

## Limnological characteristics and recent ostracods (Crustacea, Ostracoda) of freshwater wetlands in the Parco Oglio Sud (Northern Italy)

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We report the results of a study carried out in 2002 on the main limnological characteristics and on the ostracod communities of 16 wetlands of the Parco Oglio Sud (Northern Italy). Physical and hydrochemical variables were measured and ostracod samples were collected in different seasons (April, June, August, and October). Most of the considered sites were characterised by high concentrations of nitrogenous compounds due to washing out from cultivated areas, intermittent river flooding and internal recycling. Observed differences in macrophyte communities were consistent with trophic status of waters, with pleustonic forms dominating most degraded areas. Both morphology of valves (by scanning electron microscopy) and anatomy of soft parts were analysed for ostracod species identification. Nineteen ostracod species in five families were found. Two species, *Candona weltneri* and *Pseudocandona compressa*, are new records for Italy. *Cypria ophthalmica* was collected from all sampling sites; other relatively common species were *Cypridopsis vidua*, *Cyclocypris ovum*, and *Candona weltneri*. No clear seasonality was observed in community structure; highest species diversity occurred in June in most of the studied wetlands. The maximum number of species per site was seven, and a maximum of six species was found in a single sample. Ostracod occurrence in relation to environmental factors was examined using Canonical correspondence analysis (CCA). Total alkalinity and pH were the most important variables structuring the species assemblages. The ostracod fauna found in this area was compared to the known distribution of recent non-marine ostracods in Italy, and the validity of published checklists is discussed.

Keywords : riverine wetlands, water quality, Oglio River, ostracods, biodiversity.

### Introduction

During the last 30 years the importance of riparian areas and marginal wetlands along the course of rivers and channels has been increasingly acknowledged, due to their role as natural filters for diffuse nutrients control and because they host peculiar niches and nursery areas for a variety of organisms, from microbial, meio and macrobenthic communities to fish and birds (Wetzel 1990, Reddy & D'Angelo 1994, Mitsh & Goselink 1993, Cronk & Fennessy 2001). The control of nutrients is a result of the combined action of macrophytes and the associated epiphytic communities; but important biogeochemical processes such as denitrifi-

cation and phosphorus sequestration occur within surface sediments (Soderquist et al. 2000, Kadlec & Knight 1996). Rooted wetland macrophytes connect sediments to the atmosphere with their aerenchima: gas transport mechanisms favour the loss or the reoxidation of end products of the anaerobic metabolism and create microoxic zones around root hair with implications for microbial coupled processes (i.e. nitrification and denitrification) and benthic meiofauna colonisation (Armstrong 1964, Dacey 1981, Mevischutz & Grosse 1988). In Northern Italy, floodplains of larger rivers host marginal wetlands which are severely threatened by water pollution, rapid burial, and invasions by exotic species. Extreme and apparent consequences of such pressures are the simplification of plant communities due to low water transparency and reduced anoxic sediments and general loss of the above mentioned wetland functions.

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Ostracods are bivalved Crustacea commonly found in most inland waters where they abound in the benthic and periphytic animal communities, but also occur in marine, interstitial and even (semi-) terrestrial environments (Horne et al. 2002). Although the autoecology of ostracods is still largely unknown and often based on speculative assumptions, these organisms are of particular interest as environmental indicators in freshwater ecosystems. Recently, several papers have been published on this subject, considering both fossil (Bellis 1997, Park et al. 2003) and recent (Curry 1999, Rosenfeld et al. 2000, Mezquita et al. 2001, Külkölyüoglu 2003) ostracod faunas. Here, we describe the main limnological features of lowland wetlands located along the lower stretch of the Oglio River and we aim to analyse the ostracod distribution in relation to physical and chemical habitat characteristics. This contribution is part of a larger project to investigate the values and functions of wetlands of the Parco Oglio Sud, aimed at the management and restoration of the aquatic ecosystems (Delfini 2003). As pointed out by Rossi et al. (2003), data on recent freshwater ostracods in Italy are relatively scarce, although the checklist compiled by Ghetti & McKenzie (1981) reported an extra-

ordinary high species diversity and a large number of endemic taxa. Unfortunately, the prevalent inadequacy of taxonomic descriptions and often also the absence of collections and type repositories make it difficult to confirm the reliability of many earlier Italian records. In the present paper, special attention is paid to the taxonomic analysis of the present faunas, and Scanning Electron Microscope images of ostracod valves are also offered to confirm identifications.

## Material and methods

Four sampling campaigns were carried out in 2002 (April 8, June 4, August 5, and October 31). On each date, 16 wetlands were visited, all included within the Parco Oglio Sud, a regional park established in 1988 which encompasses the lower plains along the Oglio River in the provinces of Cremona and Mantova (Northern Italy) (Table 1, Fig. 1). The area is characterised by industrial crop productions, and poplar plantations prevail in the embanked floodplain. Different kinds of wetlands (ponds, channels, oxbows, peatlands) are still a conspicuous element within this landscape; those

Table 1. Location and selected habitat features of the study sites.

