

Mediterranean saline streams in southeast Spain: What do we know?

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ABSTRACT

Many Mediterranean streams in arid and semiarid areas are naturally saline systems due to the presence of evaporitic rocks of Miocene or Triassic origin. Despite the fact that these aquatic ecosystems are rare in Europe, they are common in southeast of Spain. The environmental constraints of these semiarid saline streams are imposed by both geological and climatic conditions. This paper is a compilation and summary of the principal results obtained from various studies on semiarid saline streams in the Iberian southeast. Available data for these typical environments in the region covers diverse issues such as those regarding their physical and chemical features, typology, biodiversity, community structure and ecosystem functioning, as well as different ecological and evolutionary aspects of their biota (e.g. ecophysiological responses, life cycles and phylogeography). Issues concerning the conservation of these habitats, such as the main human uses, impacts, threats and their management are also summarised. Finally, topics in need of further research are provided. The current knowledge of saline streams in southeastern Spain highlights the physical and ecological singularity of these environments, and their high conservation value. Saline streams are particularly interesting due to their halotolerant/halophilic biota and high number of rare and endemic species.

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1. Introduction

The Mediterranean basin is a region of special biogeographic interest, and is regarded as one of World's biodiversity hotspots (Myers et al., 2000), which host a wide variety of inland aquatic habitats. Among them, saline ecosystems are considered especially singular. These ecosystems are naturally saline due to the presence of evaporitic rocks of Miocene or Triassic origin. Although these environments are rare in a European context, globally they are distributed in arid lands (Williams, 1996) such as southeast Spain.

However, most research has focused on Mediterranean freshwater streams, and much less attention has been paid to the ecology of saline streams. This may be due to their scarcity and scattered geographical distribution, and the low economic value assigned to the environmental services which these systems provide (Moreno et al., 2010). Several reviews dealing with aquatic ecosystems, saline or freshwater, in xeric areas reflect this dearth of knowledge (Gasith and Resh, 1999; Gómez et al., 2005).

Research on natural saline streams has been principally carried out in the semiarid southeast of Spain. The *Chicamo* and *El Reventón* streams, both hyposaline, and the *Rambla Salada*, a naturally hypersaline stream which became a mesosaline system due to human influence, have been intensively studied (Fig. 1). These studies highlighted ecological, biogeographical and conservation interests in terms of physical and chemical features (Moreno et al., 1995; Vidal-Abarca et al., 2000, 2001), organic matter dynamics (Martínez et al., 1998; Vidal-Abarca et al., 2004), primary production (Suárez and Vidal-Abarca, 2000; Velasco et al., 2003), life cycles and secondary production (Barahona et al., 2005; Moreno et al., 2008; Perán et al., 1999, 2000), and singularity of both aquatic invertebrates (Gallardo-Mayenco, 1994; Moreno and De las Heras, 2009; Moreno et al., 1997, 2010; Velasco et al., 2006; Sánchez-Fernández et al., 2008), and flora taxa (Aboal, 1986; Aboal and Fletcher, 1996; Moreno et al., 2001; Ros et al., 2009). The response of these systems to some natural and anthropogenic disturbances has been also studied, such as the reestablishment of macroinvertebrate communities after floods (Ortega et al., 1991), and the effects of dilution disturbances on community structure (Velasco et al., 2006) and ecosystem metabolism (Gutiérrez-Cánovas et al., 2009). Other recent studies have dealt with the development of a biological index to determine ecological status

