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# *Loss of Ostracoda biodiversity in Western Mediterranean wetlands*

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## ABSTRACT

1. The coastal area of Valencia (Spain) in the Western Mediterranean is rich in freshwater and brackish wetlands. These areas are mostly protected for bird conservation but are also highly affected by human impacts. Six shallow lakes located in Ramsar wetland sites of this area were studied in order to assess past and present ostracod biodiversity and relate it to the status of the lakes, taking into consideration the indicator value of these easily fossilizable crustaceans.

2. In all the wetlands studied, ostracod taphocoenoses showed much higher species richness than the corresponding biocoenoses. This is expected from the time accumulative character of the taphocoenosis, but the trend is clearly evident in the most disturbed sites which indicated loss of ostracod diversity owing to human impacts.

3. By considering the ecology of most frequent species, multivariate ordination of both tapho- and biocoenoses showed trends within and between lakes in their limnological status, which were related mainly to water chemistry, and also to temporality and eutrophication to a certain extent. Some lakes have apparently lost most of their past ostracod community owing to an increasing trophic status in some cases and to modifications of the hydrological regime in others.

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## INTRODUCTION

The Mediterranean coast of the Iberian Peninsula harbours a large number of wetlands considered of special ecological relevance by national and international laws and treaties, especially in relation to bird

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conservation. Not only are these systems essential for migrating water birds, they also shelter a high biodiversity of all kinds of organisms, play a fundamental role in regulating hydrological regimes, climate and biogeochemical cycles, and are crucial for many other biological and socio-economic values (Burbridge, 1994; Jeffries, 1997). Despite this, the coastal fringe of the Valencian Community, consisting of extensive wetland areas, suffered and still suffers a great loss of these areas by drainage and other hydrological alterations, firstly for agricultural reasons and more recently for housing, industry and tourism development. The small segments remaining are now protected as Natural Parks, Important Bird Areas (IBA) or Ramsar sites. However, laws and governmental actions for wetland conservation in Valencia are so insufficient, that even protected areas are increasingly deteriorating and threatened by diversion of waters. Several endemic species formerly common in the area, including cyprinodontid fish such as *Lebias ibera* and *Valencia hispanica*, and crustacean decapods such as *Dugastella valentina*, are disappearing in many sites and their natural populations are now rare and under severe threat (Sanz and Gómez, 1984; Moreno-Amich *et al*., 1999).

Besides desiccation, one major effect of surface and subterranean water exploitations in these coastal wetlands is the alteration of the salinity of wetland water masses. On the other hand, eutrophication is the main pollution threat in these wetland areas. The community of benthic invertebrates of shallow lakes and wetlands is drastically affected by eutrophication and salinity changes (e.g. Wetzel, 1983; Hargrave, 1991). Even though much work has been done to use the composition of benthic macroinvertebrates for river water quality assessment (Armitage *et al*., 1983; Alba-Tercedor and Sánchez-Ortega, 1988; Rosenberg and Resh, 1993; Wright *et al*., 1994), very little has been done on the indicator values of shallow lake invertebrates. Furthermore, less attention has been paid to meiofauna, among which ostracods are particularly interesting for several reasons (De Deckker and Forester, 1988; Griffiths and Holmes, 2000; Meisch, 2000). This group is (i) a widely distributed and common inhabitant of all kinds of water bodies; (ii) rich in species, each with particular environmental requirements and, consequently, of indicator value; and (iii) its species present a bivalve calcitic carapace that remains in the sediment after the animal dies. These valves are useful for specific determinations, which make ostracod taphocoenoses valuable tools for palaeoenvironmental reconstruction.

The present work is part of a larger research project (ECOFRAME) involved in the implementation of water quality and biodiversity assessment tools for the study of European water bodies (Moss *et al*., 2003) in relation to the European Water Framework Directive (WFD2000/60/EC; European Commission, 2000). It was an interdisciplinary pan-European project in which many biological variables were measured and tested. However, ostracods were not analysed at a species level in most of the countries involved because it was not a priority for the project. This work focuses on the study of ostracods as indicators of past and present biodiversity in six shallow lakes located in four wetland systems of high international importance on the Valencian coast. The main aim of the work was to use ostracod assemblages as clues to the recent environmental evolution of these systems, which could be taken into account in future management policies for their conservation. Besides the trophic level, salinity and hydrological conditions were the main environmental variables for which the indicator value of ostracod assemblages were investigated since the studied sites are on the border of land masses near the coastline where a great variety of salinity and hydrological characteristics can be found. Prior to this, and since studies on ostracod fauna in these wetlands are very scarce, good identifications of the ostracod species present are needed. Therefore it is extremely helpful to elaborate a catalogue of high resolution valve pictures. SEM images of valves for all the ostracod species found are provided in this paper, not only to report them with a name, but also with their specific valve characteristics so that they can be used as a practical guide for future (palaeo)-ecological works in the area.

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## MATERIALS AND METHODS

### Study sites

Figure 1 shows the six shallow lakes studied, located in four wetland systems: the Prat de Cabanes-Torreblanca Natural Park, the Albufera of Valencia Natural Park, Marjal de La Safor and the Fondo d'Elx Natural Park. General limnological surveys of wetlands on the eastern Spanish seacoast (López and Tomás, 1989; Oltra and Armengol-Díaz, 1999; Rodrigo and Colom, 1999) also include information on water chemistry, plankton composition and other limnological features of some of the studied wetlands. Some general characteristics of these sites and the values of some limnological variables from the same sampling campaign can be found in Moss *et al.* (2003) and Sahuquillo *et al.* (2007). All sites studied were