Code	Biotope name	Lat N	Long E	Habitat characteristics
OG01	Valli di Mosio	45°09'37"	10°27'26"	Peatland, almost completely silted up
OG02	Mosio	45°09'24"	10°28'26"	Small channel, slowly flowing waters
OG03	Castelfranco 1	45°09'38"	10°21'23"	Very shallow oxbow
OG04	Castelfranco 2	45°09'42"	10°20'57"	Very shallow oxbow
OG05	Bicocca	45°09'56"	10°20'25"	Small oxbow, occasionally fed by the Oglio River
OG06	Canale Molino	45°11'24"	10°18'38"	Small channel intermittently flooded by running water
OG07	Runate destra	45°10'15"	10°21'19"	Pond mostly fed by groundwater
OG08	Runate sinistra	45°10'15"	10°21'20"	Pond mostly fed by groundwater
OG09	Gerre Gavazzi	45°10'16"	10°20'54"	Pond mostly fed by groundwater, high sediment accumulation rate
OG10	Lago Carpe	45°04'41"	10°32'15"	Pond fed by groundwater, very shallow
OG11	Canale	45°04'40"	10°32'12"	Channel, flowing waters
OG12	Chiaro	45°04'48"	10°32'18"	Small, relatively deep pool
OG13	Laghetto	45°04'48"	10°32'16"	Pond formed by excavation of a former disposal site
OG14	Golena S. Alberto 1	45°02'42"	10°36'12"	Pond with steep slopes and relatively deep
OG15	Golena S. Alberto 2	45°02'18"	10°36'28"	Relatively large and deep pond with steep slopes
OG16	Golena S. Alberto 3	45°02'14"	10°36'26"	Relatively large and deep pond, sandy bottom

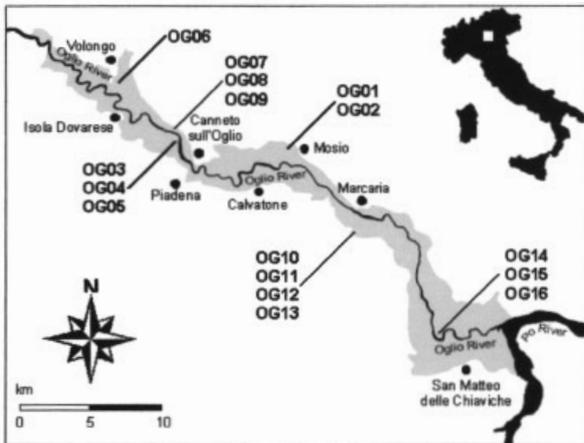


Fig. 1. Map of the Parco Oglio Sud showing location of sampling sites (see also Table 1).

considered in this study are mainly lentic environments fed by surface aquifers associated with the river or are occasionally flooded; OG06 and OG11 are channels with slowly flowing water. Two wetlands (OG01 and OG03) were found to be devoid of water in August; other permanent wetlands are stocked with different fish species.

Water temperature, electric conductivity at 25°C, pH, and dissolved oxygen concentration were measured by a YSI 560 multiprobe. Water samples were collected from a depth of 0.5 m (or from the surface water layer in shallower sites) and kept refrigerated until analysed in the laboratory, where additional hydrochemical and physical variables and parameters were determined as follows: total alkalinity by potentiometric end-point titration at pH 4.5 and 4.2 (TIM 90, Radiometer) and linearization according to Rodier (1984); ammonium (Koroleff 1970), nitrous nitrogen (APHA, AWWA, WPCF 1975), nitric nitrogen (Rodier 1984), dissolved reactive silica (APHA, AWWA, WPCF 1975), soluble reactive phosphorus (Valderrama 1981), and chlorophyll-*a* (Golterman et al. 1978) by spectrophotometry (Beckman DU 65).

Ostracods were collected with a 250 µm handnet pulled close to the sediment and through the vegetation along the wetland shore or within the water body from shallower sites. Living samples were transferred to the laboratory, where specimens were sorted under a binocular microscopy and then fixed in 90% ethanol. Both soft parts (dissected in glycerine and stored in sealed slides) and valves (stored dry in micropal slides and

used for scanning microphotographs) were checked for species identification, using Meisch (2000) and the papers by Danielopol (1980), Meisch (1984) and González-Mozo et al. (1996) as reference. All the illustrated material is deposited in the Ostracod Collection (OC) of the Royal Belgian Institute of Natural Sciences, Brussels.

Similarity between species assemblages was assessed by Cluster Analysis (CA) (unweighted pair-group average) performed by means of the software package PAST ver. 1.06 (Hammer et al. 2001), using the Jaccard coefficients derived from the matrix of presence/absence data. The same matrix and the full hydrochemical data set were used to examine the relationships between ostracod distribution and environmental data by Canonical Correspondence Analysis (CCA) using the software package CANOCO version 4.5 (ter Braak & Milauer 2002). Hydrochemical variables were transformed using  $\log(x+1)$ , except for pH. The direct gradient technique of CCA constrains ordination axes as linear combination of environmental variables. Monte Carlo permutation tests were used to assess the significance of the canonical axes and of the environmental variables that were selected in the forward selection procedure.

## Results

### Limnological characteristics

Seasonal temperatures displayed wide fluctuations due to the general shallowness of the investigated environments. The highest water temperatures, between 20 and 35°C, were found during the survey of August. The relative maximum was measured at OG10, a shallow open water body (~20 cm deep). Conductivity values were high and typical for shallow eutrophic environments on the Oglio plain, ranging between ~300 and >900 µS cm<sup>-1</sup>. At OG05, OG09, OG13, OG14, OG15 and OG16, conductivity values were strongly correlated with temperatures and exhibited maximum summer values (up to 951 µS cm<sup>-1</sup> measured in August at OG09), whilst at OG01, OG02, OG03, OG04, OG06, OG07 and OG08, on the contrary, conductivity peaks occurred in autumn (up to 681 µS cm<sup>-1</sup> measured in October at OG03).