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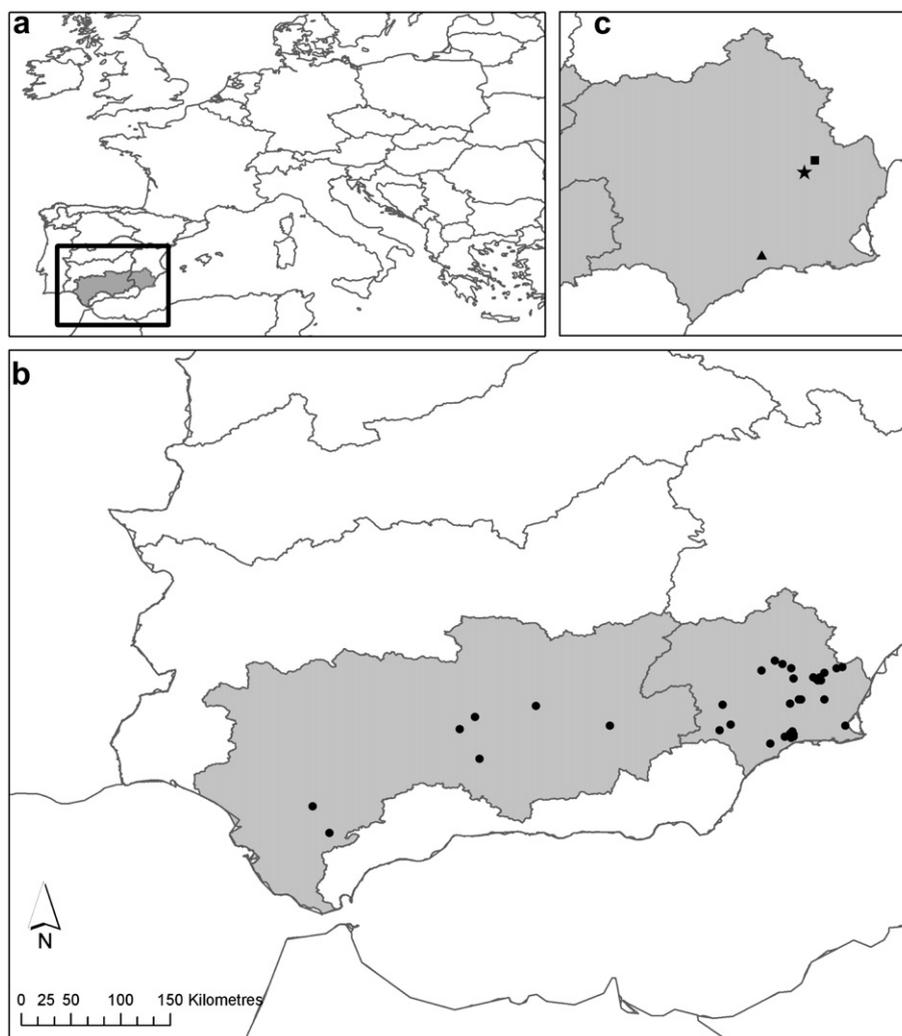


Fig. 1. Location of principal saline streams in the Guadalquivir and Segura basins (shaded areas). (a) Location of basins; (b) Location of studied saline streams; (c) Location of Chícamo stream (square), Rambla Salada stream (star), Reventón stream (triangle) in the Segura basin.

(Gutiérrez-Cánovas et al., 2008), molecular studies of genetic diversity and phylogeography of endangered aquatic coleoptera (Abellán et al., 2007, 2009), and physiological studies on the thermal tolerance of selected water beetles (Sánchez-Fernández et al., 2010). These studies suggest that while semiarid saline streams share some characteristics with Mediterranean freshwater streams, they differ in many other structural and functional aspects, fundamentally species composition, due to the strong selective pressure exerted by salinity.

The present work aims to compile and summarise the main results obtained from various studies focused on saline streams carried out in the Segura and Guadalquivir basins, southeast Iberia, to determine current knowledge and further research needs.

2. Geomorphology, hydrology and biochemistry

In general, the occurrence of saline streams in the Iberian southeast seems to be linked to the specific lithologic and the maintenance of climatic features for thousand of years. On one hand, calcareous (limestone and marls) and evaporitic outcrops (mainly made up of anhydrite, gypsum, halite and sylvine) are abundant as a consequence of marine introgression and regressions incidents to continent. Around 200 million years ago, during the

Late Triassic period, the eastern half of the Iberian Peninsula was invaded by the Tethys Sea, which suffered cyclical processes of seawater evaporation and refilling. Other evaporitic processes have occurred in more recent times, such as the Messinian crisis during the Miocene period (Carrasco and Hueso, 2008). Within the dataset of saline streams studied from the Segura and Guadalquivir basins, the percentage of evaporitic rocks in the basin is usually higher than 20% and accounts for the 30% of the water conductivity variance when modelling (linear regression) mean site conductivity using site's basin percentage of evaporitic rocks as predictor variable (see Appendix A).

Saline ecosystems are generally located in small watersheds at low and medium altitudes (Fig. 1), with low mean precipitation (369 mm) and high mean and maximum mean temperatures (16.4 and 31.6 °C, respectively) (Appendix A). Only 33% of the streams display a permanent flow regime, while 55% have intermittent flow (with a dry phase) both at spatial and temporal scales, and 12% are ephemeral courses (flow only after strong rains).