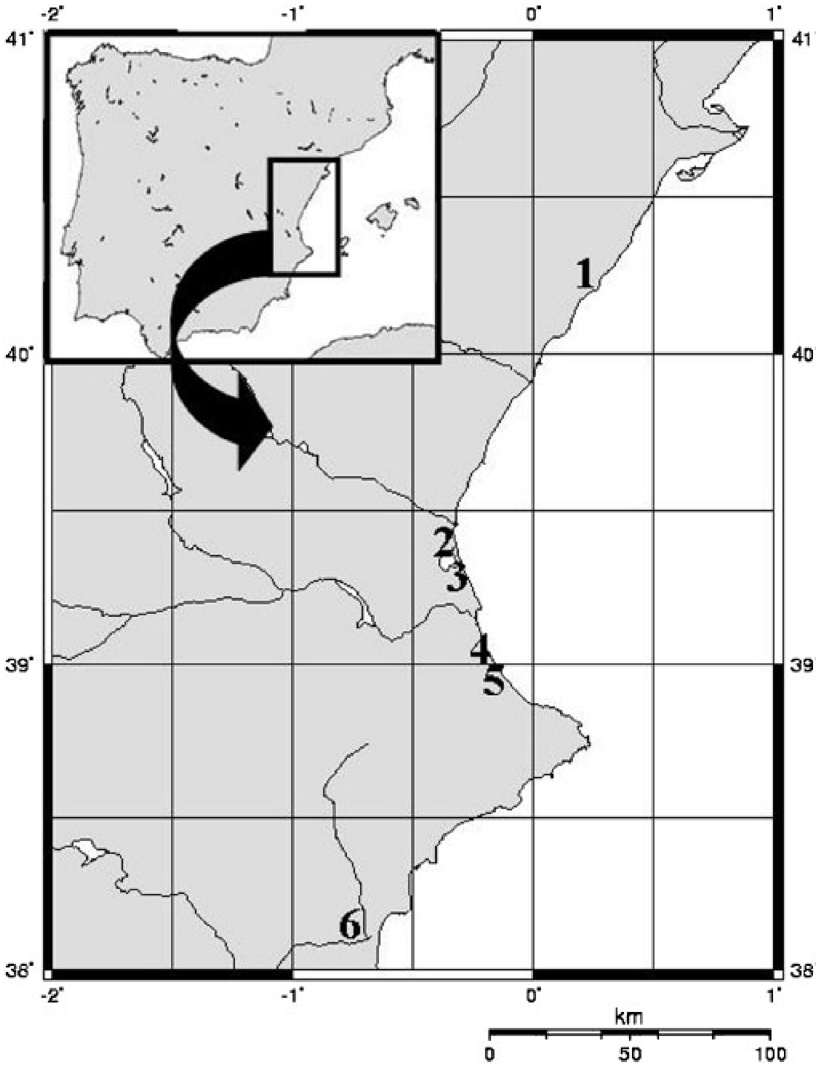

Figure 1. Location map of the six lakes studied: Prat de Cabanes (1), Albufera de Valencia (2), Baldoví (3), Cap de Terme (4), Xeresa (5) and Fondo d'Elx (6).

permanently inundated at the sampling point, although some of them are close to temporary water bodies, and differences among lakes in water chemistry were larger than intra-lake seasonal variability.

The wetland of Prat de Cabanes is a Natural Park covering 812 ha located in the province of Castelló. It consists of a marshland area along the seacoast, mainly composed of alluvial deposits of Quaternary origin. A large section of this system is composed of approximately 4 m deep peat sediments, which have been commercially exploited since the end of the 19th century, but more intensively since the second half of the 20th century. Peat extraction results in more or less quadrangular depressions that become flooded with water; one of these excavated ponds was the northernmost sampling point called the Pozo pond in the Cabanes wetland (UTM coordinates: 31TBE 615525).

The Albufera Natural Park comprises a large lagoon (23 $km^2$), called the Albufera of Valencia, together with the surrounding wetland, mostly transformed into rice fields with an overall area of 21120 ha, geologically comprising mainly Quaternary alluvia. Two sites were selected for this study: the Albufera Lagoon itself (UTM coordinates: 30SYJ 280570) and a limnocrene spring called Baldoví (UTM coordinates: 30SYJ 316480), surrounded by rice fields. The Albufera Lagoon is a large shallow hypertrophic system whose limnology has been thoroughly studied (reviewed in Vicente and Miracle (1992) and Romo *et al.* (2005)). Far less information is available for Baldoví, which is reduced to works focused on plankton communities (Alfonso and Miracle, 1987; Colom and Miracle, 1990; Miracle *et al.*, 1995).

The La Safor wetland covers an area of 1267 ha, located at the southernmost edge of the province of Valencia. Most of the former wetland has now been transformed into orange groves and other agricultural lands. Similarly to the Cabanes system, past peat extraction took place in La Safor which led to the formation of quadrangular ponds. In the La Safor wetland, two sites were sampled for this study, one pond excavated in the 1970s in the marshland for agricultural drainage (Cap de Terme; UTM coordinates: 30SYJ 403265) and another called Xeresa (after the name of the nearby town), located inside a small protected area for the conservation of the endangered fish *Valencia hispanica* (UTM coordinates: 30SYJ 433219).

The wetland called Fondo d'Elx is also under legal protection as a Natural Park, with an extension of 2387 ha. This wetland is of high ecological and economic importance, and is used as a water reservoir for agricultural supply. The various reservoirs included were excavated in the natural lagoon that existed there at the beginning of the 19th century. The reservoirs are very shallow, confined by dams built with the soil from the excavations themselves, and stabilized mainly by reeds (recently a few spots have been cemented). In this study, samples were taken from the south-western pond adjacent to the Poniente reservoir, which does not receive waters from it, rather from a separate water circuit fed from the water table and drainage from agricultural fields (UTM coordinates: 30SXH 970285). This water circuit encircles the reservoir but is not connected to it; the reservoir receives water which is pumped from the River Segura and is distributed for irrigation purposes. The site is described in Viñals *et al.* (2001) and the plankton composition and dynamics were studied by Armengol-Díaz *et al.* (2002) and Rodrigo *et al.* (2001).

### Sampling and laboratory methods

The sampling campaign at the six lakes was carried out from 27 July to 7 August 2000. Ten sediment samples were taken at around 1 m depth in permanently inundated areas of each lake using 5-cm-diameter plastic cylinders which were inserted 10 cm into the sediment. Although no published information is available on sediment deposition rates, the history of the human regulation of lakes as well as unpublished information on isotopic dating from the Albufera shows that this sediment layer probably accounts for a time that spans a few decades. Samples were fixed in the field with 4% buffered formalin, and were washed and sieved through 240 μm mesh sieves and stored in 70% ethanol in the laboratory. Ostracods were hand-picked under a stereomicroscope and stored in 70% ethanol for specific determinations. All complete animals living at the time of sampling (i.e. belonging to the biocoenosis) were recovered, as well as the disarticulated valves and empty shells belonging to the taphocoenosis. One ostracod valve is considered

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equivalent to 0.5 individuals, but since left and right valves were also distinguished, abundances were obtained directly from the most common of both. Determinations of ostracods were carried out up to the species level, whenever possible, mainly using the taxonomic monographs by Bronshtein (1947), Athersuch *et al.* (1989) and Meisch (2000).

Water temperature and conductivity were measured *in situ* at the centre of each lake using portable pH probes, and water samples were later analysed in the laboratory for alkalinity, total phosphorus (TP), chlorophyll *a*, chloride and main cations using standard methods (APHA, 1992).

Data on absolute abundances of species in biocoenoses and taphocoenoses were considered separately, and were $\log_{10}$-transformed for a multivariate ordination of all samples using correspondence analysis (CA). This ordination was performed by downweighting rare species and by means of the MVSP software ver.3.0 (Kovach, 1998).

## RESULTS

### Ostracod biodiversity

The number of ostracod species found in the biocoenosis and taphocoenosis of each lake is presented in Figure 2, together with the corresponding data on water chemistry, and shows that the number of species in each lake biocoenosis is lower than that recorded in the taphocoenosis. Normally, the species that appear in the biocoenoses are also frequent in the taphocoenoses (Table 1).