In most of the investigated environments (11 out of 16 sites), dissolved oxygen concentrations were below saturation for the entire investigated period; in particular, at OG01, OG03, OG04 and OG05 the imbalance between primary production and system respiration was extreme during summer, when the water column

was strictly anoxic. Conversely, at OG07, OG08, OG10, OG15 and OG16 dissolved oxygen saturation was never below 50%. In August, at OG10 dissolved oxygen concentration reached 17 mg l<sup>-1</sup> (~300% saturation) and gas bubbles were evident on the sediment surface. Saturation values above 100% were also occasionally found at OG12, OG13, OG14, OG15 and OG16. In all the sites, pH values were always ≥ 7, the only exception being the measurement of June at OG03 (6.96); values above 8 were found at sites with photosynthetically active submerged vegetation or with dense microalgal assemblages (OG05, OG10, OG12, OG13, OG14, OG15 and OG16). At OG10, during summer, a maximum of 9.67 was measured, presumably due to intense assimilation of inorganic carbon by microphytobenthos. Total alkalinity showed significant fluctuations among sampling sites. The lowest values (ranging from 2.2 to 4.1 meq l<sup>-1</sup>) were measured in OG16, the highest in OG06 and OG08 (peaks of 24.4 and 27.2 meq l<sup>-1</sup>, respectively).

Water column chlorophyll-*a* concentrations were extremely variable among sites and seasons, ranging between ~3 and over 230 µg l<sup>-1</sup>; highest values were generally found in spring and fall, when macrophytes were absent or less abundant and thus when light and nutrients were available to phytoplankton. Relatively homogeneous chlorophyll-*a* values of less than 10 µg l<sup>-1</sup> were found at OG01, OG07 and OG15; such low concentrations were most likely the result of shading and nutrient limitation (i.e. reactive phosphorus, see below), amongst others. Chlorophyll-*a* values above 50 µg l<sup>-1</sup>, typical of eutrophic environments, were found at OG02, OG04, OG05, OG06, OG08, OG09, OG10, OG12, OG13, OG14 and OG16. Values above 100 µg l<sup>-1</sup> were found at OG5, OG8 and OG14. The three southernmost environments (OG14, OG15, and OG16) had a different chlorophyll-*a* content, despite their proximity and the similar morphometric and structural features. For example, OG15 was always characterised by very transparent waters and chlorophyll-*a* values never exceeded 3 µg l<sup>-1</sup>.

Ammonium concentrations were extremely variable between sites and sampling periods, showing values between 1 and 92 µM. Annual average values above 20 µM were found in 8 out of 16 sites (OG01, OG02, OG03, OG04, OG05, OG06, OG09 and OG10); values below 10 µM were determined at OG07, OG08, OG11, OG13, OG14 and OG15. Nitrous nitrogen was the least abundant form of dissolved inorganic nitrogen, with concentrations ranging between 1 and 13 µM; in a few sites (OG02, OG06 and OG09), the annual average was above 5 µM. Nitric nitrogen content was one

order of magnitude higher and reached values up to 800 µM. At OG01, OG10, OG12, OG13, OG14, OG15 and OG16 this oxidised form of nitrogen was relatively low (<40 µM), whilst at OG06, OG07, OG08, OG09 and OG11 its concentration was on average >400 µM. For most of the sites the NO<sub>x</sub>- to NH<sub>4</sub><sup>+</sup> ratio was always far above 1, with peaks of ~600 at OG09. Reactive phosphorus concentrations were low and generally ranged between 0 and 2.5 µM; values above 5 µM were determined at OG01 and OG05 and at OG06.

### Ostracod communities

Altogether 19 ostracod species were collected (Table 2, Figs. 2-4). Ostracod diversity was highest in June (with an average of c. 3 species per site and a maximum of 6 species in OG03) and lowest in August (with an average of less than 2 species per site and a maximum of 3 species in OG07, OG09, and OG11). A temporary wetland, OG03, exhibited the highest number of ostracod species (7). *Cypria ophthalmica* occurred in all the study sites and *Cypridopsis vidua* in 13 habitats; conversely, 10 species were found exclusively in one site (Fig. 4). Co-occurrence of *Cyclocypris ovum* and *C. laevis* was observed only in OG08, but the two species were not found at the same time. The most frequent species were generally detected throughout the sampling period, without showing any clear seasonal pattern. Amongst species collected from more than one site, *Fabaeformiscandona fragilis* was found only in April and June (Table 3).

CA separated four distinct groups of ostracod assemblages (Fig. 4). Grouping of habitats mostly reflects their geographic location, with the exception of OG09 and OG11 (Fig. 1). Cluster I includes sites with high species diversity, and it is mainly characterised by the presence of *Candona weltneri* and *Pseudocandona compressa*; it also incorporates the two lotic environments considered in this study (OG06 and OG11). The second cluster (II) aggregates communities with low diversity (except for OG10), in which *Cypria ophthalmica* and *Cypridopsis vidua* are each time associated with species rarely encountered in the area (e.g., *Darwinula stevensoni*, *Dolerocypris sinensis*, *Herpetocypris chevreuxi*, and *Potamocypris smaragdina*). *Cyclocypris ovum* and other rare species (*Ilyocypris decipiens*, *I. monstifica*, *Prionocypris zenkeri*, and *Pseudocandona hartwigi*) are found in cluster III, which consists of only two sites (OG07 and OG08). Also cluster IV groups two sites (OG01 and OG02), i.e. the only habitats in which *Notodromas persica* is present.

The first two axes of CCA ordination account for

Table 2. Taxonomic status of the ostracods identified in this study.

