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ORIGINAL ARTICLE

The dynamics of seasonal ostracod density in groyne fields of the Oder River (Poland)

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ABSTRACT

The study investigated seasonal dynamics of the ostracod population in the Oder River (Poland), in the area of groyne fields. Groyne fields were lenitic areas in that river system, providing favourable conditions for ostracod development. The main aims of the study were to find information on seasonal differences in ostracod occurrence, determine models of density dynamics and become acquainted with the effect of environmental factors on seasonal changes of ostracod assemblages. Samples were collected from 15 research stations in the littoral. The respective zones of the groyne fields abounded in various microhabitats. Average density, frequency coefficient, dominance, Shannon-Wiener diversity index (H), and Pielou's evenness index (J) were calculated for Ostracoda assemblages in order to point out differences between seasons. In total, 237 samples were collected; forty-seven species were identified, and the average density was 658 indiv. was studied during the vegetation season. The highest average density of the ostracods was discovered in spring (1160 indiv. m^{-2}*) with maximum of 9472 indiv. m*$^{-2}$*.); in the subsequent seasons it dropped by about half. The density dynamics of particular Ostracoda species was often different from their overall density. Significant differences between seasons were discovered with regard to the number of taxa, density and evenness index. The species that dominated throughout the year included* Limnocythere inopinata *and* Physocypria kraepelini. *Furthermore, juvenile Candoninae dominated in spring,* Cypridopsis vidua *dominated in summer, and* Candona neglecta, C. vidua *and juvenile* Pseudocandona *dominated in autumn. It turned out that the dynamics of occurrence of certain species observed in the present study contradicted data from literature related to the following species:* Darwinula stevensoni, Cypria ophtalmica, Physocypria kraepelini, Limnocythere inopinata. *All obtained models of density dynamics pointed out maximum density in spring, indicating that during that period the conditions in the river were optimal for ostracod development, as confirmed by the results of studying environmental factors. Ecological condition of the Oder was also good in the other seasons. Temperature, visibility, and dissolved oxygen content were among factors which most strongly affected ostracod assemblages. Availability of organic matter could result in decreasing their density.*

Key words: seasonality, invertebrates, benthos, lenitic area, life cycle.

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INTRODUCTION

Publications devoted to the occurrence of the Ostracoda in rivers are still rather few in comparison to those focusing on stagnant waters. What is more, groyne fields in rivers still remain almost terra incognita. Higuti *et al.* (2009) investigated the biodiversity of ostracods of the upper part of the alluvial valley of the Parana River among several substrates, including sediment and root systems of various floating aquatic macrophytes from 48 environments. Higuti *et al.* (2010) investigated variation in ostracod communities in relation to the substrates, including littoral sediment and root and leaf systems of macrophyte species in four hydrological systems, in wet and dry seasons, in the alluvial valley of the upper Parana River. Kiss (2006) analyzed the occurrence of the Ostracoda of the Danube River system, on various bottom types. Szlauer-Łukaszewska and Kowaluk-Jagielska (2011) studied the distribution of ostracods in various sediment types in the river bed of the lower reaches of the Oder River. Szlauer-Łukaszewska (2013) compared the occurrence of the ostracods in the littoral and on the bottom of the river bed in the Oder River. Numerous studies on ostracods have focused on the Rhone River in France: Creuzé des Châtetelliers and Marmonier (1993) investigated the ecology of benthic and interstitial ostracods, Marmonier and Creuzé des Châtetelliers (1992) investigated their biogeography and Claret *et al.* (1999) studied the effect of management works in the floodplain of this river. Mezquita *et al.* (1999a, 1999b) studied the ecology and distribution of ostracods associated with flowing waters, and the latter of the two publications focused on a polluted river.

As can be concluded from the review of the above publications, problems connected with seasonality of ostracod occurrence in rivers have not been studied so far. Slightly more information regarding these issues is available with respect to lakes, but still just a few individual studies have been conducted on the subject, as has also been pointed out by Griffiths and Holmes (2000). Studies on the seasonal character of ostracod occurrence in lakes have been conducted by Martens and Tudorancea (1991), Rieradevall and Roca (1995), Külköylüoğlu and Dügel

(2004), and Kiss (2007). Several studies have also been conducted that were devoted to the seasonal occurrence and life cycles of specific ostracod species, *e.g. Darwinula stevensoni* (McGregor, 1969 and Ranta, 1979), *Candona candida* (Semenova, 1979), *Mytilocypris henricae* (Martens *et al.*, 1985), *Cytherissa lacustris* (Geiger, 1990), *Eucypris virens* (Baltanás, 1994).

Among the Ostracoda there are species that belong to permanent forms, with adult individuals appearing throughout the season in roughly the same numbers. On the other hand, there are stenochronic species, with adult forms occurring only during a specific season of the year. According to Meisch (2000), the following forms can be distinguished in the latter category: early year forms, summer forms, and autumnal forms. A different division was proposed by Sywula (1974), who distinguished eurytermic, stenotermic-oligotermic and stenotermic-politermic forms. Erytermic species correspond to the stenochronic ones, distinguished by Meisch (2000). In the case of stenotermic-oligotermic forms, adult individuals appear during a cool season, whereas in the case of stenotermic-politermic forms, adults appear during a warm season. Both of the above classifications are based on the season when adult individuals occur (Sywula, 1974).