In Figure 2, lakes are ordered by conductivity to show that brackish water lakes with the highest conductivities and chlorinities ($Cl^{-1}$: 4.5–5 g $L^{-1}$) — Prat de Cabanes and Fondo d'Elx — have a low

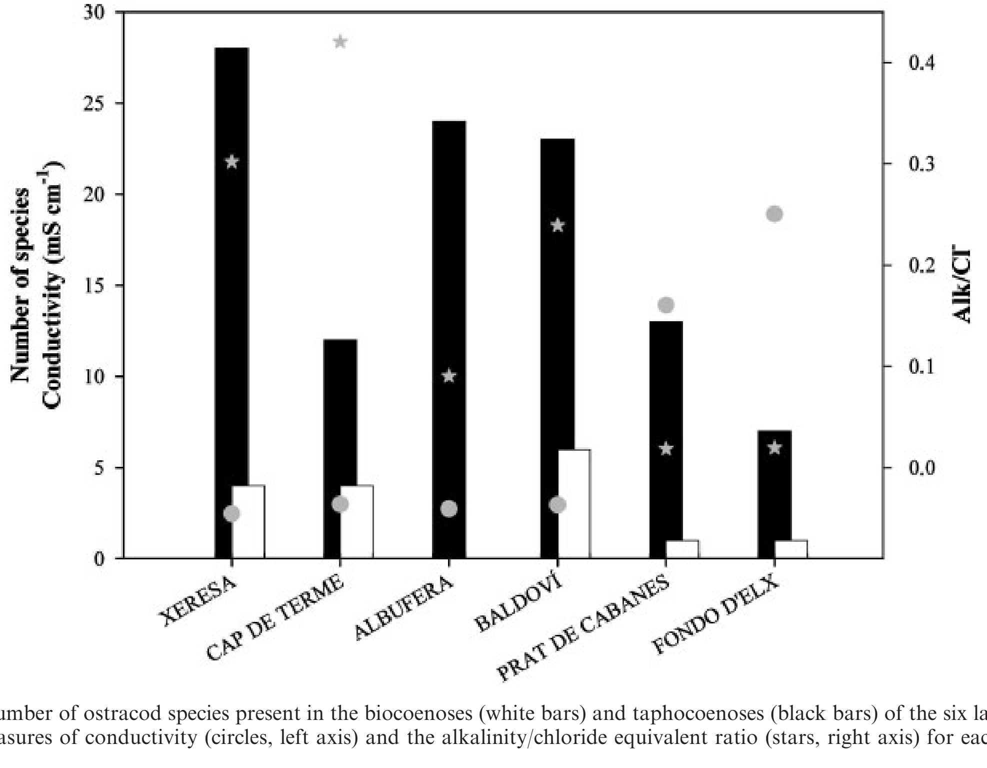

Figure 2. Number of ostracod species present in the biocoenoses (white bars) and taphocoenoses (black bars) of the six lakes studied, and measures of conductivity (circles, left axis) and the alkalinity/chloride equivalent ratio (stars, right axis) for each lake.

Table 1. Total number of living individuals collected (in bold) and total number of dead individuals (in parentheses) for each ostracod species present in the different lakes (corresponding to $0.02\,m^2$)

| Ostracod species | Code | Lakes | | | | | |
|---|---|---|---|---|---|---|---|
| | | Xeresa | Cap de Terme | Albufera | Baldoví | Cabanes | Fondo d'Elx |
| *Darwinula stevensoni* (Brady & Robertson, 1870) | DST | **9** (292) | **1** (70) | (265) | **79** (24) | (32) | — |
| *Penthesilenula* sp. | PEN | (1) | — | — | — | — | — |
| *Vestalenula* sp. | VCY | (41) | — | (2) | — | — | — |
| *Candona angulata* G. W. Müller, 1900 | CAN | — | (49) | (438) | (4) | (3) | — |
| *Candona neglecta* Sars, 1887 | CNE | — | — | — | (11) | — | — |
| *Fabaeformiscandona* cf. *wegelini* (Petkovski, 1962) | FWE | (17) | — | — | — | — | — |
| *Fabaeformiscandona japonica* Okubo, 1990 | FJA | (52) | **3** (10) | (73) | (8) | — | — |
| *Fabaeformiscandona* cf. *brevicornis* (Klie, 1925) | FBR | — | — | — | (11) | (2) | — |
| *Fabaeformiscandona* cf. *latens* (Klie,1940) | FLA | — | — | (18) | — | — | — |
| *Pseudocandona* cf. *marchica* (Hartwig, 1889) | PMA | (48) | (12) | (14) | (241) | (235) | (1) |
| *Candonopsis kingsleii* (Brady & Robertson, 1870) | CKI | (160) | — | — | (8) | — | — |
| *Candonopsis scourfieldi* Brady, 1910 | CSC | — | — | — | **1** (6) | — | — |
| *Cypria ophtalmica* (Jurine, 1820) | COP | (1) | — | (12) | **54** (49) | (6) | — |
| *Cypria* cf. *subsalsa* Redeke, 1936 | CSB | — | — | — | (8) | (6) | — |
| *Ciclocypris ovum* (Jurine, 1820) | COV | (1) | — | — | — | — | — |
| *Ilyocypris gibba* (Ramdohr, 1808) | IGI | (278) | (7) | (14) | **11** (40) | (5) | (1) |
| *Ilyocypris monstrifica* (Norman, 1862) | IMO | — | — | (4) | — | — | — |
| *Cypris* sp. | CYP | — | — | — | (1) | — | — |
| *Cypris bispinosa Lucas*, 1849 | CBI | (1) | — | — | (1) | — | — |
| *Cypris subglobosa* Sowerby, 1840 | CSU | — | — | (5) | (3) | — | — |
| *Eucypris virens* (Jurine, 1820) | EVI | — | — | (1) | — | — | — |
| *Bradleycypris obliqua* (Brady, 1868) | BOB | **1** (61) | — | — | — | — | — |
| *Bradleystrandesia reticulata* (Zaddach, 1844) | BRE | (125) | (4) | (18) | — | — | — |
| *Herpetocypris chevreuxi* (Sars, 1896) | HCH | (37) | **1** (6) | (12) | — | — | — |
| *Stenocypris major* (Baird, 1859) | SMA | (2) | — | — | (3) | — | — |
| *Heterocypris incongruens* (Ramdohr, 1808) | HIN | — | — | (2) | — | (9) | — |
| *Heterocypris salina* (Brady, 1868) | HSA | (3) | (1) | (78) | (50) | (379) | (1214) |
| *Heterocypris* sp. | HET | — | — | — | (20) | — | — |
| *Heterocypris* cf. *rotundata* (Bronshtein, 1928) | HRO | — | — | — | (2) | — | — |
| *Isocypris beauchampi* (Paris, 1920) | IBE | — | — | (2) | — | — | — |
| *Cypridopsis vidua* (O. F. Müller, 1776) | CVI | **7** (430) | **32** (355) | (243) | **4** (73) | (39) | — |
| *Plesiocypridopsis newtoni* (Brady & Robertson, 1870) | PNE | (14) | — | — | — | — | (1) |
| *Sarscypridopsis aculeata* (Costa, 1847) | SAC | — | — | (39) | (24) | — | (4) |
| *Potamocypris producta* (Sars, 1924) | PPR | (1) | — | — | — | — | — |
| *Potamocypris* sp. | POT | (2) | — | — | — | — | — |
| *Cypretta seurati* Gauthier, 1929 | CSE | (1) | — | — | — | — | — |
| *Limnocythere stationis* Vávra, 1891 | LST | (1) | (1) | — | — | — | — |
| *Limnocythere inopinata* (Baird, 1843) | LIN | (1) | — | (86) | — | — | — |
| *Paralimnocythere psammophila* (Flössner, 1965) | PPS | **1** (59) | (33) | (47) | (3) | (199) | — |
| *Leptocythere* sp. | LEP | — | — | (2) | — | — | — |
| *Cyprideis torosa* (Jones, 1850) | CTO | (5) | (1618) | (602) | **355** (649) | **62** (540) | **444** (1293) |
| *Pontocythere* sp. | PON | (2) | — | — | — | — | — |
| *Loxoconcha elliptica* Brady, 1868 | LEL | (1) | — | (92) | (3) | (1) | (162) |
| *Xestoleberis nitida* (Liljeborg, 1853) | XNI | — | — | (50) | — | — | — |
| *Cytherois* sp. | CYT | (1) | — | — | — | — | — |