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Superfamily Darwinuloidea	Brady & Norman, 1889
Family Darwinulidae	Brady & Norman, 1889
Genus <i>Darwinula</i>	Brady & Robertson, 1885
1. <i>Darwinula stevensoni</i>	(Brady & Robertson, 1870)
Superfamily Cypridoidea	Baird, 1845
Family Candonidae	Kaufmann, 1900
Subfamily Candoninae	Kaufmann, 1900
Genus <i>Candona</i> s. str.	Baird, 1845
2. <i>Candona weltneri</i>	Hartwig, 1899 <b>species new to Italy</b>
Genus <i>Fabaeformiscandona</i>	Krstić, 1972
3. <i>Fabaeformiscandona fragilis</i>	(Hartwig, 1898)
Genus <i>Pseudocandona</i>	Kaufmann, 1900
4. <i>Pseudocandona hartwigi</i>	(G.W. Müller, 1900)
5. <i>Pseudocandona compressa</i>	(Koch, 1838) <b>species new to Italy</b>
Genus <i>Candonopsis</i>	Vávra, 1891
6. <i>Candonopsis kingsleii</i>	(Brady & Robertson, 1870)
Subfamily Cyclocypridinae	Kaufmann, 1900
Genus <i>Cypria</i>	Zenker, 1854
7. <i>Cypria ophthalmica</i>	(Jurine, 1820)
Genus <i>Cyclocypris</i>	Brady & Norman, 1889
8. <i>Cyclocypris laevis</i>	(O.F. Müller, 1776)
9. <i>Cyclocypris ovum</i>	(Jurine, 1820)
Subfamily Candoninae	Kaufmann, 1900
Family Ilyocyprididae	Kaufmann, 1900
Subfamily Ilyocypridinae	Kaufmann, 1900
Genus <i>Ilyocypris</i>	Brady & Norman, 1889
10. <i>Ilyocypris gibba</i>	(Ramdohr, 1808)
11. <i>Ilyocypris monstifica</i>	(Norman, 1862)
12. <i>Ilyocypris decipiens</i>	Masi, 1905
Family Notodromadidae	Kaufmann, 1900
Subfamily Notodromadinae	Kaufmann, 1900
Genus <i>Notodromas</i>	Lilljeborg, 1853
13. <i>Notodromas persica</i>	Gurney, 1921
Family Cyprididae	Baird, 1845
Subfamily Eucypridinae	Bronshstein, 1947
Genus <i>Prionocypris</i>	Brady & Norman, 1896
14. <i>Prionocypris zenkeri</i>	(Chyzer & Toth, 1858)
Subfamily Herpetocypridinae	Kaufmann, 1900
Genus <i>Herpetocypris</i>	(Brady & Norman, 1889)
15. <i>Herpetocypris brevicaudata</i>	Kaufmann, 1900
16. <i>Herpetocypris chevreuxi</i>	(Sars, 1896)
Subfamily Dolerocypridinae	Hartmann & Puri, 1974
Genus <i>Dolerocypris</i>	Kaufmann, 1900
17. <i>Dolerocypris sinensis</i>	(Sars, 1903)
Subfamily Cypridopsinae	Kaufmann, 1900
Genus <i>Cypridopsis</i>	Brady, 1867
18. <i>Cypridopsis vidua</i>	(O.F. Müller, 1776)
Genus <i>Potamocypris</i>	Brady, 1870
19. <i>Potamocypris smaragdina</i>	(Vávra, 1891)

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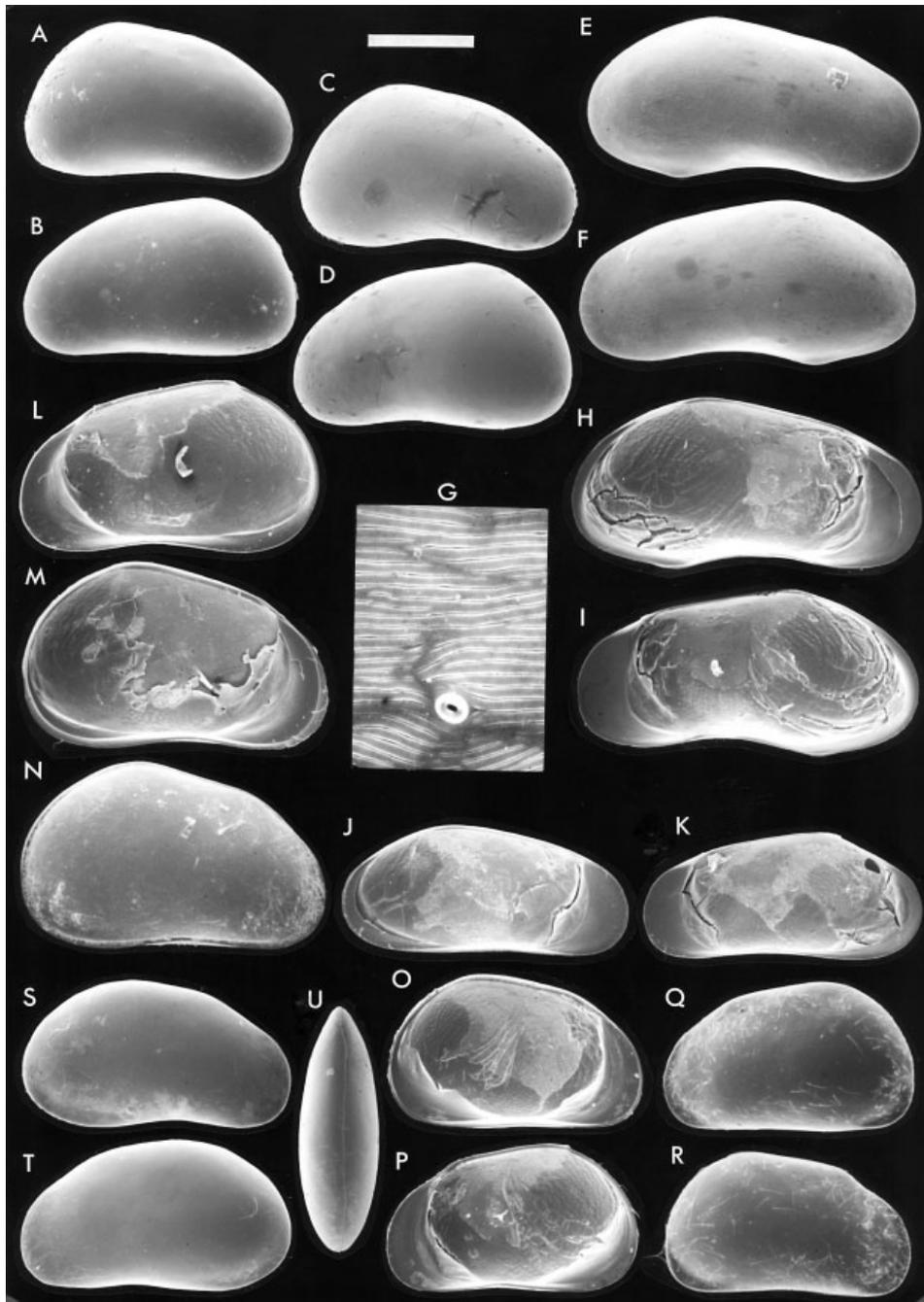