The present study investigated the seasonal dynamics of the ostracod population in the Oder River in the area of groyne fields. The following hypotheses have been tested: i) Are there significant differences in ostracod occurrence at particular periods during the season? ii) What elements of the structure of ostracod assemblages undergo differences during the vegetation season? iii) What is the density dynamics of particular species during the season and what types of models of density dynamics can be developed? iv) Could the observed changes in the dynamics of ostracods result from environmental factors other than changing seasons?

Methods and sampling area

The Oder River is the second largest river in Poland and forms one of the six largest river systems in Europe; it is 854 km long, with 742 km within the territory of Poland. Its drainage basin has the area of 11,886 km^2. Since the 19th century, groynes have been built in order to protect its banks against lateral erosion by moving the main current towards the central part of the river bed and also in order to improve the conditions for shipping. In total, about 10 thousand such groynes have been built (Rast *et al.*, 2000). Artificial bays called groyne fields were formed between groynes, characterized by slow water flow and in some places even the absence of any flow. Such artificial lenitic areas partially compensated for the natural ones, of which the river had been deprived as a result of straightening its bed and shortening its reach. Groyne fields are almost incessantly present along the banks of the Oder River within the section from Brzeg Dolny to Czelin. In this way a very long river stretch (350 km) of uniform character has evolved that provides ideal conditions for the development of ostracods due to regular occurrence of lenitic area and accumulation of detritus. Furthermore, the groyne fields continually exchange waters with the main river channel, ensuring good oxygen conditions in the immediate proximity of the bottom. The Ostracoda are small benthos crustaceans feeding on algae, bacteria, organic detritus and remnants of living organisms (Meisch, 2000).

The middle and lower reaches of the Oder were studied, from the town of Ścinawa (N: 51°24'40.86", E: 16°26'32.01") to the village of Czelin (N: 52°44'4.56", E: 14°22'38.65"). The study was conducted in the years 2009-2010, in May, August and October, *i.e.* in the high season of spring, summer and autumn, respectively. Quantitative ostracod samples were collected from the littoral from 15 research stations (Fig. 1). In total, 237 samples were col-

Fig. 1. Distribution of research stations along the course of the Oder River.

lected from the surface layer of the sediments. Simultaneously, physico-chemical parameters of water from every station were studied. A drag mounted on a rod, with 50 µm mesh net was used for collecting quantitative samples of sediments from the littoral zone, from the depths ranging from 0.05 to 2 m. We dragged for a specified distance at the places when it was possible to scrape the surface layer of the sediment. The drag was 25 cm wide and the dragged distance was known, so that it was possible to calculate the area of sampling. In the cases when the bottom was rocky or covered with vegetation, samples were taken from a specific area by disturbing the sediment from the substratum. The density of ostracods was determined by calculating the number of individuals collected in the field per square meter of the area of sampling. The collected samples varied with respect to the composition of bottom sediments and the extent of vegetation cover. After preliminary cleaning, the samples were preserved in 96% ethanol. In the laboratory, ostracod individuals were picked up from the sediment, using the decantation method to separate sand, and the bubbling technique described by Szlauer-Łukaszewska and Radziejewska (2013) to move the ostracods to the surface membrane. The Ostracoda were separated from the debris on a Petri dish under a Zeiss Discovery V12 stereoscopic microscope and finally identified on the basis of Meisch (2000), using a Zeiss Axioscope A1 microscope. In order to prepare permanent slides the soft parts of Ostracoda bodies were embedded in Hydro-Matrix®.

Groynes on the Oder River are built out of stone blocks. In the places where the current is slower, the spaces between the stones have become filled with sandy or muddy sediments. At the points where the current strikes, the blocks are uncovered. Muddy sediments prevail inside the groynes and bog vegetation very often develops there, with reed canarygrass (*Phalaris arundinacea* L.) as a dominant plant (Fig. 2). Submergent plants (elodeids) can be encountered in that zone. In the areas behind the groynes the current is slow and sandy and muddy sediments dominate. The areas before the groynes, where the incoming, turbulent river water strikes, are usually characterized by sandy and gravelly sediments. The conditions encountered in the above discussed zones correspond to those found in the littoral of lakes. Fig. 2 shows the lentic zone, where the finest sediments containing much organic matter prevail; they are usually river alluvium. On the other hand, the deepest central part of the area is characterized by the presence of sandy sediments, often bearing traces of deoxygenation; large rocks and a considerable amount of shell hash are present there. Habitat conditions found in that area resemble the sublittoral zone (Fig. 2).

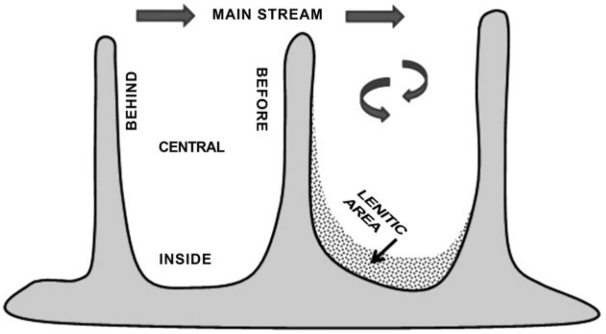

Fig. 2. An outline of the studied groyne fields in the Oder River.