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number of species. The other four lakes studied had chloride concentrations lower than 1 g $L^{-1}$. It is remarkable that both Cap de Terme and Prat de Cabanes are excavated ponds in the peat of calcareous marshes, yet contain almost the same number of species in their taphocoenoses, sharing 66.66% of them (Table 1). At present, however, they do not share any species, and the number of species in their biocoenoses differs considerably because of the different salinity conditions (Figure 2).

With regard to the present trophic level based on chlorophyll *a* concentrations (Moss *et al.*, 2003), the study sites can be classified as (i) oligotrophic: Prat de Cabanes, Baldoví and Xeresa, with chlorophyll concentrations of 3, 4 and 5 $\mu g\,L^{-1}$, respectively; (ii) mesotrophic: Fondo d'Elx (15 $\mu g\,L^{-1}$); (iii) eutrophic: Cap the Terme (85 $\mu g\,L^{-1}$); and (iv) hypertrophic: the Albufera (328 $\mu g\,L^{-1}$). The influence of eutrophication in species richness is very well indicated by the fact that no ostracods were found alive in the hypertrophic Albufera Lagoon, although its taphocoenoses displayed the second highest number of species (Figure 2). On the other hand, the highest species richness in the biocoenoses was found in Baldoví, the most oligotrophic (lowest chlorophyll *a*) of the non-brackish sites. However, Baldoví and the Albufera, both lying in the same wetland area, had more than 50% of coincident species in their ostracod taphocoenoses.

From the ostracod biocoenoses, 1065 individuals were counted, representing 10 species and six families. The most abundant species were *Cyprideis torosa* (80.85%), *Darwinula stevensoni* (8.36%) and *Cypria ophtalmica* (5.07%). In the taphocoenoses, 11 297 individuals were recorded. These represent 45 species and six families, and the most abundant species were *C. torosa* (41.67%) and *Heterocypris salina* (15.27%).

In Figures 4–8, SEM pictures for all the ostracod species found in this study are shown. Eight of the 45 taxa are new records for the Iberian Peninsula: *Limnocythere stationis* (Vávra, 1891), *Candonopsis scourfieldi* Brady, 1910, *Fabaeformiscandona* cf. *wegelini* (Petkovski, 1962), *Ilyocypris monstrifica* (Norman, 1862), *Cypretta seurati* (Gauthier, 1929), *Cypria* cf. *subsalsa* (Redeke, 1936), *Vestalenula* sp. and *Penthesilenula* sp. The presence of *Fabaeformiscandona* cf. *latens* (Klie, 1940) and *Fabaeformiscandona japonica* Okubo, 1990 represent the second record for the Iberian Peninsula and confirm the results of Rueda Sevilla *et al.* (2006). Two morphotypes of *C. torosa*, forma *littoralis* (unnoded) and forma *torosa* (noded) were found, which are shown in Figure 8. Following Meisch (2000), the individuals of *Cypridopsis obesa* (Brady and Robertson, 1869) were considered to belong to the species *Cypridopsis vidua* (see Figure 7). In the case of *Penthesilenula* sp. and *Potamocypris* sp., only juvenile specimens were found (Figures 4 and 7). However, the latter may probably belong to *Potamocypris producta*. *Vestalenula* sp. is close to *Vestalenula* sp. D in Rossetti and Martens (1999), but its taxonomy is doubtful since only valves were found.

## Ordination analysis

Figure 3 shows the ordination of species from either biocoenoses or taphocoenoses, and samples on the planes defined by the first three CA axes. These three axes accounted for 55.5% of variability.

Axis I (Figure 3(A,B)) separates samples in a salinity gradient, and more precisely, in accordance with the variation of the alkalinity/$Cl^{-1}$ ratio (see also Figure 2). The biocoenosis and taphocoenosis samples from the two brackish water lakes, Fondo d'Elx and Cabanes, were located at the positive extreme of this axis, whereas the two less saline ones, with the lowest alkalinity/$Cl^{-1}$ ratios (Xeresa and Cap de Terme), were on the opposite side. Baldoví, with an intermediate alkalinity/$Cl^{-1}$ ratio, was set in the middle, as well as all the taphocoenosis samples from Albufera, which has no biocoenosis samples (no living ostracods were collected). In accordance with this, salinity indicator species such as *C. torosa* (CTO), *H. salina* (HSA) and *Loxoconcha elliptica* (LEL) were located on the positive side of Axis I (Figure 3(C)). The other more common species found in the biocoenosis after *C. torosa*, i.e. *D. stevensoni* (DST) and *C. vidua* (CVI), which are less tolerant to high salinities, were clearly separated from it on the left side of the diagram. Figure 3(B)