Fig. 2. Scanning electron micrographs of ostracods found in the studied wetlands: *Candona weltneri* (A-D), *Fabaeformiscandona fragilis* (E-K), *Pseudocandona hartwigi* (L-N), *Pseudocandona compressa* (O-R), *Candonopsis kingsleii* (S-U). RV: right valve; LV: left valve; Cp: carapace; ev: external view; iv: internal view; lv: lateral view; dv: dorsal view. All adult specimens. Scale bar: 457  $\mu$ m for A-D; 400  $\mu$ m for E, F, H-U; 13  $\mu$ m for G. A: OC2845, female, RV, ev (OG06). B: idem, LV, ev. C: OC2852, male, RV, ev, (OG09). D: idem, LV, ev. E: OC2847, male, RV, ev (OG10). F: idem, LV, ev. G: idem, RV, ev, detail of valve striature. H: idem, LV, iv. I: idem, RV, iv. J: OC2838, female, LV, iv, (OG03). K: idem, RV, iv. L: OC2839, male, LV, iv (OG08). M: idem, RV, iv. N: OC2841, male, Cp, right lv (OG08). O: OC2843, female, LV, iv (OG09). P: idem, RV, iv. Q: OC2846, female, LV, ev (OG09). R: idem, RV, ev. S: OC2849, male, RV, ev (OG09). T: idem, LV, ev. U: OC2853, female, Cp, dv (OG15).