Data analysis

We determined average density, frequency coefficient and dominance for Ostracoda assemblages for each vegetation season, calculating the average values of these parameters based on two years of study. Engelmann's (1978) classification was adopted while calculating the dominance coefficient, differentiating the following groups: eudominants (32-100%), dominants (10-31%), subdominants (3.2-9%), recedents (1-3.1%), subrecedents (0.32-0.99%), and sporadic species (<0.31%). Trojan's (1975) classification was adopted for calculating the frequency coefficient, with such classes as: euconstants (100-76%), constants (75-51%), accessory species (50-26%), and incidental species (25-0%). The following biodiversity indices were calculated: Shannon-Wiener diversity index (H), Pielou's evenness index (J), as well as average population density and the number of taxa per sample. For the above indexes the significance of differences between groups of samples collected in various periods of the vegetation season was checked with the aid of Kruskal-Wallis test.

The dynamics of density changes of particular ostracod species during the vegetation season was based on those species, whose frequency equaled or exceeded 25% at least during one season of the year. The significance of differences regarding the abundance (density) of individuals in respective seasons was checked with the aid of Kruskal-Wallis test. The comparisons have been visualized using box-and-whisker plots containing information about mean standard errors and mean standard deviations. This visualization shows density models of the Ostracoda. The population dynamics of individual species divided into adults and larvae was not analyzed, because whenever representatives of several species belonging to the same genus were found in a sample, it was impossible to distinguish their larval forms. Juvenile specimens belonging to these genera (*Pseudocandona, Fabaeformiscandona*) were analyzed separately. Juvenile *Fabaeformiscandona levanderi* and *Candona* were identified only as the Candoninae, because of morphological similarity between them.

Significance of differences between seasons was tested with respect to each of the studied physico-chemical parameters of water using Kruskal-Wallis test. The relationship between the species composition of the Ostracoda and physico-chemical parameters was studied using CANOCO ver. 4.5 software package. The patterns of species distribution in connection with environmental variables were studied utilizing the CCA (canonical correspondence analysis) (ter Braak, 1986), having previously obtained the results of the indirect DCA (detrended correspondence analysis) that outlined the structure of data (Jongman *et al*., 1987). Data were not transformed; no weights were used for respective species and samples. The significance of the effect of respective environmental variables on the diversity of species composition was determined using stepwise variable selection ($P \leq 0.05$). Monte Carlo test was conducted in order to pinpoint the most significant variables.

For the purposes of statistical tests and data analysis the following software was utilized: STATISTICA ver. 10 INC StatSoft based on methods applied by Sokal and Rohlf (1995) and PAST (Hammer *et al.*, 2001).

RESULTS

In the spring season 83 samples were collected; 81 samples were collected in the summer season and 73 were collected in the autumn season. Forty-seven species were identified. A total number of 155 978 individuals were found in the studied samples, with average density of 658 indiv. m^{-2} and maximum density of 9472 indiv. m^{-2}. The highest average density of the Ostracoda was noted in spring: 1160 indiv. m^{-2}; in the subsequent season that number dropped by about half and amounted to 505 indiv. m^{-2} in spring and just 257 indiv. m^{-2} in autumn (Tab. 1). Shannon-Wiener diversity index (H) equalled 1.374 and Pielou's evenness index (J) equalled 0.536. In spring 37 species were noted, 32 in summer and 28 in autumn; H equalled 1.375, 1.345 and 1.405, respectively, whereas J equalled 0.476, 0.549, and 0.592, respectively. However, statistically significant differences ($P<0.05$) between seasons were discovered only in the case of the number of taxa, density and evenness index. *Limnocythere inopinata* and *Physocypria kraepelini* were the species that retained the subdominant and dominant status throughout the year. In spring, the dominant status was reached by the juvenile Candoninae. In summer the subdominant status was gained by *Cypridopsis vidua*. In autumn *Candona neglecta* was subdominant, whereas *C. vidua* and juvenile *Pseudocandona* were dominants. As for frequency, the species that were dominants usually obtained a high status, from euconstants to accessory species. Throughout the year the following species were euconstants, constants and accessory species: *C. neglecta*, *Cypria ophtalmica, C. vidua*, *Darwinula stevensoni*, *L. inopinata* and *P. kraepelini*. In spring the following species were frequently encountered in samples: *Bradleystrandesia reticulata, Candonopsis scourfieldi, Fabaeformiscandona levanderi*, and juvenile *Ilyocypris* sp. In summer and autumn, the highest frequencies were reached by *Ilyocypris decipiens, Potamocypris smaragdina*, *P. variegata* and juvenile *Pseudocandona* (Tab. 1).