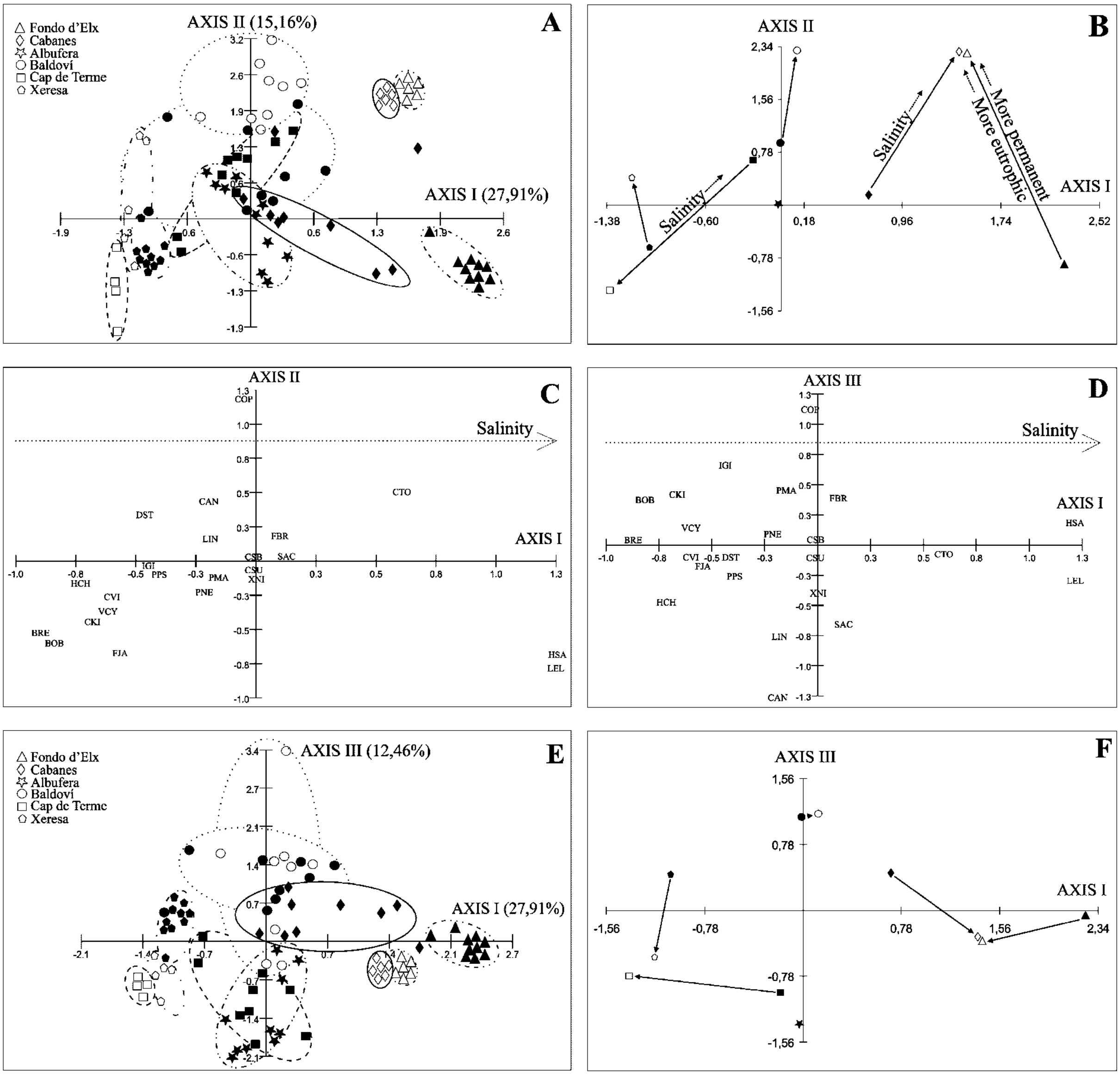

Figure 3. Ordination diagram for the first three axes of the correspondence analysis. Distribution of samples (A, E), average values of biocoenoses and taphocoenoses samples per lake (B, F) and species (C, D) on the plane determined by Axes I and II (A–C) and by Axes I and III (D–F). White symbols = biocoenoses; black symbols = taphocoenoses. Only those species present in more than three samples have been plotted in this figure.

shows the distribution of the mean biocoenoses and taphocoenoses values on the CA graph defined by Axes I and II.

In relation to Axis II, the Albufera taphocoenosis samples were arranged in the middle of the plot, as in Axis I. The biocoenosis samples of the remaining lakes were mainly found on the positive side of Axis II (Figure 3(A)), where species typical of permanent water bodies with a relatively low alkalinity/chloride ratio, such as *C. torosa*, *C. ophtalmica* and *D. stevensoni* were located (Figure 3(C)). In contrast all the

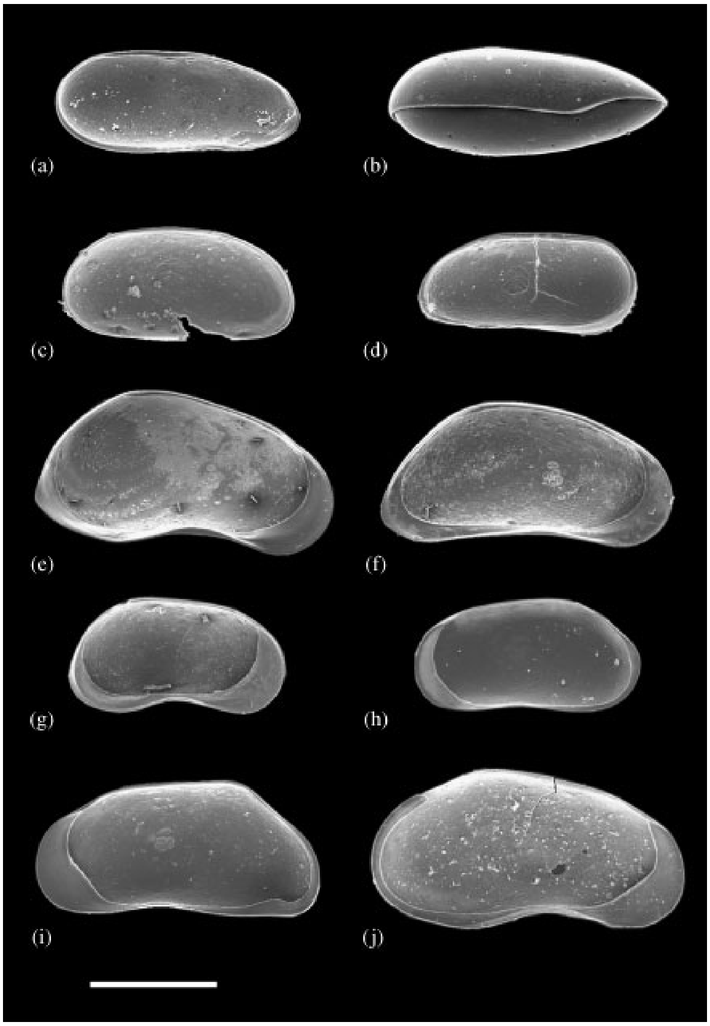

Figure 4. SEM pictures for the different ostracod species found in this work. (A) *Darwinula stevensoni*, left valve, inner view (scale bar = 358 μm). (B) *D. stevensoni*, ventral view (scale bar = 310 μm). (C) *Penthesilenula* sp., left valve, inner view (scale bar = 185 μm). (D) *Vestalenula* sp., right valve, inner view (scale bar = 286 μm). (E) *Candona angulata* male, left valve, inner view (scale bar = 687 μm). (F) *Candona angulata* female, left valve, inner view (scale bar = 669 μm). (G) *Candona neglecta*, left valve, inner view (scale bar = 770 μm). (H) *Fabaeformiscandona* cf. *wegelini*, right valve, inner view (scale bar = 376 μm). (I) *Fabaeformiscandona japonica* female, right valve, inner view (scale bar = 454 μm). (J) *F. japonica* male, left valve, inner view (scale bar = 450 μm).

biocoenosis samples from Cap de Terme were distributed on the negative side of Axis II, where *C. vidua*, common in permanent fresh waters, was also found. On the plane defined by Axes I and II the biocoenosis is separated from the taphocoenosis at each of the sites, except in Lake Baldoví.

In the case of Axis III (Figures 3(D–F)), the different lake samples were essentially distributed into two groups; samples from Baldoví and taphocoenoses from Prat de Cabanes and Fondo d'Elx were mainly located on the positive side of Axis III with all the others on the negative side. The species *Cypria ophtalmica* (COP) was arranged at the far positive edge of this axis, and *Candona angulata* (CAN) at the negative edge.

