration of the riparian vegetation.
	High	Continuous discharges of considerable magnitude.
Channelling	None	No physical effects evident in the riparian vegetation.
	Medium	Partial destruction of riparian vegetation by traditional channelling of waters (temporary ditches).
	High	Total and definitive destruction of the vegetation by diverting water through pipes.
Forestry	None	No physical effects evident in the riparian vegetation.
	Medium	Alteration of the structure and species composition of the riparian vegetation.
	High	Major or total destruction of autochthonous riparian vegetation.
Urbanization	None	Scattered country houses.
	Medium	Population centres of less than 1000 inhabitants.
	High	Population centres of more than 1000 inhabitants.

14.8% of the plots (Fig. 4), in communities scattered throughout the study area, although more prevalent along the smaller watercourses (Fig. 4). Degradation levels occurred in all four plant communities identified. Most of the plots (45.5%) occurring along a large part of the Andarax Basin had degradation level 3 (Fig. 4). The most affected part of this group proved to be the shrub communities dominated by species of *Tamarix* (group 1 of the cluster; Fig. 2), and *Alnus* and *Populus* (group 4 of the cluster; Fig. 2) in the high reaches of the Andarax (Fig. 3). The minor watercourses (the Rivers Aguas and Carboneras and the ramblas Agua and Amoladeras) also presented many plots with degradation level 3, with *N. oleander* being the dominant member of these plant communities (Figs 3 & 4). Some 20.2% of the plots proved to have a degradation level of 4 (Fig. 4). This was the case in the middle stretch of the Andarax River, at the mouths of the river Nacimiento and other substantial tributaries, and in a great number of the high and medium reaches of the Rivers Aguas and Carboneras. In 14.8% of the plots, the vegetation was almost destroyed (degradation level 5; Fig. 4), corresponding to the low courses of all the rivers and a great part of the rambla Morales.

Agriculture, mining, roads, and water channelling have probably had significant impact (Table 5). On the other hand, level of degradation did not vary with intensity of grazing, sewage, forest exploitation and the presence of human population centres (Table 5). The four activities that did show overall differences, did so between the medium and high intensities (Table 6). In agriculture and mining, differences also proved highly significant between no activity and medium intensity. In agriculture and water channelling, highly significant differences appeared between no activity and high intensity; these differences also occurred in mining ($p < 0.005$) and roads ($p < 0.05$) (Table 6).

Agricultural activities were indicated to be the most deleterious of the riparian flora, and extended throughout all the reaches of the watercourses. However, the traditional growing of grapevines and citrus trees in the river basin of the Andarax for at least 40 years has had less drastic impact than has the intensive agriculture under plastic in recent decades in the lowest and most arid zones, primarily in the rambla Morales, where the near-total destruction of natural riparian vegetation has resulted.

The road system, particularly the extensive network of rural lanes, is directly related to this activity, having expanded in recent years due to the mechanization of agriculture. Added to this is the fact that during a long period of the year the courses carry little or no flow, and the