The anionic composition of saline water is dominated by chloride and sulfate (Vidal-Abarca et al., 2000), although the relative concentration of both main anions seems to change in relation to the occurrence of different geological deposits in the basin. Carbonates are also high in comparison to other freshwater courses,

as a result of the important presence of calcareous rocks, which yield highly buffered waters and display pH values ranging from nearly neutral to slightly basic. Iberian saline streams are characterised by a high nutrient concentration, especially in nitrogen compounds (e.g., Gutiérrez-Cánovas et al., 2009; Velasco et al., 2003; Vidal-Abarca et al., 2000). This concentration tends to increase with the mineralisation degree even in natural basins, suggesting that the alternating origin of nitrogen compounds may be associated with nitrogen bedrock (Gómez et al., 2009; Holloway et al., 1998) rather than anthropogenic pollution.

3. Typology of saline streams

The first classification of Spanish saline streams based on biotic and abiotic variables identified six types of saline streams (Arribas et al., 2009). A first split separates polluted streams from those well conserved. Within each of these two main groups, three types of saline streams were outlined with respect to their different macroinvertebrates communities, especially water beetle species: low saline streams ($5\text{--}30\text{ mS cm}^{-1}$), medium-high saline streams ($>30\text{--}130\text{ mS cm}^{-1}$) and very high saline streams ($>130\text{ mS cm}^{-1}$).

For the least-disturbed saline streams of the Iberian southeast (Appendix A), three clear types were found performing a β -flexible cluster analysis based on macroinvertebrate families composition. Samples from this data set were ordinated in a conductivity gradient as shown in the Multidimensional Scaling Plot (Fig. 2). These groups may be linked to different salinity levels with similar ranges (Table 1) to those proposed by Arribas et al. (2009) for the Iberian saline streams. The lowest salinity type (hyposaline streams) are found in larger basins, at higher altitudes, and with

Table 1

Median (50th) and 10th and 90th percentiles of environmental variables that characterise the three types of basins of the semiarid saline streams in the Segura and Guadalquivir basins. (MaxTemp: Maximum Mean Temperature).

Percentile	Conductivity (mS cm^{-1})			Area (ha) 50th	Altitude (m) 50th	MaxTemp ($^{\circ}\text{C}$) 50th
	10th	50th	90th			
Hyposaline	4.1	16.7	22	920	971	30.8
Mesosaline	40	83.7	160	814	674	32.7
Hypersaline	147.3	231	315.2	172	453	32.8

lower maximum mean temperatures than are mesosaline and hypersaline streams.

4. Aquatic and riparian biodiversity

The harsh environmental conditions that occur in saline ecosystems are an insurmountable barrier for many species and shape the kind of organisms that inhabit them. Appendix B displays the most common taxa of aquatic macroorganisms (macrophytes and macroinvertebrates) and riparian vegetation in saline streams from the Iberian southeast (vertebrates and terrestrial invertebrates were not included in this review). These organisms are adapted to the extreme conditions of high salinity and temperature and to marked hydrological fluctuations of severe dry periods and floods.

In relation to submerged macrophytes, the most frequent species are the macroalgae *Chara vulgaris*, *Cladophora glomerata*, *C. fracta*, *Enteromorpha intestinalis*, *Vaucheria dichotoma* and the phanerogam *Ruppia maritima*. Low-mineralised waters may display large amounts of *C. vulgaris*, while *C. glomerata*, *E. intestinalis* and *R. maritima* may occur in mild to intermediate salinities (Gutiérrez-Cánovas et al., 2009; Moreno et al., 2001; Ros et al., 2009; Velasco et al., 2003). In hypersaline streams, diatoms and cyanobacteria are the most important autotrophic organisms, which make up a biofilm that almost entirely covers the streambed (Aboal et al., 1996; Ros et al., 2009).

In general, riparian vegetation is scarce and diminishes with increasing soil salinity. *Phragmites australis*, *Juncus maritimus* and *Tamarix canariensis* are abundant examples of riparian vegetation in hyposaline streams, while halophytic low-size plants (e.g. *Salicornia racemosa*, *Sarcocornia fruticosa* and *Arthrocnemum macrostachyum*) occur in mesosaline and hypersaline streams.

Among the aquatic macroinvertebrates, Diptera, Coleoptera and Heteroptera are the most diverse groups inhabiting saline streams (Moreno and De las Heras, 2009; Millán et al., 2009; Velasco et al., 2006). Ephemeroptera (Baetidae), Trichoptera (Limnephilidae, Hydropsychidae), Odonata (Aeshnidae, Libellulidae and Coenagrionidae), Crustaceans (Gammaridae), Hydrachnidia and Mollusca (Hydrobiidae) taxa are scarce with most inhabiting hyposaline streams (Mellado et al., 2008). Within the Diptera; Chironomidae, Ceratopogonidae, Ephydriidae, Stratiomyidae and Syrphidae families were the most common, although Dolichopodidae, Culicidae and Tabanidae, can also be present (Moreno and De las Heras, 2009).