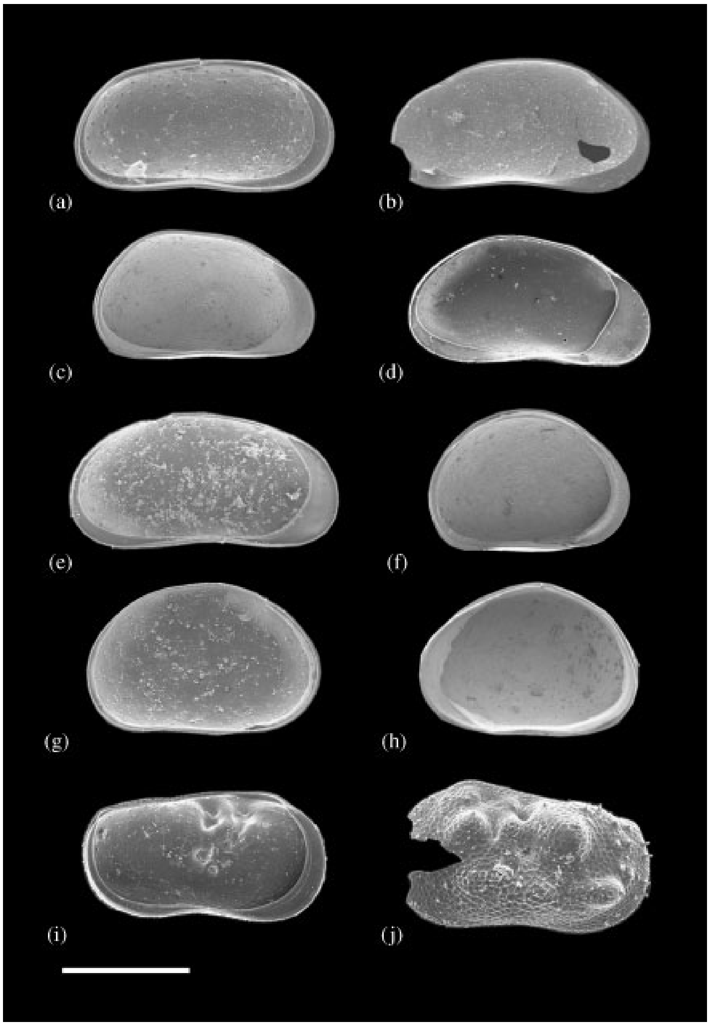

Figure 5. SEM pictures for the different ostracod species found in this work (continued). (A) *Fabaeformiscandona* cf. *brevicornis*, left valve, inner view (scale bar = 363 μm). (B) *Fabaeformiscandona* cf. *latens*, left valve, inner view (scale bar = 362 μm). (C) *Pseudocandona* cf. *marchica*, left valve, inner view (scale bar = 545 μm). (D) *Candonopsis kingsleii*, left valve, inner view (scale bar = 590 μm). (E) *Candonopsis scourfieldi*, left valve, inner view (scale bar = 351 μm). (F) *Cypria ophtalmica*, left valve, inner view (scale bar = 377 μm). (G) *Cypria* cf. *subsalsa*, left valve, inner view (scale bar = 328 μm). (H) *Cyclocypris ovum*, right valve, inner view (scale bar = 299 μm). (I) *Ilyocypris gibba*, left valve, inner view (scale bar = 436 μm). (J) *Ilyocypris monstrifica*, left valve, external view (scale bar = 377 μm).

## DISCUSSION

Ostracod assemblages appeared strongly related to the environmental variability of the sites in the multivariate ordination plots. Indeed, the taphocoenosis samples were the most relevant in the ordination analysis owing to the greater number of species and variability of the ostracod assemblages, showing the underlying ecological signal of a broader range of environments than those corresponding to the present biocoenosis.

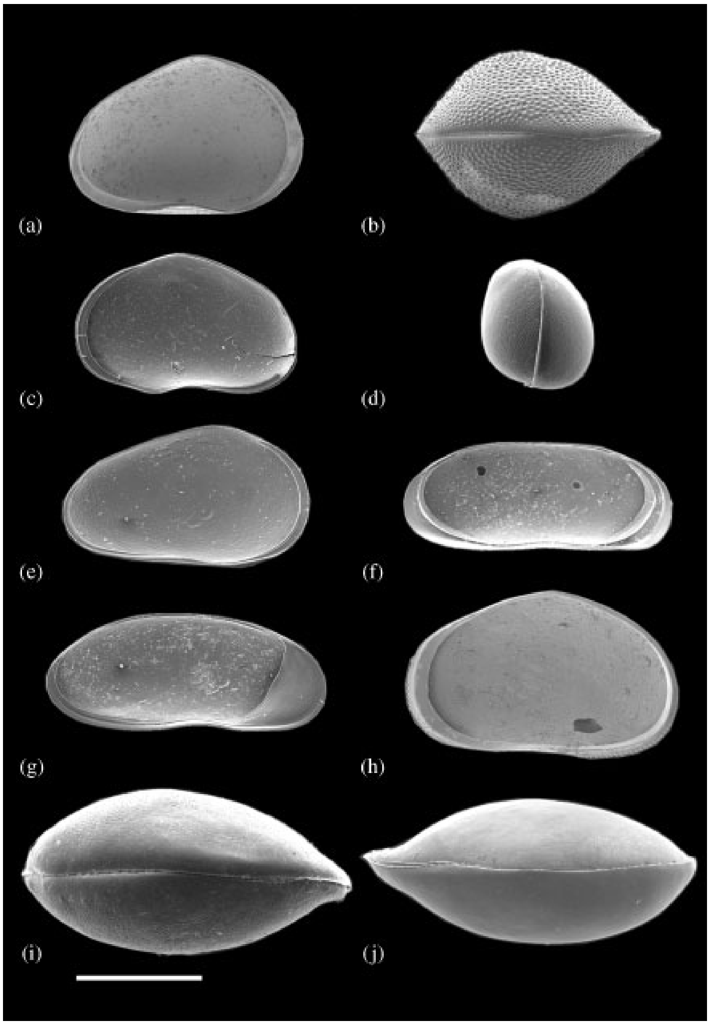

Figure 6. SEM pictures for the different ostracod species found in this work (continued). (A) *Cypris* sp., left valve, inner view (scale bar = 840 μm). (B) *Cypris subglobosa*, dorsal view (scale bar = 751 μm). (C) *Eucypris virens*, right valve, inner view (scale bar = 942 μm). (D) *Bradleycypris obliqua*, frontal view (scale bar = 693 μm). (E) *Bradleystrandesia reticulata*, left valve, inner view (scale bar = 514 μm). (F) *Herpetocypris chevreuxi*, left valve, inner view (scale bar = 1164 μm). (G) *Stenocypris major*, left valve, inner view (scale bar = 733 μm). (H) *Heterocypris incongruens*, dorsal view (scale bar = 599 μm). (I) *Heterocypris salina*, dorsal view (scale bar = 451 μm). (J) *Heterocypris* sp., dorsal view (scale bar = 522 μm).