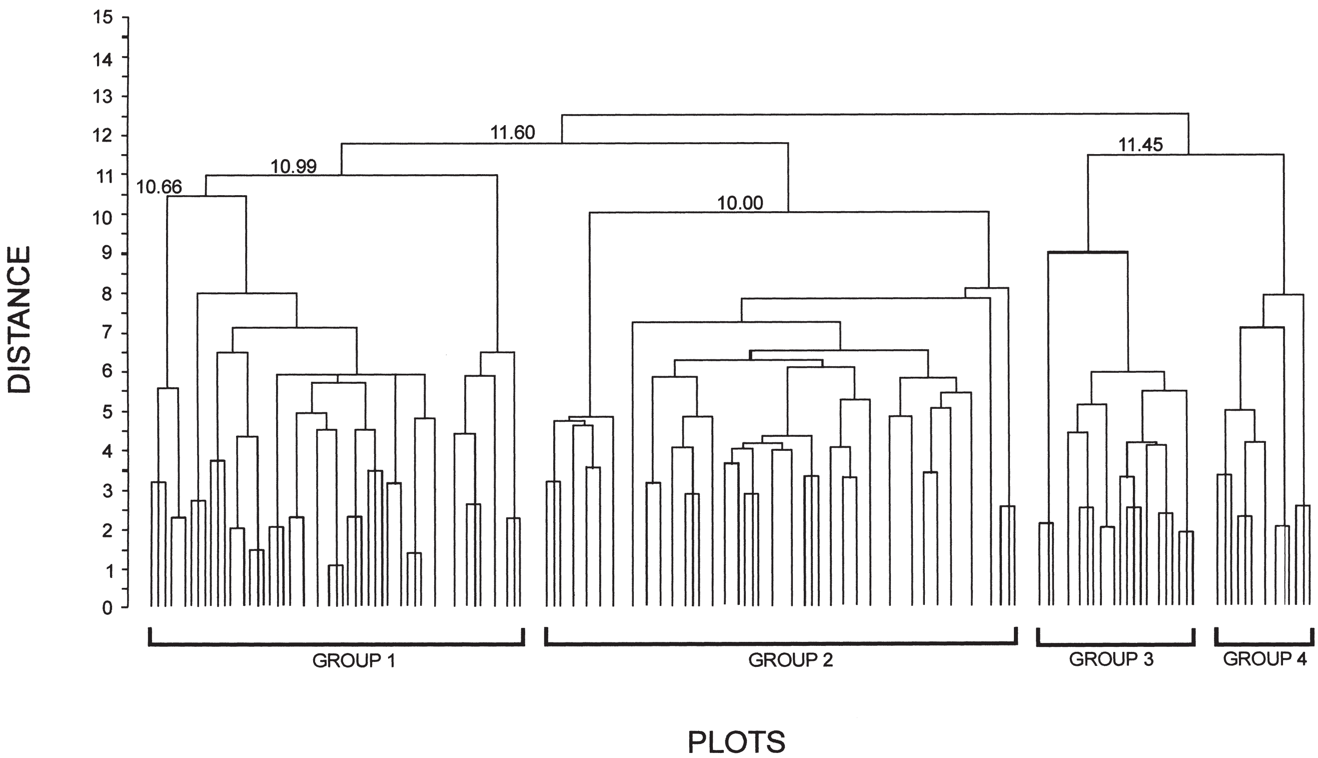

Figure 2 Cluster-analysis dendrogram of riparian vegetation.

riverbeds are used as roads for vehicles, leading to further damage to the vegetation.

Mining is restricted to the dredging of sand from the riverbeds, an activity that, although it completely destroys the vegetation, is quite limited in time and space.

Temporary ditches partially destroy the vegetation and alter the topography of the riverbeds (since the sand from these beds is used to bank the ditches); nevertheless, the consequences are reversible. Water channelling through pipes along the lower reaches of the principal watercourses (Andarax, Nacimiento, Aguas) has had negative consequences for the vegetation, by eliminating permanent riparian vegetation and replacing the natural substrata with concrete walls to channel the entire flow of the watercourse.

Although most of the population centres release sewage directly into the rivers, this factor does not seem alone to have visibly affected the state of the perennial vegetation.

Forestry has apparently not severely affected the state of the riparian vegetation, since a minimum band of 2–3 m has traditionally been left for natural vegetation near the riverbed, where a relatively good representation of autochthonous flora has survived. Despite this, there is evidence of selective chopping down of trees; when these areas were compared with less-exploited areas, the former had considerably lower species richness.

Discussion

The riparian vegetation in the study areas was found to be seriously impoverished in terms of species, compared with similar communities which have undergone less alteration, both along nearby watercourses (Cirujano 1981; Belmonte & Laorga 1987; Fernández-González *et al.* 1990; Ríos 1994; Salazar 1996), as well as geographically more distant examples (El-Sharkawi *et al.* 1982*a*, *b*; Reichembacher 1984; Hughes 1988; Szaro 1989, 1990; Roberts & Ludwig 1991; Medley 1992; Walford & Baker 1995).

The alder and willow groves of the Iberian Peninsula show a complex structure and high species richness (Rivas-Martínez *et al.* 1986; Salazar 1992; Ríos 1994). However, the low species richness and the lack of woodlands made up of alders and willows in the study area reflect the fact that these communities are far from their optimal environmental conditions (Salinas 1995), and are therefore likely to be vulnerable to any alteration caused by humans. Given that these trees are found in the highest and most inaccessible zones of the basins, the influence of human activities is not intense. Nevertheless, areas of alder and willow provide clear examples of marginal plant communities within the overall plant distribution area, a factor commonly associated with regression dynamics due to climatic stress (Silvertown & Lovett-Doust 1993; Eriksson 1996). An intense alteration

Table 3 Cover (%) for the four plant communities classified with the cluster analysis. * = exotic species, – = not recorded.