Nevertheless, the fauna of Coleoptera and Heteroptera is well known. Appendix B shows the 29 and 15 species of aquatic Coleoptera and Hemiptera respectively, most commonly found in saline streams. Among the Hemiptera, Corixidae are frequent in depositional patches of low to moderate mineralisation. The most representative species are *Sigara scripta* in hyposaline streams, and *S. selecta* in mesosaline streams. Within the Coleoptera, three families (Hydraenidae, Hydrophilidae and Dytiscidae) contain halotolerant species along the salinity gradient. The genus *Ochthebius*

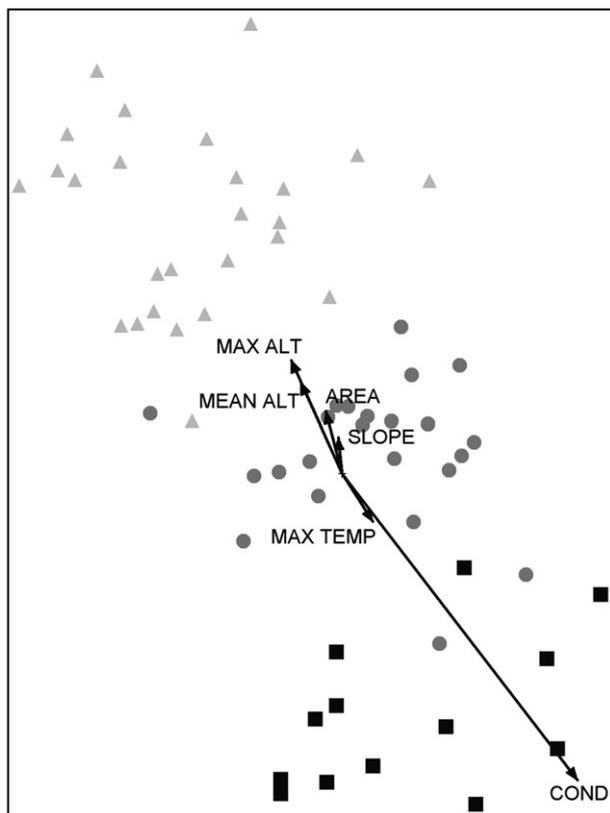


Fig. 2. Multidimensional scaling plot based on macroinvertebrate communities of southeast Spain saline streams (Triangles: Hyposalines; Circles: Mesosalines; Squares: Hypersalines). Environmental gradients are also plotted. Stress = 0.11.

(Hydraenidae) has the greatest number of halophilic species. *O. glaber* exhibits the highest salinity tolerance, as it is present throughout the entire salinity range and is able to inhabit saturated brine. Among diving beetles, *Nebrioporus baeticus* is typical of mesosaline streams, as well as the hydrophilids *Enochrus falcarius* (Velasco et al., 2006).

5. Ecophysiological responses

Physiological tolerance to the extreme physical and chemical conditions in saline aquatic ecosystems represents an avenue of escape from the adverse influences of predation and competition found in more diverse freshwater communities. Salt acts like a toxic substance that threatens an organism's internal hydric stability. Thus, species inhabiting saline water habitats show different physiological mechanisms that palliate salt's effects. Osmoregulators maintain their internal solute concentrations at a level lower than the external medium by producing a hyperosmotic fluid secretion. Osmoconformers, however, accumulate high levels of ions and compatible solutes in the haemolymph, so that their osmotic concentration exactly matches that of the external medium (Bradley, 2008, 2009). To date, there are no studies about osmotic mechanisms for Spanish semiarid saline species, but it could be expected that osmoconformers would be found at lower salinities and osmoregulators at higher salinities, as occurs with the Diptera species (Garrett and Bradley, 1987).

Climatic, geomorphologic and hydrologic conditions in semiarid saline streams enable important daily thermal fluctuations. This is especially relevant concerning the maximum temperatures that occur during summer, when air temperatures can exceed 40 °C. For example, eggs of the boatmen *Sigara selecta* tolerate an extremely wide range of salinity (2–75 g L⁻¹) and very high water temperatures (32 °C) (Barahona et al., 2005). Furthermore, some aquatic beetles studied in thermal tolerance experiments have shown a wide tolerance to extreme air temperatures, in some cases, nearly at the limits recorded for insects. The upper thermal tolerance, of *Nebrioporus baeticus*, is greater than 45.4 °C and the lower thermal tolerance is below -5.20 °C (Sánchez-Fernández et al., 2010). For *Enochrus falcarius*, thermal limit range from 53.07 to -11.57 °C (Arribas et al., unpublished results). Salinity influences the thermal tolerance and acclimatory ability of these saline beetles as evidences by Sánchez-Fernández et al. (2010) who showed that lowered salinity compromises the ability of adult *Nebrioporus* to cope with high temperatures.