In spite of a declining tendency in the general density of the Ostracoda in the course of the season, models of seasonal occurrence of particular species considerably differed from one another. Taking into account solely those species whose frequency was equal to or higher than 25% at least during one season of the year, the following models of density dynamics of the Ostracoda during the vegetation season were obtained:

i) Species producing one generation a year, occurring in a specific season of the year.
    - Spring species: *Bradleystrandesia reticulata, Cypris pubera*.

ii) Species occurring throughout the whole vegetation season, producing more than one generation a year.
    - Species that reached the maximum density in spring and then displayed a gradual drop of density as the season was progressing: *Limnocythere inopinata, Physocypria kraepelini, Cypria ophtalmica, Pseudocandona compressa, Darwinula stevensoni* (Fig. 3a).
    - Species that reached the maximum density in summer and were characterized by very low densities in the remaining seasons of the year: *Potamocypris smaragdina, P. variegata, Ilyocypris decipiens, I. monstrifica, Cypridopsis vidua* (Fig. 3b).
    - Species that reached the maximum density in autumn and were characterized by very low densities in the remaining seasons of the year: *Candona neglecta*, *Fabaeformiscandona levanderi* (Fig. 3c).
    - Species that reached the maximum density in spring and in autumn and were characterized by very low densities in summer: *Candona candida* (Fig. 3d).

Furthermore, differences in seasonal occurrence were also noticed in the case of species whose frequencies were lower than 25% (Tab. 2). However, because those were incidental species, such data should be treated as preliminary information to be investigated further while studying the density dynamics of those species. The only dependable information in this case seems to be the identification of species occurring throughout the year.

The results of testing physico-chemical parameters of water in particular seasons of the year are given in Tab. 3. On the basis of norms regarding the classification of ecological status of waters in Poland (Republic of Poland, 2011), ecological status of the northern part of the studied area was classified as good (from Czelin station to Nowe Kaleńsko), whereas the remaining part of the area was classified as moderate. Such results indicated that ecological conditions in the studied area were favourable for ostracods. According to the results of Kruskal-Wallis test conducted in order to determine statistical significance of

Tab. 1. A comparison of density, frequency, and dominance of ostracods at various times during the season.

Taxa	Abbrev.	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
		Density Indiv. m^{-2}			Dominance %			Frequency %		
Bradleystrandesia reticulata (Zaddach, 1844)	Bra ret	79	0	0	*7*	0	0	75	0	0
Candona candida (O.F. Müller, 1776)	Can can	1	0	1	0	0	1	11	0	25
Candona spp. juvenile	Can juv	0	0	0	0	0	0	0	0	1
Candona neglecta Sars, 1887	Can neg	11	10	85	1	2	*33*	*48*	*36*	60
Candona weltneri Hartwig, 1899	Can wel	0	0	0	0	0	0	0	0	1
Candoninae juvenile	Canae	226	9	1	20	2	0	*82*	*47*	25
Candonopsis scourfieldi Brady, 1910	Cas sco	0	0	0	0	0	0	0	1	1
Cyclocypris laevis (O.F. Müller, 1776)	Cyc lae	3	1	0	0	0	0	10	11	4
Cyclocypris ovum (Jurine, 1820)	Cyc ovu	0	0	0	0	0	0	2	1	3
Cypria exculpta (Fischer, 1855)	Cyp exc	0	0	0	0	0	0	0	1	1
Cypria ophtalmica (Jurine, 1820)	Cyp oph	85	31	15	*7*	*6*	*6*	*84*	63	*78*
Cypria/Physocypria juvenile	Cyp Phy	0	0	1	0	0	0	0	0	11
Cypridopsis elongata (Kaufmann, 1900)	Cpr elo	0	0	0	0	0	0	0	0	1
Cypridopsis vidua (O.F. Müller, 1776)	Cpr vid	37	212	27	3	*42*	10	*78*	*94*	*84*
Cypris pubera O.F. Müller, 1776	Cps pub	24	0	0	2	0	0	25	0	0
Darwinula stevensoni (Brady & Robertson, 1870)	Dar ste	19	5	5	2	1	2	53	*40*	*48*
Dolerocypris fasciata (O.F. Müller, 1776)	Dol fas	0	0	0	0	0	0	1	4	3
Eucypris pigra (Fischer, 1851)	Euc pig	0	0	0	0	0	0	7	0	0
Eucypris virens (Jurine, 1820)	Euc vir	0	0	0	0	0	0	4	0	1
Fabaeformiscandona alexandri (Sywula, 1981)	Fab ale	1	1	0	0	0	0	10	1	0
Fabaeformiscandona fabaeformis (Fischer, 1851)	Fab fab	0	0	0	0	0	0	4	1	1
Fabaeformiscandona fragilis (Hartwig, 1898)	Fab fra	0	0	0	0	0	0	2	2	1
Fabaeformiscandona holzkampfi (Hartwig, 1900)	Fab hol	2	1	0	0	0	0	11	11	0
Fabaeformiscandona levanderi (Hirschmann, 1912)	Fab lav	9	1	18	1	0	*7*	*49*	10	8
Fabaeformiscandona protzi (Hartwig, 1898)	Fab pro	0	0	0	0	0	0	2	0	1
Fabaeformiscandona spp. Juvenile	Fab juv	0	0	5	0	0	2	0	5	10
Fabaeformiscandona weigelini (Petkovki, 1962)	Fab wei	0	0	0	0	0	0	0	0	8
Herpetocypris chevreuxi (Sars, 1896)	Her che	0	0	0	0	0	0	2	0	0
Herpetocypris spp. juvenile	Her juv	0	0	0	0	0	0	0	2	1
Herpetocypris reptans (Baird, 1835)	Her rep	0	1	0	0	0	0	1	9	3
Heterocypris incongruescens (Ramdohr, 1808)	Het inc	0	0	0	0	0	0	0	0	1
Heterocypris salina (Brady, 1868)	Het sal	0	0	0	0	0	0	0	1	0
Ilyocypris bradyi Sars, 1890	Ily bra	4	4	1	0	1	1	*28*	*26*	23
Ilyocypris decipiens Masi, 1905	Ily dec	2	21	1	0	*4*	0	12	*44*	*26*
Ilyocypris gethica/decipens	Ily g/d	0	0	0	0	0	0	0	1	0
Ilyocypris gibba (Ramdohr, 1808)	Ily gib	0	0	0	0	0	0	0	1	5
Ilyocypris monstrifica (Norman, 1862)	Ily mon	0	2	1	0	0	0	2	22	25
Ilyocypris spp. juvenile	Ily juv	34	11	5	3	2	2	67	52	*47*
Isocypris beauchampi (Paris 1920)	Iso beu	0	1	0	0	0	0	2	6	0
Limnocythere inopinata (Baird, 1843)	Lim ino	415	87	27	*36*	17	10	*88*	75	64
Limnocytherina sanctipatricii (Brady & Robertson, 1869)	Lim san	2	0	0	0	0	0	5	0	3
Ostracoda juvenile	Ost juv	0	0	0	0	0	0	0	0	8
Physocypria kraepelini G.W. Müller, 1903	Phy kra	186	75	26	16	15	10	*89*	67	*81*
Potamocypris smaragdina (Vavra, 1891)	Pot sma	0	13	2	0	3	1	6	60	*40*
Potamocypris spp. juvenile	Pot juv	0	0	0	0	0	0	0	2	0
Potamocypris variegata (Brady & Norman, 1889)	Pot var	1	4	2	0	1	1	7	*30*	*36*
Prionocypris zenkeri (Chyzer & Toth, 1858)	Pri zen	1	0	0	0	0	0	5	4	3
Pseudocandona albicans (Brady, 1864)	Pse alb	3	0	0	0	0	0	5	6	0
Pseudocandona compressa (Koch, 1838)	Pse com	9	7	0	1	1	0	*46*	*42*	0
Pseudocandona hartwigi (G.W. Müller, 1900)	Pse har	1	0	0	0	0	0	6	9	1
Pseudocandona insculpta (G.W. Müller, 1900)	Pse ins	1	0	0	0	0	0	5	0	0
Pseudocandona marchica (Hartwig, 1899)	Pse mar	0	0	0	0	0	0	2	1	1
Pseudocandona pratensis (Hartwig, 1901)	Pse pra	0	0	0	0	0	0	1	2	0
Pseudocandona spp. juvenile	Pse juv	2	7	34	0	1	13	19	52	64
Sarscypridopsis aculeata (Costa, 1847)	Sar acu	0	0	0	0	0	0	0	4	4
Schellencandona belgica (Klie, 1937)	Sch bel	0	0	0	0	0	0	0	2	4
Tonnacypris lutaria (Koch, 1838)	Ton lut	0	0	0	0	0	0	5	0	0
Total		1160	505	257	100	100	100	100	100	100