The three main axes of the obtained CA may be interpreted from the autoecological knowledge of the species. The first is clearly associated with salinity since the brackish water species *L. elliptica*, *H. salina* and *C. torosa* are arranged on the positive side and clearly separated from the rest of the species. At the most negative edge the common freshwater species *C. vidua* occurred, together with *Bradleycypris obliqua*, *Bradleycypris reticulata* and *Herpetocypris chevreuxi*. *C. torosa*, *L. elliptica* and *H. salina*, which showed the highest positive loadings on the first CA axis, are species related to waters with a low alkalinity–chloride ratio, usually brackish waters (Athersuch *et al*., 1989; Mezquita *et al*., 1999, 2005; Frenzel and Boomer, 2005). In particular, *C. torosa* shows an exceptional tolerance towards different environmental factors, especially salinity, as it is euryhaline and common in this sort of habitat. Its ecology has been well studied

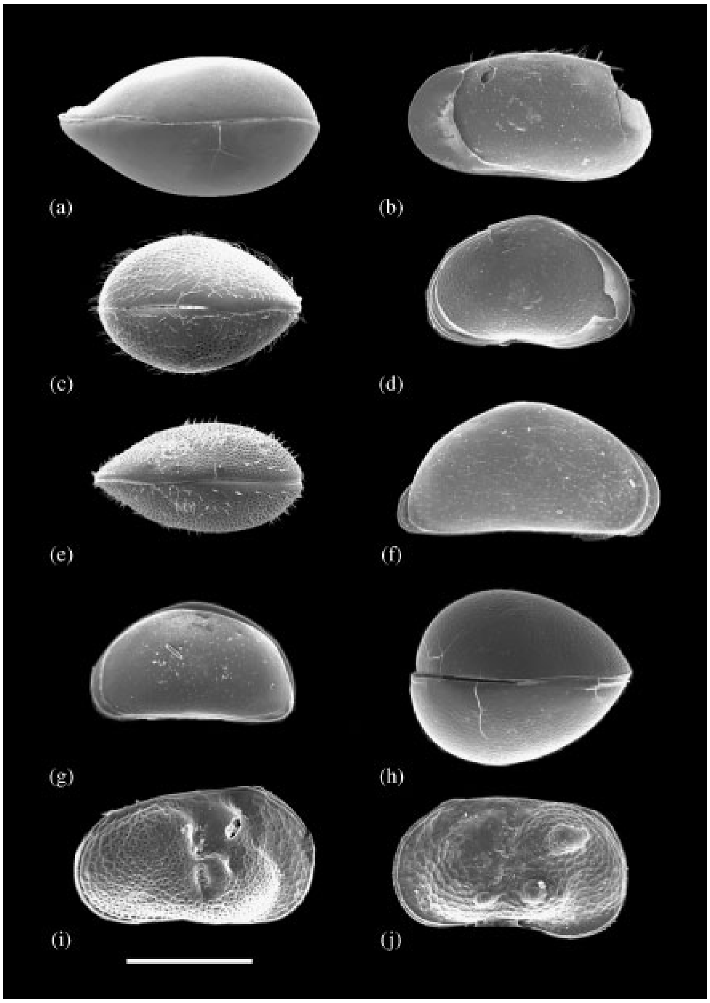

Figure 7. SEM pictures for the different ostracod species found in this work (continued). (A) *Heterocypris rotundata*, dorsal view (scale bar = 557 μm). (B) *Isocypris beauchampi*, right valve, inner view (scale bar = 731 μm). (C) *Cypridopsis vidua*, dorsal view (scale bar = 409 μm). (D) *Plesiocypridopsis newtoni*, left valve, inner view (scale bar = 471 μm). (E) *Sarscypridopsis aculeata*, dorsal view (scale bar = 414 μm). (F) *Potamocypris producta*, right valve, external view (scale bar = 286 μm). (G) *Potamocypris* sp., right valve, inner view (scale bar = 329 μm). (H) *Cypretta seurati*, dorsal view (scale bar = 426 μm). (I) *Limnocythere stationis*, right valve, external view (scale bar = 224 μm). (J) *Limnocythere inopinata*, left valve, external view (scale bar = 335 μm).

(see Athersuch *et al*., 1989; Meisch, 2000; Mezquita *et al*., 2000), and it is known to be an indicator of palaeosalinity by virtue of its morphological changes at different salinities (Vesper, 1975; Rosenfeld and Vesper, 1977). *L. elliptica* and *H. salina* are species that appear in slightly saline to brackish waters, but they are less euryhaline than *C. torosa*. This last-mentioned species is also the most competitive in permanent brackish waters and is the only species recorded living in the brackish water sites studied. On the other hand, species such as *D. stevensoni* or *Ilyocypris gibba* were located on the negative side of the first CA axis with species of the genus *Bradleycypris* and *Herpetocypris chevreuxi* at its extreme edge; these species are typical inhabitants of subsaline, hyposaline or freshwater ponds where the alkalinity/chloride ratio is high and conductivity is low in comparison to the above-mentioned species (Mezquita *et al*., 2005).

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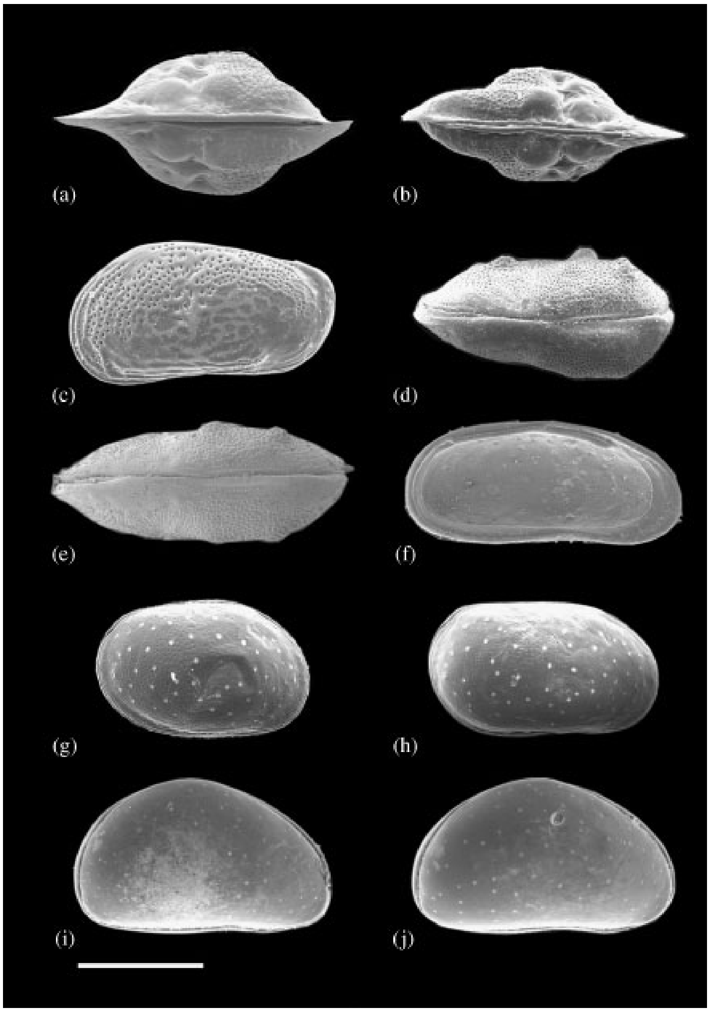

Figure 8. SEM pictures for the different ostracod species found in this work (continued). (A) and (B) *Paralimnocythere psammophila*, female and male, dorsal view (scale bar = 250 μm). (C) *Leptocythere* sp., left valve, external view (scale bar = 214 μm). (D) *Cyprideis torosa* female, dorsal view (scale bar = 539 μm). (E) *Cyprideis torosa* male, dorsal view (scale bar = 480 μm). (F) *Pontocythere* sp., left valve, inner view (scale bar = 366 μm). (G) and (H) *Loxoconcha elliptica*, female and male, right valve, external view (scale bar = 335 μm). (I) and (J) *Xestoleberis nitida*, female and male, right valve, external view (scale bar = 257 μm).