6. Life cycles

In warm-water streams, such as those found in arid and semi-arid zones, rapid growth rates and asynchronous development are common features of insect populations (Fisher and Gray, 1983; Jackson and Fisher, 1986). To date, only two species of saline insects have been studied in terms of life cycle and secondary production: the mayfly *Caenis luctuosa* (Perán et al., 1999, 2000) and the hemipteran *Sigara selecta* (Barahona et al., 2005). In addition, Moreno and De las Heras (2009) have also reported data on the life cycles of the Diptera taxa in a hyposaline stream. Other studies have been conducted on the life cycle of water mites (Moreno et al., 2004, 2008), focusing on the behavior of *Ignacarus salarius*, which is the first case of ovoviviparity reported in this group. All the insects studied were multivoltine displaying three to five generations per year. These species presented continuous reproduction, indiscernible and overlapping cohorts and rapid development. These studies also reported high secondary production rates in relation to other less arid habitats (Barahona et al., 2005; Perán et al., 1999). These species traits are possibly due to

mild winters and warm springs and summers which allow an abundance of food resources. Moreover, these features are a response to frequent flash floods and droughts.

7. Community structure and ecosystem functioning

Several studies covering a broad salinity gradient have reported an inverse relationship between mineralisation degree and taxa richness in saline lakes (e.g., Herbst and Blinn, 1998; Williams et al., 1990) and wetlands (e.g., Pinder et al., 2005). However, this relationship has yet to be studied in streams. Linear regression models using our saline stream data set reflected a negative correlation between conductivity and macroinvertebrate family richness ($R^2 = 80\%$). Similar, but slightly less accurate models were obtained for Coleoptera ($R^2 = 63\%$), Hemiptera ($R^2 = 69\%$) and the rest of the macroinvertebrate families ($R^2 = 70\%$). Water conductivity, hydrological stability and seasonality appears to be the most important factors determining the aquatic community composition for benthic diatoms (Ros et al., 2009), submerged macrophytes (Moreno et al., 2001) and macroinvertebrates (Gutiérrez-Cánovas et al., unpublished results; Moreno et al., 1997, 2010; Velasco et al., 2006).

In saline streams, aridity and soil salinity diminish the presence of riparian vegetation (Hart et al., 1991) which allows light to easily reach the streambed (Fig. 3c). Thus, autotrophic streams are expected to occur frequently in the most arid areas of Mediterranean basin (Gasith and Resh, 1999). Studies of metabolism performed in saline streams found high primary producer standing crops and primary production rates compared with perennial and temporary freshwater Mediterranean streams (Fig. 3c), which peak in spring and summer (Gutiérrez-Cánovas et al., 2009; Velasco et al., 2003, 2006). These studies reported positive net production rates that suggest saline streams are autotrophic ecosystems. Among primary producers, epipellic biofilm dominated in biomass and coverage terms, accounting for most of the gross primary production (GPP) and ecosystem respiration (ER) in the Chicamo stream (Velasco et al., 2003). Temperature and light are the most important predictors of GPP and ER in saline courses (Gutiérrez-Cánovas et al., 2009; Velasco et al., 2003). However, nutrient concentrations did not explain an important amount of metabolic rate variability, reflecting lower nutrient limitation in comparison to other freshwater Mediterranean streams (Guasch et al., 1995; Sabater et al., 2006).

Due to the scarcity of riparian vegetation, fine and ultrafine benthic organic matter are most commonly found, while coarse particles (i.e., leaves, stems and wood) are scarce (Martínez et al., 1998; Vidal-Abarca et al., 2004; see Fig. 3). Detritus dynamics are driven by the hydrologic regime and peaks in primary production. During late spring and summer, low flow and high primary production rates contribute to a large accumulation of organic detritus. However, the ultimate factor that determines detritus standing stock in saline streams is flash flood frequency. Thus, spates can completely wash up a streambed at any time (Gutiérrez-Cánovas et al., 2009; Vidal-Abarca et al., 2004). Food webs appear to be supported by an important amount of autochthonous resources as found in other open canopy streams (Gasith and Resh, 1999). Thus, in biomass terms, the most abundant functional feeding groups are gathering-collectors, scrapers and predators, while filtering-collectors and shredders are scarce or even absent (Gutiérrez-Cánovas et al., unpublished results; Moreno et al., 2010).