Species	*Stratum*	*Group 1*		*Group 2*		*Group 3*		*Group 4*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Alnus glutinosa (L.) Gaertner	1	–	–	–	–	–	–	71.8	25.6
Populus nigra L.	1	–	–	–	–	–	–	10.4	16.5
Adenocarpus decorticans Boiss.	2	–	–	–	–	3.9	7.6	0.1	0.5
Arundo donax L. *	2	6.5	14.3	1.3	4.5	–	–	–	–
Berberis hispanica Boiss. & Reuter	2	–	–	–	–	0.2	0.7	–	–
Coriaria myrtifolia L.	2	–	–	–	–	2.7	5.7	–	–
Coronilla juncea L.	2	–	–	0.6	1.8			–	–
Crataegus monogyna Jacq.	2	–	–	–	–	2.7	8.0	–	–
Cytisus grandiflorus DC.	2	–	–	–	–	–	–	0.7	2.7
Elaeagnus angustifolia L. *	2	1.6	6.5	–	–	–	–	–	–
Ephedra fragilis Desf.	2	0.1	0.1	0.1	0.9	–	–	–	–
Genista spartioides Spach	2	–	–	1.8	7.8	0.7	2.9	–	–
Lonicera periclymenum L. subsp. *hispanica* (Boiss. & Reuter) Nyman	2	–	–	–	–	2.4	4.5	–	–
Lycium barbarum L.*	2	1.9	5.3	–	–	–	–	–	–
Lycium intricatum Boiss.	2	0.4	3.1	0.3	1.6	–	–	–	–
Nerium oleander L.	2	2.7	8.8	56.3	22.7	–	–	–	–
Phragmites australis L. (Cav.) Trin ex Steud	2	1.3	5.4			–	–	–	–
Retama sphaerocarpa (L.) Boiss.	2	1.5	3.5	3.6	8.7	0.5	2.0	–	–
Rhamnus lycioides L.	2	–	–	0.1	0.3	–	–	–	–
Rosa canina L.	2	–	–	–	–	0.6	2.6	0.9	2.4
Rosa micrantha Borrer ex Sm.	2	–	–	–	–	1.9	3.4	1.5	4.7
Rosa pouzinii Tratt.	2	0.2	2.2	1.2	4.1	0.8	3.5		
Rubus ulmifolius Schott	2	1.3	6.3	0.8	3.7	5.4	7.7	2.5	2.2
Saccharum ravennae (L.) Murray	2	0.8	3.6	1.2	3.5	–	–	–	–
Salix atrocinerea Brot.	2	–	–	–	–	63.1	23.7	17.8	19.5
Salix purpurea L. subsp. *lambertiana* (Sm.) A. Neumann ex Rech. fil.	2	–	–	–	–	0.7	2.8	–	–
Salsola oppositifolia Desf.	2	0.6	3.4	1.6	6.1	–	–	–	–
Sambucus nigra L.	2	0.6	3.6	–	–	–	–	–	–
Sarcocornia fruticosa (L.) A. J. Scott	2	0.1	0.8	–	–	–	–	–	–
Scirpus holoschoenus L.	2	0.9	3.2	0.6	2.2	4.1	7.7	–	–
Suaeda vera Forskal ex. J. F. Gmelin	2	0.4	1.9	–	–	–	–	–	–
Tamarix africana Poiret	2	33.8	33.5	4.1	1.4	–	–	–	–
Tamarix canariensis Willd.	2	37.5	31.4	–	–	1.5	4.9	–	–
Withania frutescens (L.) Pauquy	2	–	–	0.8	3.9	–	–	–	–
Ziziphus lotus (L.) Lam.	2	–	–	4.3	14.9	–	–	–	–
Andryala ragusina L.	3	–	–	0.3	1.5	–	–	–	–
Anthyllis cytisoides L.	3	0.2	1.1	2.2	5.5	–	–	–	–
Anthyllis terniflora (Lag.) Pau	3	–	–	0.8	4.4	–	–	–	–
Artemisia barrelieri Besser	3	0.8	2.5	1.8	4.7	–	–	–	–
Artemisia campestris L.	3	0.6	2.3	1.8	6.2	–	–	–	–
Asparagus acutifolius L.	3	–	–	0.2	0.2	–	–	–	–
Atriplex halimus L.	3	2.4	6.9	–	–	–	–	–	–
Ballota hirsuta Bentham	3	0.5	2.5	1.9	6.9	–	–	–	–
Bupleurum fruticosum L.	3	–	–	–	–	0.9	2.5	–	–
Carlina corymbosa L.	3	–	–	0.6	0.4	–	–	–	–
Carthamus arborescens L.	3	0.1	1.1	0.3	1.9	–	–	–	–
Daphne gnidium L.	3	–	–	0.6	2.4	0.2	0.5	–	–
Dittrichia viscosa (L.) W. Greuter	3	2.1	5.2	2.4	6.1	1.1	3.0	–	–
Dorycnium pentaphyllum Scop.	3	–	–	0.6	3.5	–	–	–	–
Euphorbia characias L.	3	–	–	0.2	1.0	–	–	–	–
Helianthemum almeriense Pau	3	–	–	0.2	0.8	–	–	–	–
Helichrysum stoechas (L.) Moench	3	–	–	0.3	1.8	–	–	–	–
Helleborus foetidus L.	3	–	–	–	–	0.3	1.5	–	–
Hyparrhenia hirta (L.) Stapf	3	–	–	2.9	9.0	–	–	–	–
Inula crithmoides L.	3	0.2	0.2	–	–	–	–	–	–