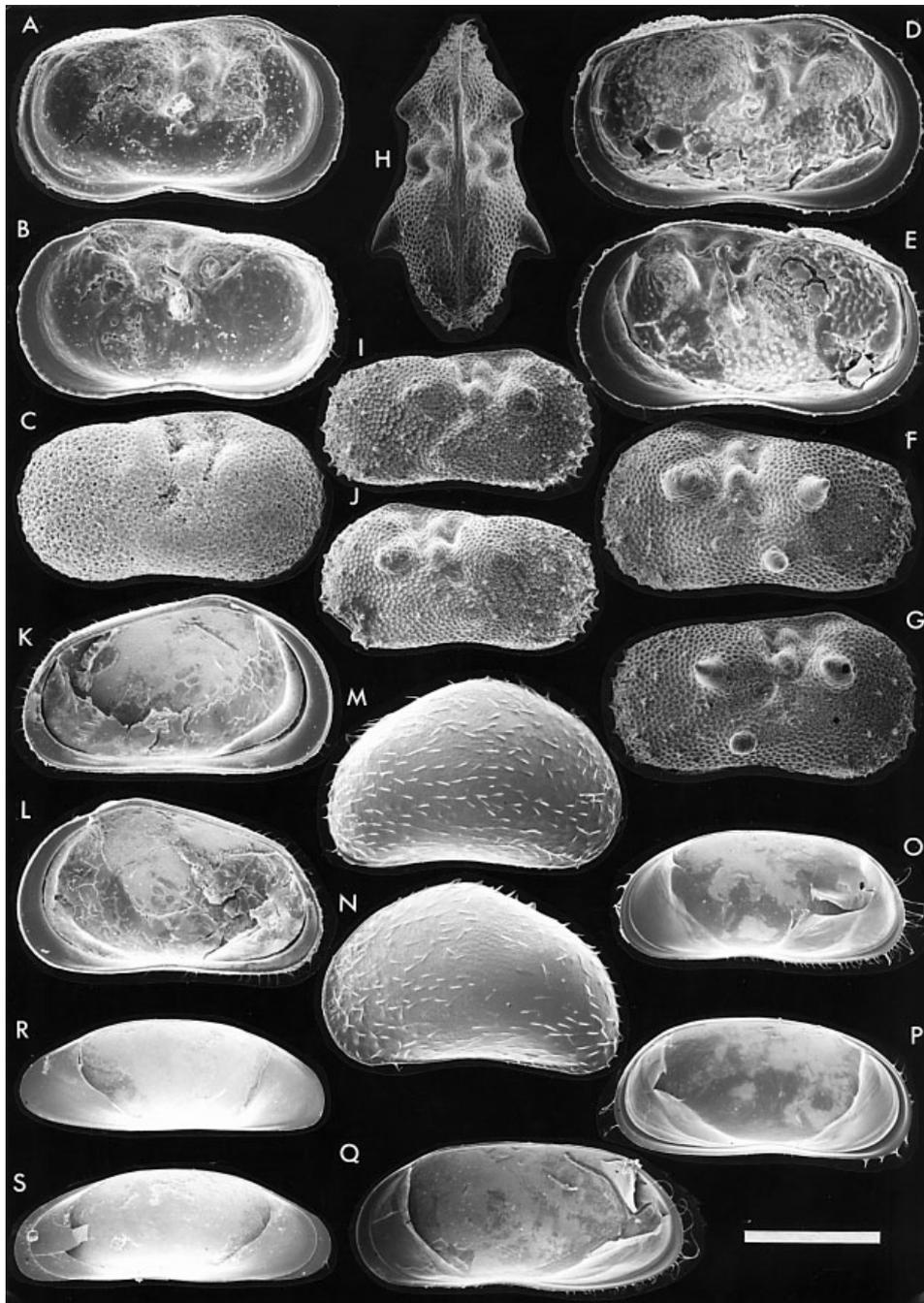


Fig. 3. Scanning electron images of ostracods found in the study wetlands: *Ilyocypris gibba* (A-C), *Ilyocypris monstifca* (D-J), *Prionocypris zenkeri* (K, L), *Potamocypris smaragdina* (M, N), *Herpetocypris brevicaudata* (O, P), *Herpetocypris chevreuxi* (Q), *Dolerocypris sinensis* (R, S). RV: right valve; LV: left valve; Cp: carapace; ev: external view; iv: internal view; dv: dorsal view. All adult specimens. Scale bar: 400  $\mu$ m for A-J; 667  $\mu$ m for K, L; 250  $\mu$ m for M, N; 800  $\mu$ m for O-S. A: OC2851, female, LV, iv (OG06). B: idem, RV, iv. C: idem, RV, ev. D: OC2836, female, LV, iv (OG07). E: idem, RV, iv. F: OC2837, female, LV, ev (OG07). G: idem, RV, ev. H: OC2842, female, Cp, dv (OG07). I: OC2835, male, RV, ev (OG07). J: idem, LV, ev. K: OC2840, female, LV, iv (OG08). L: idem, RV, iv. M: OC2850, female, RV, ev (OG16). N: idem, LV, ev. O: OC2848, female, LV, iv (OG06). P: idem, RV, iv. Q: OC2834, female, RV, iv (OG10). R: OC2844, female, LV, iv (OG12). S: idem, RV, iv.



29.0% and 22.9% of the total variance. The species-environment correlations are 0.837 for axis 1 and 0.772 for axis 2. The Monte Carlo permutation test shows that all the canonical axes are significant ( $P < 0.001$ ). Total alkalinity (permutation test:  $F = 3.33$ ,  $P = 0.006$ ,  $A = 0.32$ ) and pH (permutation test:  $F = 3.07$ ,  $P = 0.002$ ,  $\Lambda = 0.29$ ) have the strongest correlations to the first and second canonical axes and are most important in explaining the observed ostracod distribution (Fig. 5). The most common species are displaced in the lower part of the ordination diagram; a first group of species (*Ilyocypris decipiens*, *I. monstifrica* and *Notodromas persica*) are placed along a gradient of alkalinity, while a second group (*Candona weltneri*, *Fabaeformiscandona fragilis*, *Cyclocypris ovum*, *Pseudocandona compressa* and *Candonopsis kingsleii*) is primarily associated with higher trophic conditions and elevated ionic content. Rare species form two distinct clusters in the upper part of the ordi-

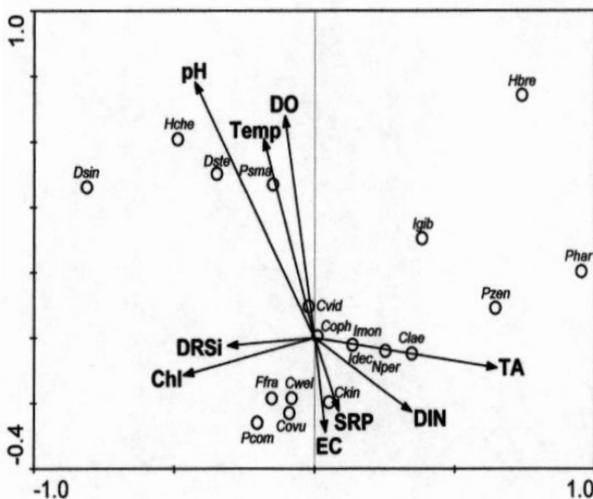


Fig. 5. CCA ordination of ostracod species and environmental parameters on the space defined by the first two canonical axes. *Dste*: *Darwinula stevensoni*. *Cwel*: *Candona weltneri*. *Ffra*: *Fabaeformiscandona fragilis*. *Phar*: *Pseudocandona hartwigi*. *Pcom*: *Pseudocandona compressa*. *Ckin*: *Candonopsis kingsleii*. *Coph*: *Cyprina ophthalmica*. *Clae*: *Cyclocypris laevis*. *Covu*: *Cyclocypris ovum*. *Igib*: *Ilyocypris gibba*. *Imon*: *I. monstifrica*. *Idec*: *I. decipiens*. *Nper*: *Notodromas persica*. *Pzan*: *Prionocypris zenkeri*. *Hbre*: *Herpetocypris brevicaudata*. *Hche*: *H. chevreuxi*. *Dsin*: *Dolerocypris sinensis*. *Cvid*: *Cypridopsis vidua*. *Pama*: *Potamocyparis smaragdina*. EV: eigenvalues. Temp: water temperature. EC: electric conductivity at 25°C. TA: total alkalinity. DO: dissolved oxygen. SRP: soluble reactive phosphorus. DIN: dissolved inorganic nitrogen (sum of ammonium, nitrous nitrogen, and nitric nitrogen). DRSi: dissolved reactive silica. Chl: chlorophyll-*a*.

nation diagram, denoting a preference for higher pH values and dissolved oxygen content; their position with respect to the temperature gradient indicates a prevailing summer occurrence. The upper right part displays species which prefer well-buffered waters; the upper left quadrant comprises species which seem to be related to a higher habitat productivity.