8. Evolutionary and phylogeographic aspects

Phylogeographical information on organisms living in saline environments is scarce and limited to only a few species.

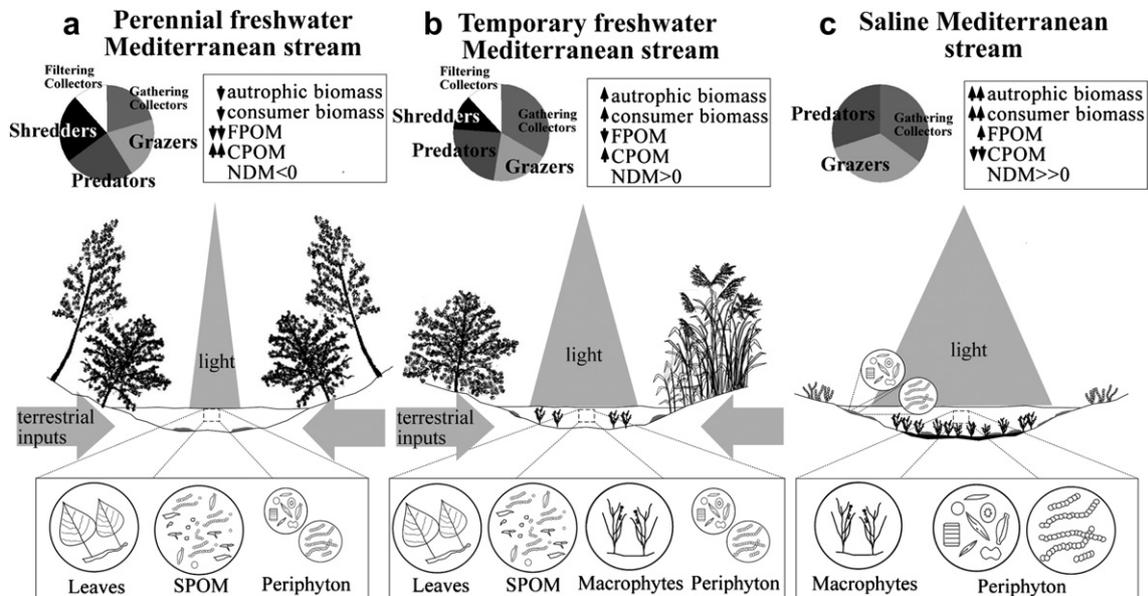


Fig. 3. Scheme outlining the functioning of a Mediterranean stream along a gradient of aridity and water salinity. (FPOM: Fine particulate organic matter; CPOM: Coarse particulate organic matter; SPOM: suspended particulate organic matter; NDM: net daily metabolism).

Nevertheless, the published studies show that the discontinuous and patchy distribution of aquatic saline environments seems to have promoted allopatric speciation and high levels of divergence amongst isolated populations of invertebrate taxa. Habitat discontinuities operate as an effective barrier to gene exchange and are emerging as a critical factor shaping phylogeographical structures (Abellán et al., 2007, 2009; Gómez et al., 2000). Thus, some aquatic beetle species from hypersaline streams have been reported to have, on average, high levels of genetic diversity and phylogeographical structure. This is especially the case of *Ochthebius glaber*, a small hydraenid endemic to the south of the Iberian Peninsula. This species reveal a surprisingly high degree of geographical structure that is detectable among populations separated by relatively short geographical distances. Phylogeographical analyses have revealed three main groups of haplotypes throughout its distribution range, one of which groups populations from southeastern Iberia (Fig. 4). Apparently, they have been isolated for significant periods of time, supporting the recognition of these three lineages as separate evolutionary units (Abellán et al., 2007).

Furthermore, the type of habitat, whether a standing (lentic) or running (lotic) water body, has emerged as a determinant in the variation of the degree of phylogeographical structure found between pairs of sister species of saline water beetles (Abellán et al., 2009). Species typical of running waters tend to display higher levels of genetic diversity and phylogeographical structure than their correlatives that inhabit standing waters. These results have been interpreted to be the result of a higher colonisation propensity of lentic species due to lower habitat persistence, in concordance with the general framework proposed for aquatic organisms (Ribera, 2008).