Table 3 – continued

Species	*Stratum*	*Group 1*		*Group 2*		*Group 3*		*Group 4*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Lavandula multifida L.	3	–	–	0.1	1.1	–	–	–	–
Lygeum spartum L.	3	–	–	0.8	3.8	–	–	–	–
Nicotiana glauca R. C. Graham *	3	0.3	0.3	–	–	–	–	–	–
Ononis natrix L.	3	0.7	0.7	–	–	–	–	–	–
Phagnalon saxatile (L.) Cass.	3	–	–	0.5	2.6	–	–	–	–
Phlomis purpurea L.	3	–	–	0.4	1.9	–	–	–	–
Rosmarinus officinalis L.	3	–	–	0.1	1.3	–	–	–	–
Scolymus hispanicus L.	3	–	–	0.3	1.4	–	–	–	–
Thymelaea hirsuta (L.) Endl.	3	–	–	0.9	3.9	–	–	–	–
Thymus hyemalis Lange	3	–	–	0.2	1.1	–	–	–	–
Thymus zygis Loefl. Ex L. subsp. *gracilis* (Boiss.) R. Morales	3	–	–	0.2	1.2	–	–	–	–
Ulex parviflorus Pourret	3	–	–	0.6	3.6	–	–	–	–

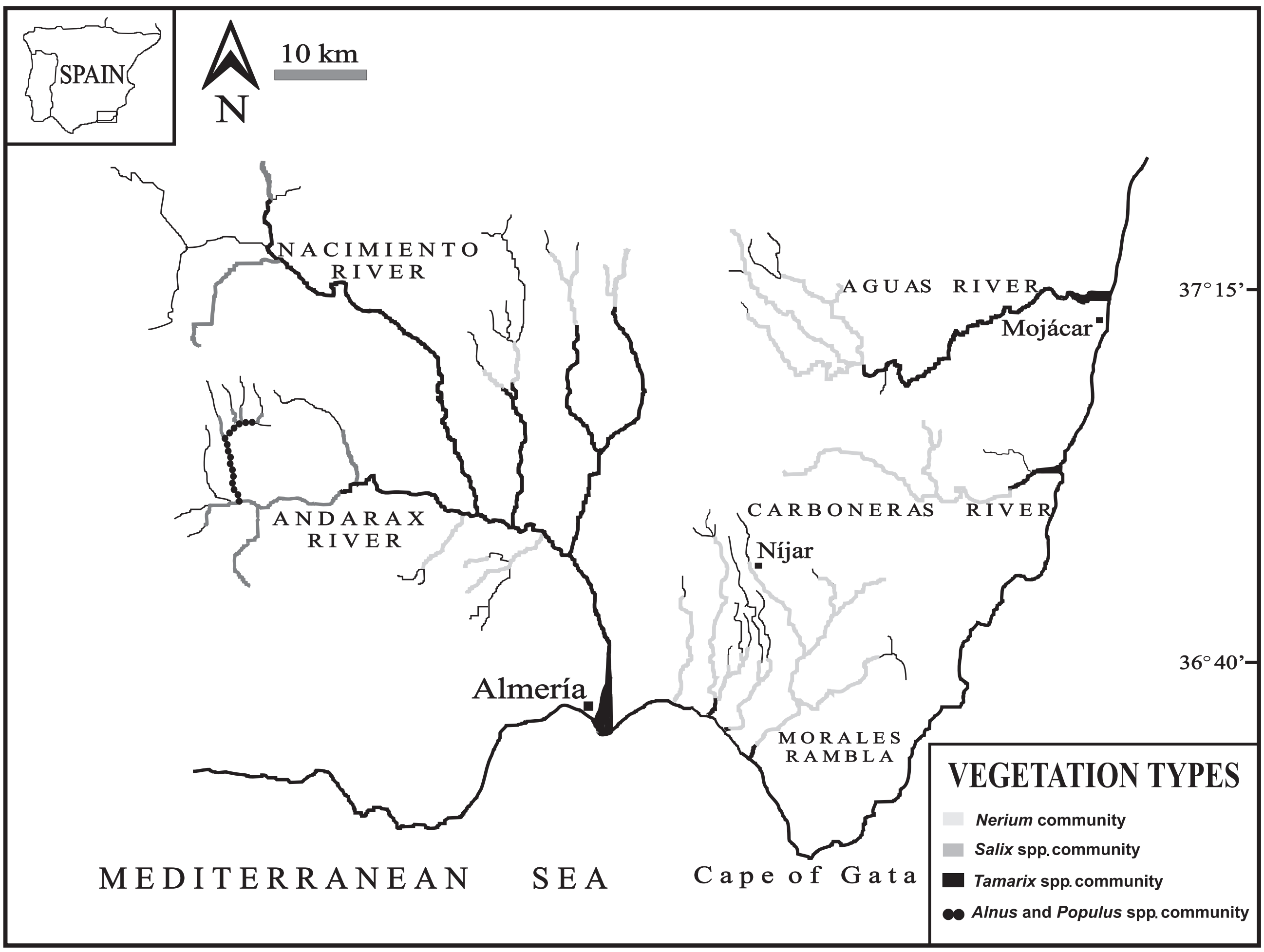

Figure 3 Distribution of the four groups of vegetation differentiated according to the cluster analysis.

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Table 4 Main abiotic characteristics of plant communities identified (per cent of plots).

		Plant community			
		Alders and poplars	*Salix spp.*	*Tamarix spp.*	*Nerium oleander*
Altitude (m)	0–250	0	0	13.2	34.9
	251–500	0	0	47.2	39.5
	501–750	0	0	28.6	13.9
	751–1000	0	34.8	8.8	11.7
	1001–1250	0	26.1	2.2	0
	1251–1500	0	26.1	0	0
	1501–1750	100	13	0	0
Landform	V-shaped valley, narrow foodplain	100	100	0	25.6
	Wide valley, narrow foodplain	0	0	12.1	34.9
	Wide valley, broad foodplain	0	0	87.9	39.5
Substratum	Limestones (rocky)	0	26.1	0	19.8
	Schists (rocky)	100	73.9	11.0	19.8
	Siliceous sandstones and conglomerates	0	0	35.2	41.9
	Marine origin marls	0	0	53.8	18.6