Taxa representing eudominants and euconstants are marked using italic font and underlining; dominants and constants are underlined; subdominants and accessory species are marked are in italics.

seasonal differences regarding values of studied physicochemical parameters of water, the differences were statistically significant in most cases. Only for nitrates and water hardness no statistically significant (P>0.05) differences were found: P=0.77, and P=0.55, respectively. Summing up, the most favourable environmental conditions on the Oder were in spring, when dissolved oxygen content was the highest, *i.e.*, 11.7 mg L^{-1} on average, corresponding to 117% saturation. At that time the values of the remaining factors were low, apart from nitrate content, which reached its maximum in spring, *i.e.*, 6.8 mg L^{-1} on average. In summer the conditions were still rather good, with slightly lower dissolved oxygen content: 6.8 mg L^{-1} on average, corresponding to 98% saturation. The highest phosphate content was noted in summer, equal to 0.31 mg L^{-1}, and the lowest visibility: 0.64 m. The conditions deteriorated in autumn, when the highest ammonia nitrogen and nitrate contents, as well as he highest TDS and conductivity were noted. However, good oxygen conditions continued in autumn: 11 mg L^{-1}, corresponding to 94% saturation.

The DCA analysis for ostracod samples collected from the studied stretch of the Oder River revealed that the length of gradient represented by the first ordination axis equalled 4.404 SD (the species covered the full Gaussian spectrum), which justified conducting a direct ordination analysis of the CCA type in order to determine the relationships between species occurrence and substrate parameters. The results of direct CCA analysis for the Ostracoda pointed out that the environmental variables used in the ordination explained about 28% of the total variability of occurrence of the Ostracoda. The results of stepwise variable selection revealed that only two environmental variables: ammonia nitrogen content and salinity were not significant in forming ostracod assemblages (P>0.05). The factors that had the greatest effect on the formation of ostracod assemblages included: temperature, visibility, and dissolved oxygen content (7% each) and phosphate content (4%). The ordination diagram illustrating results of the CCA (Fig. 4) shows that the taxa have various positions with respect to environmental vectors.