9. Human uses and impacts

Despite their high conservation interest and narrow distribution in a European context, saline streams are subjected to intense anthropogenic pressures (Sánchez-Fernández et al., 2008; Velasco et al., 2006). This fact is probably a result of the low economic value that society places on such habitats. In addition, saline streams are located in lowland and coastal areas which are subject to more intense and frequent changes in land use (Martínez-Fernández et al.,

2000). These particular ecosystems are adversely affected by a set of anthropogenic activities (see Table 2), of which agriculture is the most relevant in southeast Spain.

Agriculture in large areas of the Mediterranean basin has changed from extensive dry crops to intensively irrigated crops. This transformation has caused a diffuse and continuous freshwater input to the channels which has led to a gradual decline in the natural salinity of the streams and also an increase in nutrient concentration due to widespread use of fertilisers (Gómez et al., 2005). The effects of dilution on the composition and structure of the aquatic community and ecosystem function have been studied

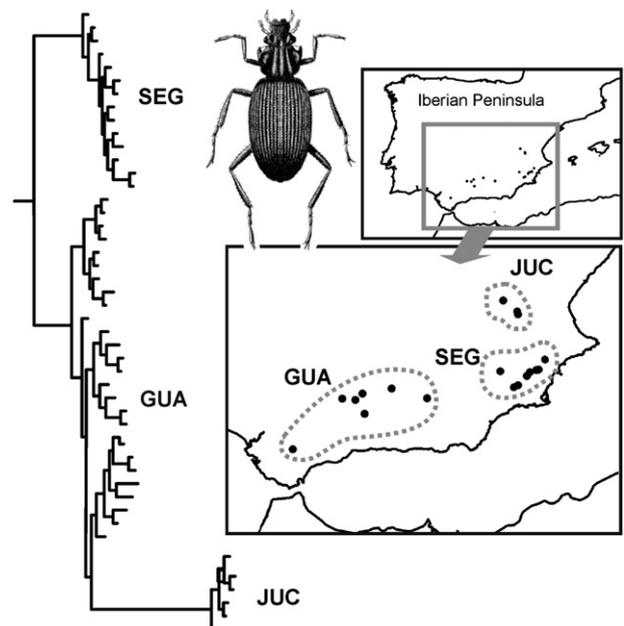


Fig. 4. Phylogeographical structure found in the water beetle *Ochthebius glaber*. The figure shows the phylogenetic tree obtained from mitochondrial DNA data (Abellán et al., 2009), with populations grouped in three main clades (SEG, Segura River Basin; GUA, Guadalquivir River Basin; and JUC, Júcar River Basin), and the geographical distribution of its known populations.

Table 2

Summary of the main human activities and their impacts in saline Mediterranean streams (modified from Gómez et al., 2005).

Human activities	Impacts
1. Water derivation and cultivation of irrigated crops	Channel desiccation (1, 2, 4)
2. Dam construction	Alteration of water flow regime and sediment transport (1, 2, 3, 4)
3. Water transfer projects	Physical barrier for organisms (2)
4. Groundwater extraction	Decrease of water salinity (1, 3)
5. Sand and gravel extraction	Changes in aquatic community composition (2, 3)
6. Rubbish and effluent (liquids and solids) dumping	Introduction of exotic species (3)
7. Channelization	Groundwater overexploitation (4)
8. Urbanization (parking places, parks and building construction)	Alteration of the channel bed geomorphology (5, 7, 8)
9. Vegetation burning (to create fresh pastures)	Elimination of riparian vegetation (5, 7, 8, 9, 10, 11)
10. Grazing	Alteration of hydrological processes (1, 5, 7, 8, 9)
11. Moto-cross and all-terrain vehicles	Habitat destruction and alteration of aquatic communities (1, 5, 7, 8, 9, 10) Replacement of natural plant communities by weed species (5, 6, 7) Hyporheic habitat disappearance (5, 7, 8) Surface and groundwater pollution (1, 6, 10)

in *Rambla Salada* stream (Gutiérrez-Cánovas et al., 2009; Velasco et al., 2006). Short-term, freshwater inputs caused by periodic losses of water through an irrigation channel reduce the biofilm biomass, while enhancing filamentous algae proliferation. At a local scale these inputs also cause an increase in the richness and diversity of macroinvertebrate species, whilst provoking a decrease in the abundance, or elimination, of the most halophilic species (Velasco et al., 2006), thereby causing a loss in global biodiversity. Dilution events appear to relax osmotic stress allowing macrophyte proliferation and a significant increase of predator and total macroinvertebrate biomass. However, long-term dilution disturbances can lead to a change from an autotrophic to a heterotrophic ecosystem metabolism, as well as an increase of benthic organic matter and a depletion of the aquatic primary producer and consumer biomass.