## Discussion

### Limnological characteristics

Most of the investigated sites are remnant of wider wetland areas previously connected to or periodically flooded by the Oglio River, and are characterized by extreme shallowness, small surface area and expanding belts of macrophytes. Dissolved nitrogen and phosphorus concentrations were typical of eutrophic aquatic environments; loads were probably a consequence of washing out from surrounding cultivated fields, occasional floodings by nutrient-rich Oglio waters, or internal recycling. During early spring and autumn nitric nitrogen was the dominant inorganic nitrogen form with concentrations in the order of mM; ammonium and reactive phosphorus peaked on the contrary during summer months. Organic loads resulted in anoxic sediments and fuelled intense microbial activity, determining low summer oxygen concentrations and nutrient regeneration (Delfini 2003). Light and nutrient availability explained production rates by planktonic and macrophytic primary producers resulting in high sedimentation rates and enhancing the shift of these water bodies towards terrestrial environments. In the summer of 2002, two sites characterised by organically rich, chemically-reduced sediments (OG01 and OG03) fell dry and the reed belts expanded toward the centre of the ponds.

At OG11 and OG15 the presence of submerged vegetation (*Myriophyllum demersum*) was coupled with well-oxygenated, transparent waters with minimum concentrations of planktonic chlorophyll-*a*. In a few sites, sediments were colonized by rooted plants such as *Nuphar luteum*, *Nymphaea alba*, and *Nymphoides peltata*. The ability of these plants to detoxify sediments through root radial oxygen loss is widely demonstrated (Dacey 1981, Smits et al. 1990) and this has important implications for meio- and macrobenthic communities, due to simultaneous occurrence of oxic-anoxic conditions within surficial sediment horizons, causing higher environmental heterogeneity (Begg et al. 1994, Carpenter et al. 1983). On the contrary, at most sites, macrophytic vegetation was

mainly composed by floating plants (Lemnaceae and the aquatic fern *Salvinia natans*) which exploit nutrients directly from the water column (Koles et al. 1987). Dense floating beds of pleustonic communities inhibited light penetration, microalgal photosynthesis and the development of submerged vegetation. They also turned out to be a physical barrier for the gas exchanges through the atmosphere-water interface. At OG03, OG04 and OG05, in full summer, pleustonic communities caused water column anoxia.

### Ostracod communities

All the ostracods found in the study area are typical members of the Western and Central Europe ostracod fauna, apart from *Dolerocypris sinensis* which is frequently encountered in the circum-Mediterranean region (Meisch 2000). Two species, *Candona weltneri* and *Pseudocandona compressa*, are new for Italy. *Candona weltneri* has a Palaearctic distribution. It has frequently been recorded in Central and Northern Europe, although it is rare or absent from the South. *Pseudocandona compressa* has a broader distribution, being widespread throughout Europe, Turkey, Iran, Siberia and probably North America (Meisch 2000). The occurrence of *Ilyocypris monstifica* is also of particular interest, since this species was known in Italy only from two ricefields in the Po River Valley and one locality in Sicily (Rossi et al. 2003). It is nevertheless possible that this species has previously been reported as *I. gibba*, so its exact distribution remains at present unknown. Congeneric species (*Herpetocypris brevicaudata* and *H. chevreuxi*, *Pseudocandona hartwigi* and *P. compressa* and, to a lesser extent, also *Cyclocypris laevis* and *C. ovum*) found in the study area are displaced in opposite directions with respect to the plane defined by the first two canonical axes, most likely revealing different ecological requirements. In the case of *Ilyocypris*, *I. decipiens* and *I. monstifica* are found in the same habitat, whilst *I. gibba* seems to prefer more buffered waters and higher pH. Species characterising cluster I obtained from CA tend to also be aggregated in the CCA distribution. They are preferentially found in habitats with elevated ionic content and higher concentrations of chlorophyll-*a* and inorganic nutrients, and seem to be tolerant of lower oxygen concentrations. Species that are mainly associated with higher pH values (*Dolerocypris sinensis*, *Herpetocypris chevreuxi*, *H. brevicaudata*, *Darwinula stevensoni*, and *Potamocypris smaragdina*) are found only in spring and summer months and denote a preference for well-oxygenated waters. *Herpetocypris brevicaudata* seems to prefer waters with high alkalinity as well; this is also true for the other species (in particular *Priono-*

*cypris zenkeri* and *Pseudocandona hartwigi*) located on the right side of the first axis of CCA. *Darwinula stevensoni* is an obligate parthenogen with a cosmopolitan and ubiquitous distribution (Rossetti & Martens 1996, 1998); for this species, a broad tolerance to different environmental conditions has been demonstrated and the existence of a general purpose genotype has been proposed (Rossi et al. 2002, Van Doninck et al. 2002). Nevertheless, *D. stevensoni* is rare in the study area, where it was collected from April to August only in OG10, usually at low densities. Its disappearance in October is puzzling, because this species is thought to have no resting stages and long life cycles (up to 3-4 years, Ranta 1979), although temporary disappearance of *D. stevensoni* from typical sampling stations was also reported by Gandolfi et al. (2001). *Herpetocypris brevicaudata* and *Ilyocypris gibba* were found in only one of the two lotic environments included in this study (OG06). In fact, these two species are commonly (but not exclusively) found in slowly flowing waters, brooks and springs (Meisch 2000, Mezquita et al. 1999). The other ostracods collected in the two lotic biotopes (*Candona weltneri*, *Pseudocandona compressa*, *Cyprina ophthalmica*, and *Cypridopsis vidua*) were also present in the neighboring lentic waters.