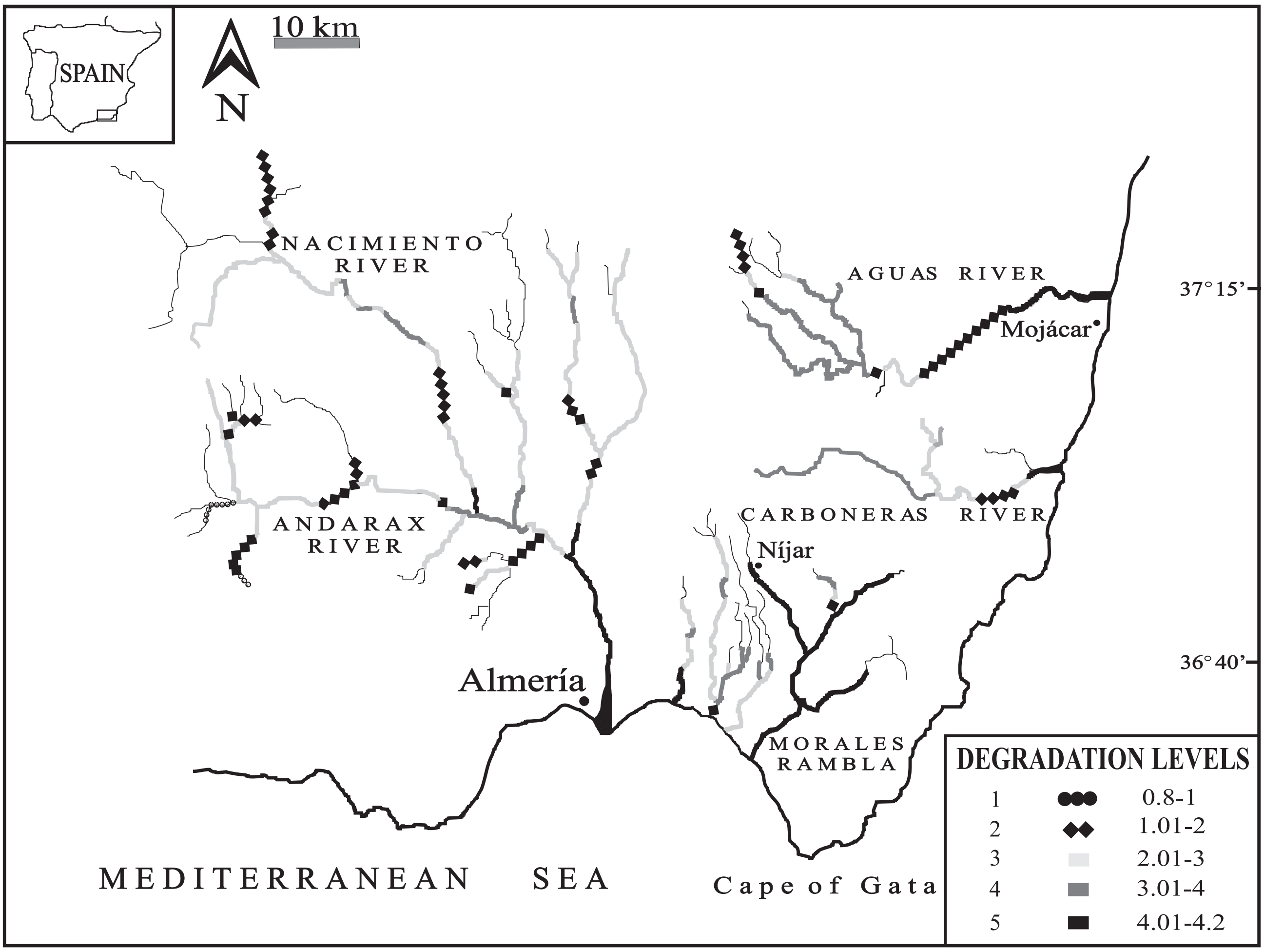

Figure 4 Means degradation levels of the vegetation along the different stretches of the watercourses.

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Table 5 Results of the ANOVA between the human activities and the status of the riparian vegetation: NS = non-significant, *** = $p < 0.0001$.

Activity	*Degrees of freedom*	*F*	*P*
Agriculture	2	165.85	***
Grazing	2	0.622	NS
Mining	2	50.749	***
Roads	2	88.51	***
Sewage dumps	2	0.394	NS
Channelling	2	86.86	***
Forestry	2	1.823	NS
Urbanization	2	1.303	NS

Table 6 Results of Tukey pairwise comparisons between intensity levels: NS = non-significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.0001$. (N = None, M = medium, H = high).