DISCUSSION

Spatiotemporal patterns of ostracod occurrence are connected with biological properties of species as such. In the case of many species, especially common, cosmopolitan

Tab. 2. Occurrence of incidental species of the Ostracoda during vegetation season.

	Spring	Summer	Autumn
Cyc lae	X	X	X
Cyc ovu	X	X	X
Dol fas	X	X	X
Fab fab	X	X	X
Fab fra	X	X	X
Her rep	X	X	X
Pri zen	X	X	X
Pse har	X	X	X
Pse mar	X	X	X
Her che	X		
Euc pig	X		
Pse ins	X		
Ton lut	X		
Fab ale	X	X	
Fab hol	X	X	
Iso beu	X	X	
Pse alb	X	X	
Pse pra	X	X	
Cas sco		X	X
Cyp exc		X	X
Ily gib		X	X
Sar acu		X	X
Sch bel		X	X
Can wel			X
Cpr elo			X
Fab wei			X
Het inc			
Euc vir	X		X
Fab pro	X		X
Lim san	X		X
Het sal		X	

X, presence of the species.

ones, researchers have determined their biology and become well acquainted with their life histories. However, there are still many species which occur rarely and have not been fully described so far (Meisch, 2000; Sywula, 1974). Environmental changes stimulate seasonal reactions of organisms. The effects of some environmental factors, such as photoperiod and temperature, seem obvious. A crucial role of temperature has been confirmed by many scientists, *i.e.* Sywula (1974), Horne (1983), Rieradevall and Roca (1995), Külköylüoğlu and Dügel (2004), Külköylüoğlu (2005). In the present study temperature also was the factor with the strongest influence, as confirmed by the results of stepwise variable selection. The relationship between spatiotemporal patterns and other ecological factors is not obvious and still requires confirmation. In their study devoted to an artificial Lake Gölcük (Turkey) Külköylüoğlu and Dügel (2004) showed that pH, dissolved oxygen, and redox potential were also factors strongly influencing ostracod assemblages. On the other hand, according to Külköylüoğlu (2005), dissolved oxygen was the most potent factor in the relatively shallow Lake Gölköy (Turkey). Furthermore, according to Mezquita *et al.* (1999a), the most important factors in flowing waters in eastern Iberian Peninsula were water chemistry (ionic concentration and ionic composition) and temperature. In the present study the factors which were the most influential in shaping ostracod assemblages in the littoral of the studied lowland river included visibility, and dissolved oxygen content. Differences in ecological status of water bodies studied by various researchers make drawing clear, universal conclusions difficult. Water in a river is subjected to constant mixing so as a habitat type, river are much more homogenous with respect to physico-chemical conditions than lakes, which are characterized by summer and winter stagnation. In spite of differences between the water bodies discussed above, it can be concluded that apart from temperature, dissolved oxygen seems to be the most important factor in shaping ostracod assemblages.

Tab. 3. Physical and chemical parameters of water in particular seasons.

Factor	Season	Average	SD
NH_4 (mg L^{-1})	Spring	0.245	0.130
	Summer	0.216	0.073
	Autumn	0.306	0.094
NO_2 (mg L^{-1})	Spring	0.027	0.016
	Summer	0.040	0.036
	Autumn	0.036	0.025
NO_3 (mg L^{-1})	Spring	6.8	2.3
	Summer	5.4	1.6
	Autumn	6.9	2.0
PO_4 (mg L^{-1})	Spring	0.102	0.173
	Summer	0.310	0.227
	Autumn	0.258	0.090
TDS (mg L^{-1})	Spring	473	99
	Summer	358	38
	Autumn	531	192
Salinity (‰)	Spring	0.481	0.100
	Summer	0.356	0.039
	Autumn	0.527	0.191
Hardnes (mg L^{-1})	Spring	12.4	1.4
	Summer	11.7	1.4
	Autumn	12.3	2.0
Conductivity (µS m^{-1})	Spring	958	218
	Summer	733	76
	Autumn	1083	373
pH	Spring	8.6	0.6
	Summer	8.0	0.3
	Autumn	7.9	0.2
O_2 (mg L^{-1})	Spring	11.7	1.1
	Summer	8.5	1.0
	Autumn	11.0	0.5
O_2 (%)	Spring	117	13
	Summer	98	12
	Autumn	94	3
Visibility (m)	Spring	0.85	0.16
	Summer	0.64	0.13
	Autumn	0.98	0.24
Temperature (C°)	Spring	15.2	1.6
	Summer	21.8	1.1
	Autumn	8.3	1.2

SD, standard deviation; data indicating the worst environmental conditions are underlined.