Although the results of this study seem to indicate a fairly clear relationship between the occurrence of ostracod species and the physical and chemical characteristics of habitats measured here, other environmental factors may be invoked to explain the observed distribution. Fish are likely to have a substantial effect by predation on the ostracod assemblages (Torras et al. 2000, Garc a-Berthou 2001, Zimmer et al. 2002). It is interesting to note that the highest ostracod diversity is found in a temporary habitat (OG03), even though the species occurring there are not necessarily typical of astatic waters and all of them are also present in permanent waters within the study area.

As reported above, aquatic macrophyte cover strongly influences water and sediment characteristics of shallow wetlands and, as a consequence, the structure of invertebrate communities. For instance, CCA results showed that dissolved oxygen and chlorophyll-*a* arrows are perpendicular, indicating that the two variables are uncorrelated and that oxygen content of the waters is likely to be regulated by macrophytes and by sediment respiration and re-oxidation processes, rather than by planktonic algae production. Ostracods may also use macrophytes as refugia from fish predators (Roca et al. 1993).

This preliminary study lacks a detailed characterisation of surface sediment (i.e. organic matter content,

oxygen, sulphide and redox potential microprofiles) which could be related to the ostracod species richness. Recent studies have also demonstrated that presence/absence of at least some ostracod species can be related to aspects of solute composition not measured here (Forester 1983). Nevertheless, the ostracod distribution in relation to some environmental factors seems to confirm the relevance of these organisms as environmental indicator species. The need for a solid taxonomic approach as an indispensable basis for further ecological research is stressed.

### Regional biodiversity

The investigated area can be regarded as a hotspot of ostracod diversity, when compared with other freshwater ecosystems in Northern Italy. For example, the taxon richness of the Oglio River wetlands is comparable to that found in ricefields (Rossi et al. 2003), but with a much greater proportion of autochthonous taxa. Also, the number of identified species in the Oglio wetlands was higher than that of a group of 31 lowland springs (Rossetti et al. 2004). A full-scale comparison with the Italian ostracod fauna, however, is hampered by the fact that most records listed in the synopsis by Ghetti & McKenzie (1981) originate from publications with substandard descriptions and illustrations. According to these authors, c. 134 non-marine species are present in Italy (not including taxa at subspecific rank); c. 10% are «ospiti esteri», i.e. species introduced in Italy via the spread of useful plants (McKenzie & Moroni 1986), while endemic species show a striking prevalence in Sardinia and account for c. 16% of the total Italian ostracod diversity.

It is interesting to note that a total of 157 freshwater species have been retained by Meisch (2000) in his synopsis, which includes the ostracod faunas of British Isles, Northern France, Belgium, the Netherlands, Luxembourg, Germany, Switzerland, Austria, Hungary, Czech Republic and Slovakia. Germany has the highest number of ostracod species (126): this is not too surprising, considering the size of this country and, above all, the high number of German ostracodologists and the long tradition in ostracod studies. These data reinforce the belief that Italy potentially may host an extraordinary diversified ostracod fauna, mainly due to its latitudinal extension which guarantees a wide range of climatic conditions and broad environmental heterogeneity. An interesting picture arises when analysing the ostracod diversity of the Iberian Peninsula, which shares more similar climatic and geographic characteristics with Italy. Baltanás et al. (1996) reported a total of 86 species, also including ostracods from Canary Is-

lands (belonging to the Macaronesian subregion) and retaining those taxa whose presence or taxonomic status must be confirmed.

According to what is shown above, it seems plausible that the ostracod diversity depicted by the available Italian checklist (Ghetti & McKenzie 1981) may be overestimated. This is certainly true for some groups included in recent taxonomic revisions, e.g. for the genus *Herpetocypris* (González Mozo et al. 1996). A preliminary appraisal of the extant diversity of non-marine ostracods (from surface, crenal, and subterranean waters) in Italy, following synonymisation of several taxa, elimination of doubtful records and inclusion of new species (e.g., Martens 1992 on Eucypridini, Martens et al. 2002 on *Heterocypris*, Karanovic & Pesce 2000 on *Mixtacandona taliana*) and new records for Italy (e.g., Stoch 1998, Bellavere et al. 2002, Rossi et al. 2003, this paper), leads to a rough estimation of about one hundred valid species, of which c. 15% are exotic and less than 5% endemic (Rossetti & Martens in preparation).

### Conclusions

In the Parco Oglio Sud wetlands, external and internal nutrient loads, combined with dominant primary producer dynamics, trigger positive feedback mechanisms that accelerate their burial and, in the more extreme situations, their complete disappearance. This evolution actually appears to be irreversible, unless rapid interventions (such as sediment dredging, vegetation control, and water quality improvement) are carried out by local authorities, aiming at the preservations of the most valuable sites, e.g. OG07, OG08, OG12 and OG13. In fact, although these aquatic ecosystems are small and highly fragmented, the results of this study on the ostracod fauna indicate that they may represent important biodiversity spots within a heavily cultivated area.

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