The second CA axis had some relationship with temporality of waters since species that are more frequent in permanently flooded sites, such as *C. torosa*, *C. ophtalmica*, *C. angulata*, and *D. stevensoni*, were positioned on the high positive side whereas species frequently found in temporary waters, such as *H. salina*, *B. obliqua*, *I. gibba*, were located at the other extreme of this axis. However, the common species *C. vidua* and *L. elliptica*, typical of permanent water bodies, are also arranged on the negative side of Axis II. The third axis opposes the species *C. ophtalmica* which is linked to clear water springs with high macrophytic development (Gifré *et al.*, 2002) to the remaining species, and mainly to *C. angulata*, *L. inopinata* and *S. aculeata*. The significance of the axis is uncertain but may be related to water flow and plant detritus abundance.

In summary, results show that the main sources of variation of ostracod assemblages in the eastern Iberian Peninsula wetlands are (1) salinity and alkalinity/chloride ratios, which is clearly marked by the first axis of the CA analysis, (2) water temporality, shown in part by the second axis and (3) spring waters versus more eutrophic and large standing waters.

The major differences between biocoenoses and taphocoenoses could be used as a tool to assess environmental quality changes. In terms of biodiversity, the number of species present in biocoenoses was much lower than in taphocoenoses (Figure 2). This could be due in part to the seasonality of the occurrence of some ostracod species, and it is possible that although these species could dwell in the lake at other times of the year, they were not recorded in summer of 2000. However, the study sites were permanent water bodies with dominant species living all year round, and there should not be much seasonal variation in the ostracod composition. There was no systematic under-representation of winter species since only a few valves of this group of species were found (Table 1), e.g. *Eucypris virens*, *Cypris bispinosa*, *Heterocypris incongruens* and *H. rotundata*. Inter-annual variability in ostracod assemblages in these lakes could be another source of higher species richness in taphocoenoses, but ostracod assemblages in lakes that have not been strongly disturbed remain mostly unchanged for decades (e.g. Baldoví, Cabanes, unpublished results). It may be concluded that differences between the composition of biocoenoses and taphocoenoses are so remarkable that the main reason for these differences lies in the longer term and/or in the major changes of the environmental conditions.

The most notable case is the Albufera Lagoon where 24 ostracod species were present in its taphocoenosis and none in its biocoenosis, which is most probably due to the numerous and intense human impacts that the Albufera lagoon has suffered in recent decades. Until the first half of the 19th century, the lagoon was in a clear-water state covered by macrophytes, whereas now it is in a turbid state (Vicente and Miracle, 1988, Romo *et al*., 2005) and its hypertrophic level is reflected in the concentration of chlorophyll *a* (Figure 2). The wastewaters of all the highly populated cities in the surrounding areas to the north and east of the Albufera were flowing directly into the lake until the early 1990s, when partial sewage diversions were accomplished. Meanwhile, high levels of pesticides and nitrates entered the Albufera lagoon through irrigation channels from the surrounding southern area, which is mainly composed of rice fields. All this caused a drastic increase in the trophic level of the lake, resulting in the disappearance of its macrophytic cover and the complete transformation of plankton, preventing the establishment and development of a mature benthic community as it had once existed.

Besides the extreme case of the Albufera Lagoon, in which all the ostracod species have disappeared mainly owing to eutrophication, differences between taphocoenoses and living assemblages in the other lakes also reflect some degree of change in the lacustrine environment. Obviously species richness in the biocoenoses was reduced in comparison with the taphocoenoses. In most cases the most resistant species, well adapted to changes in either salinity or the hydrological regime of the systems, are those that have been left in the present community, while species that are more sensitive to these types of change are found in the taphocoenoses. In the present study, comparisons were made between the biocoenosis and taphocoenosis, and clear examples of the detection of these hydrological and salinity changes are illustrated in the CA ordination diagrams (Figure 3).

(1) Current ostracods in the south-western pond of Fondo d'Elx, are dominated by *C. torosa*, a euryhaline species always living in permanent water bodies. The dead assemblages of this pond are rich in *H. salina*, a species highly tolerant to desiccation (Ganning, 1971), indicating that in the past this site was a temporary marsh pond in the brackish lagoon system of Fondo d'Elx. The recent modified circulation of brackish waters around a freshwater reservoir caused the disappearance of some typical species of temporary habitats and therefore a loss of biodiversity. Only one species remains alive, *C. torosa*, tolerant to variable degrees of eutrophy and salinity.

(2) The comparison of biocoenoses and taphocoenoses at Prat de Cabanes suggests a rise of salinity in this site, which might have caused the dominance of species more tolerant to high salinity, such as *C. torosa*,

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and the loss of *Cypridopsis vidua*, *Pseudocandona* cf. *marchica* and *Darwinula stevensoni*. Owing to peat exploitation, this lake has also changed to more permanent conditions that produce 4–5 m deep pools in the wetland.

(3) On the other hand, Cap de Terme has undergone a change in the opposite direction; in recent years it has become a more freshwater system, reflected in the dominance of *C. vidua* and the disappearance of *C. torosa* from the present ostracod community resulting from agricultural control of the water flow.

In general the wetlands of the Eastern Iberian Peninsula have suffered a strong human impact; the commercial exploitation of the peat sediment at Prat de Cabanes, the high level of eutrophication of the Albufera Lake due to urban, agricultural and industrial pollution, the high concentration of nitrates and pesticides from the surrounding agricultural lands of Baldoví, Xeresa and Cap de Terme, and the regulation of the hydrological regimes, affecting also salinity and eutrophication of Fondo d'Elx and Cap de Terme, are factors that negatively influence the species richness of ostracod assemblages.

With this work, we have contributed to the knowledge of the ostracod fauna of the Mediterranean coastal systems and their relationship to environmental conditions, and have shown how nowadays this fauna clearly indicates that coastal wetlands are being driven to higher trophic levels and to diverse salinity and hydrological changes. The high potential of ostracods for environmental reconstruction enable the assessment of the pristine state of lakes and wetlands prior to severe human impacts. Therefore, when the restoration of these habitats are to be planned, the analysis of ostracod remains in the sediment would provide a strong indication of past functioning, especially with regard to water chemistry, salinity and hydrology. With this information, those who manage water systems can make better decisions about how to attain those traits indicated by ostracod remains with practices such as water flow and water depth regulation, or the mixing of waters of different origin.

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