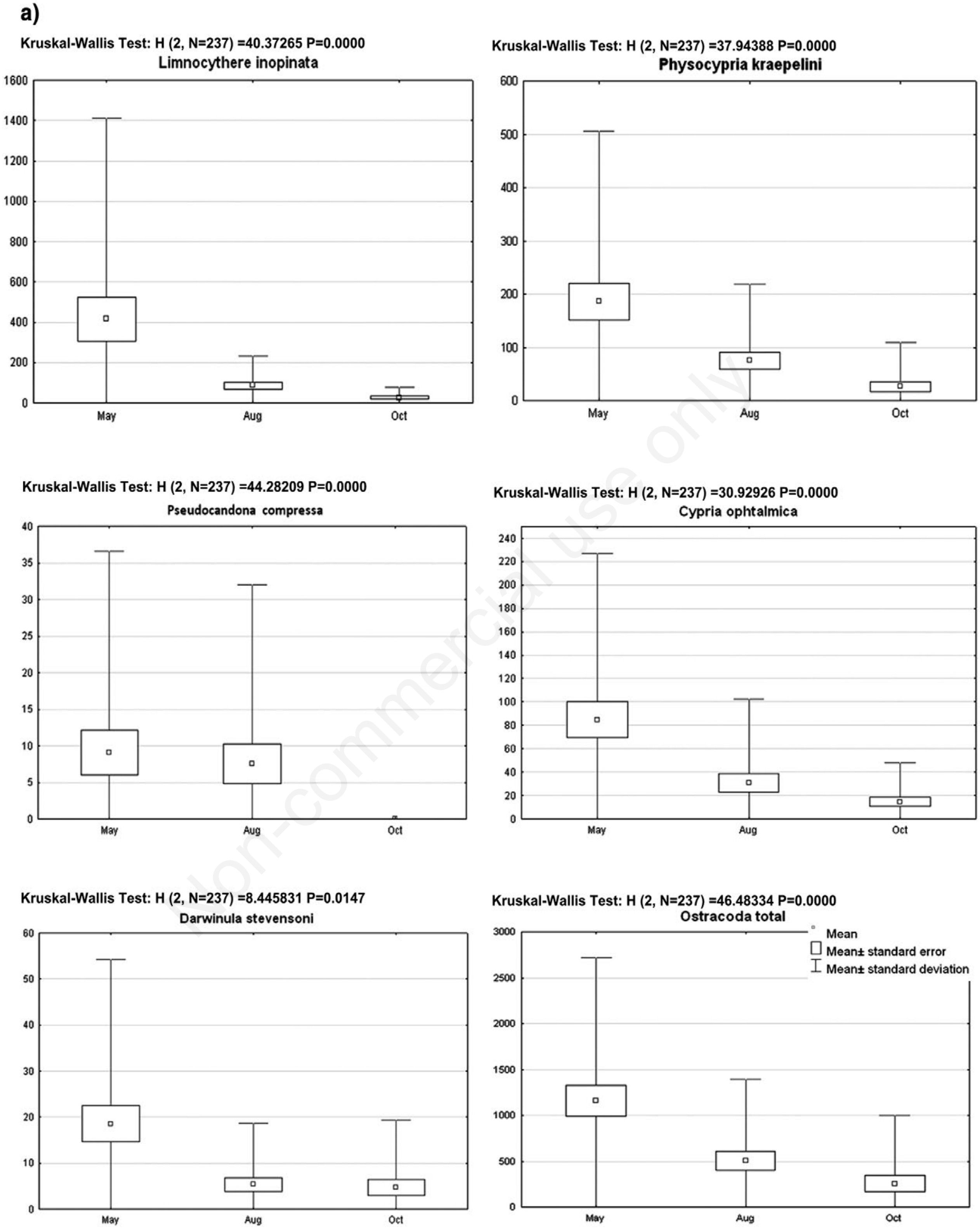

Fig. 3. Various types of density dynamics models of the Ostracoda in respective seasons; box and whisker plots. The Y-axis illustrates density of ostracods (indiv. m^{-2}). Species that reached the maximum density in: a) spring and then displayed a gradual drop of density as the season was progressing; b) summer and were characterized by very low densities in the remaining seasons of the year; c) autumn and were characterized by very low densities in the remaining seasons of the year; d) spring and in autumn and were characterized by very low densities in summer.