	Activity											
	Agriculture			*Mining*			*Roads*			*Channelling*		
Intensity level	*N*	*M*	*H*	*N*	*M*	*H*	*N*	*M*	*H*	*N*	*M*	*H*
N	—	***	***	—	***	**	—	NS	*	—	NS	***
M		—	***		—	***		—	***		—	***

would, in all probability, bring about an irreversible degradation of these communities. These communities should be considered an important focus for conservation in the study area, for their rarity and fragility in arid climates.

The oleander and tamarisk thickets, given their extent and complete adaptation to semi-arid environments would regenerate naturally with a reduction in negative human activities, notably farming. In the zones of mining and permanent ditches, it could be feasible to restore the plant cover. This procedure would not be excessively difficult or expensive, since the dominant species (*Tamarix* spp. and *N. oleander*) have a great capacity for rooting and vegetative reproduction when water is supplied, and they also tolerate periods of drought (López 1988).

The watercourses studied present an extremely reduced flow, often sporadic or null over the year. For this reason, annual perturbations due to floods hardly affect the perennial vegetation. Only floods of great magnitude, with a periodicity of decades, substantially perturb these communities. Therefore, the models of species richness applicable to wet courses (Connell 1978; Huston 1979; Sousa 1979, 1984; Nilsson 1986; Nilsson *et al.* 1989), which suggest that alpha diversity reaches a peak as a consequence of the spatial-temporal heterogeneity in fluvial areas where perturbation occurs by moderate-intensity flooding (Planty-Tabacchi *et al.* 1996; Tabacchi *et al.* 1996), are present but less evident because their temporal scale is different. In this way, it is possible to analyse their state of conservation, taking into account human activities and disregarding as much as possible the disturbances caused by the hydrological dynamics themselves.

Based on cover of natural vegetation, exotic species, and connectivity, Olson and Harris (1997) evaluated the relative potential for conservation and/or restoration of sites of the San Luis Rey River, California. In our study, we introduced, in addition, species richness and evidence of natural regeneration. Species richness provides information on the quality of the plant community, and in some instances, this has been used as the only evaluation index of zones to be preserved (Bojórquez-Tapia *et al.* 1995). In this way, the state of the community was not evaluated exclusively in terms of cover. The index of natural regeneration was a measure of the dynamism of regeneration, and thus also of the capacity for self-regeneration after a disturbance.

Except for agriculture, human activities with strong impact (mining and channelling of water), being limited to certain geographical points, have therefore apparently had less grave consequences. Paradoxically, in some instances, the zones disturbed by the extraction of sand from the riverbeds can give rise to helophyte communities that harbour important species of birds (Mota *et al.* 1995). One of these sandpits, which was abandoned after reaching the phreatic layer of the central aquifer Balanegra-Las Marinas, consisted of a large lagoon, which currently harbours one of the most important cenosis for riparian birds and ducks in the southern Iberian Peninsula (López-Martos *et al.* 1992).

In contrast to the observation of Elósegui and Pozo (1994) regarding the more mesic courses of the Iberian Peninsula, where the contaminating anions persist for long periods in the water, in the watercourses studied here, a reduction in nitrites and the ammonium ion during the hottest periods (Salinas 1995) corresponds to a rise in biological activity during the dry period, resulting in the consumption of these anions. This may explain why no alterations to the riparian vegetation were observed even on the banks adjacent to and near the sewage release points.

Conclusions

The plant communities distributed along the watercourses of the study zone have undergone major alterations and in general have been seriously degraded as a result of human activities. The most destructive of these activities has proven to be agriculture, and the expansion of roads. Intensive agriculture has proved more destructive than traditional fruit cultivation. Sand dredging is a periodic activity and, while severely damaging to the riparian vegetation, in some cases engenders new habitat. The channelling away of water and the failure to maintain minimum flows in the courses has exacerbated the aforementioned negative effects on the vegetation.

Due to long periods of dryness, the contaminating anions from local sewage do not appear to exert negative effects on the vegetation. The forestry activities do not apparently have serious consequences either for the species richness of the riparian vegetation.

The combination of five indices characteristic of the vegetation has enabled us to establish the state of conservation of the riparian vegetation in the watercourses in our study zone, where there is a semi-arid Mediterranean climate. We found this method can be of great utility in providing rapid and precise information for the management of natural spaces, and can satisfy the need for useful data which can be collected within a short time interval, so that appropriate action can be identified swiftly in the most degraded zones.

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