Other impacts on saline streams include the modification of channel bed geomorphology by sand and gravel extraction and stream channelisation, as well as alteration of flow regime by dams and the overexploitation of springs and aquifers. Additionally, grazing, solid residuals and wastewater or industrial waste inputs are relatively frequent in saline streams. Some exotic species have also been found in saline streams, being the most common the gasteropod *Potamopyrgus antipodarum* and the mosquitofish *Gambusia holbrooki* Girard, 1874 (Velasco et al., 2006).

Although these ecosystems display high stability to discrete anthropogenic disturbances, since their inhabitants are adapted to extreme, often rapid, natural environmental changes, chronic disturbances can conduct to drastic and permanent changes in metabolism and ecosystem functioning and the subsequent loss of the natural values of these singular ecosystems.

10. Management and conservation

Saline streams are valuable ecosystems whose biological, functional and cultural values must be recognised to ensure their conservation. The biodiversity of saline streams includes

physiological specialists adapted to stressful conditions (high levels of temperature and salinity), and endemic species that often occur as highly isolated populations, which display a high degree of vulnerability. From the 29 most common species of water beetles in saline streams, 5 are endemic of the Iberian Peninsula, 6 have Ibero-african distribution and 2 show a disjunct distribution. Among them, the most remarkable are the endangered species *Ochthebius montesi* and *O. glaber* (Barea-Azcón et al., 2008; Verdú and Galante, 2006). Both species are subject to high habitat specificity and habitat fragmentation due to the impact of irrigated crops surrounding the saline reaches (Sánchez-Fernández et al., 2004; Velasco et al., 2006). There is a risk that aquatic diversity at regional and global levels will be reduced as the most halophilic and vulnerable species in the Mediterranean region are eliminated.

Saline streams contain various habitats of European interest, such as salt and gypsum continental steppes, Mediterranean salt marshes and salt meadows. Despite their high conservation interest and restricted distribution of habitats and species on a European scale, the Natura 2000 network fails to protect saline streams (Sánchez-Fernández et al., 2008). Passive measures of management and conservation, such as the declaration of protected areas, are not sufficient to deal with the numerous threats to saline streams. This is especially true as the main processes which alter aquatic ecosystems occur at the basin scale and often happen outside of the boundaries of protected areas. Thus, whole-basin management and natural-flow maintenance are indispensable strategies for saline stream conservation.

Given the high genetic diversity found in halophilic species (Abellán et al., 2007, 2009) and the natural instability of hypersaline environments, it seems likely that efforts to preserve individual populations that could be considered representative of the different evolutionary units are futile as this will not warrant the preservation of the process which generates and maintains their diversity. It could be argued that the conservation of a whole network of populations and potential habitats is necessary for the preservation of the processes that underlie the generation of the observed pattern. These considerations should be useful for futures conservation and/or restoration plans for saline systems. These plans should take into account streams, associated wetlands, salt-pans (and their traditional uses) and landscape considerations (mainly controlling irrigation crops expansion in the stream basin).

11. Further research needs

Further studies appear to be needed, especially those related to the physiological, ecological and molecular genetic approaches to broaden the understanding of the evolution of saline water specialists in different lineages. Additionally, the physiological and ecological traits related to colonisation processes and the exploration of the vulnerability of populations and species to a changing environment must be addressed.

The evolutionary pathway by which organisms have colonised inland saline environments has also been poorly studied. Thus, the evolution of salinity tolerance remains unknown for many insect groups, including typical representatives of saline waters, such as beetles. Specific studies are necessary to clarify the existence of evolutionary patterns and identify the implicated ecological and physiological traits. Therefore, the study of the differential tolerances to salinity and the ionic composition of saline waters between sister species could provide us the key to understanding speciation processes.

In a number of groups, including water beetles, temperature tolerance is a trait linked to the size of range distribution. The study of tolerance to temperature in saline organisms, and its interaction with salinity could answer biogeographical and evolutionary

questions. The construction of ecological niche models that incorporate physiological data could help to predict the vulnerability of species to current and future global change scenarios, thus enhancing species conservation.

Although saline streams are recognised as autotrophic ecosystems (Martínez et al., 1998; Perán et al., 1999; Velasco et al., 2003) there is poor knowledge concerning how the energy is continuously exported to other ecosystems. Specific studies which quantify and characterise the routes and mechanism used to supply the energy to other ecosystems would be of scientific global interest.

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jaridenv.2010.12.010

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