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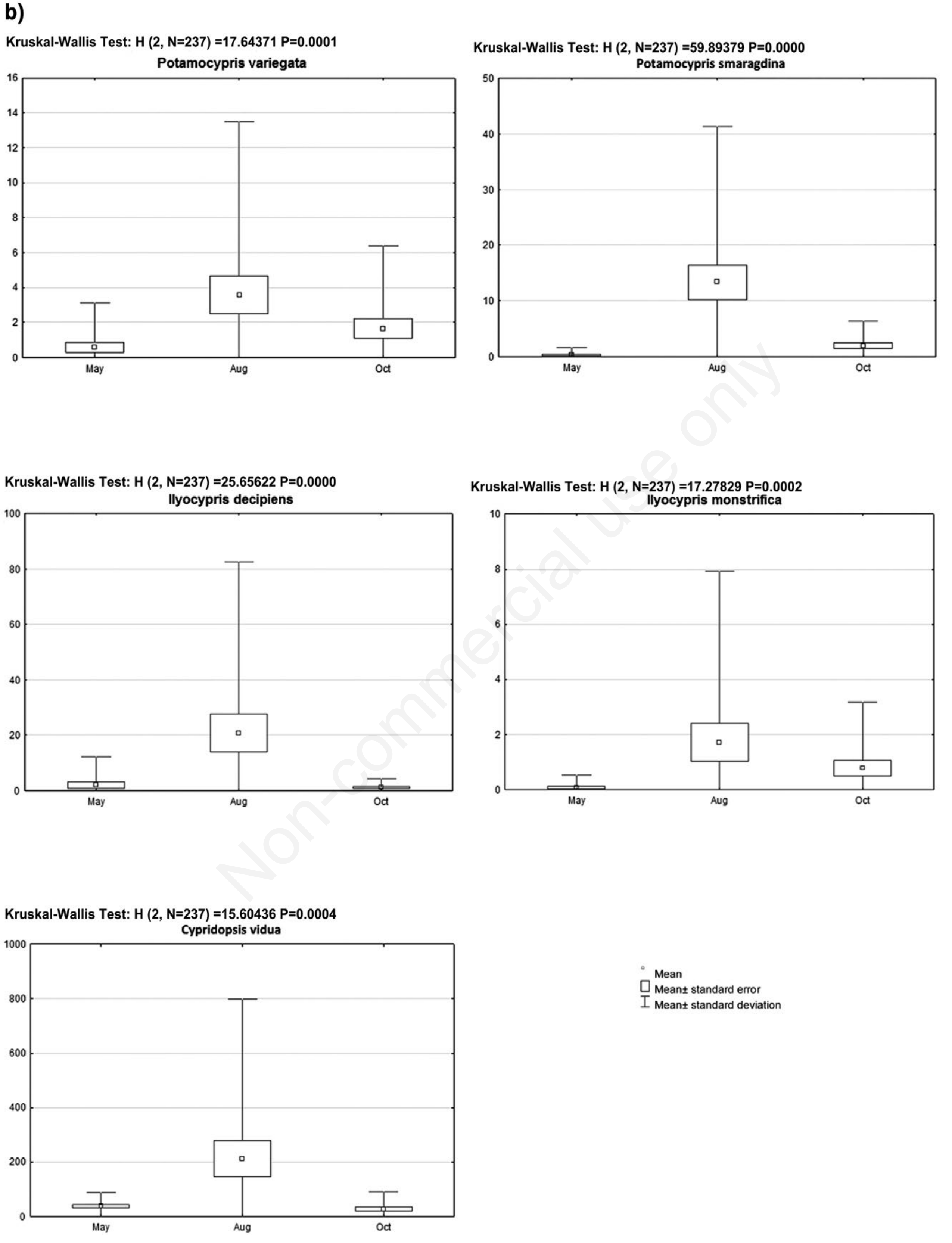

Fig. 3b.

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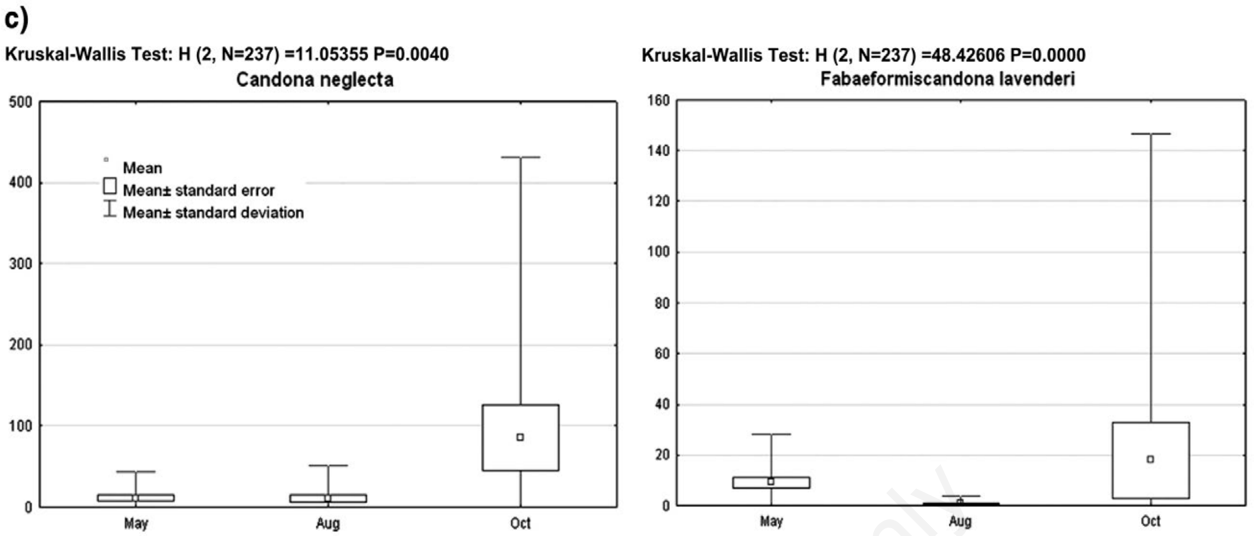

Fig. 3c.

The peak of density usually occurred in warm seasons and only occasionally in late autumn or winter (Cohen and Morin, 1990). General ostracod density in the Oder River was fluctuating in a similar way: it reached its peak in spring, when it amounted to 1160 indiv. m^{-2}, then gradually decreased as the season was progressing, and did not achieve another peak. The dynamics of occurrence of particular ostracod species was often different from the tendencies regarding overall density of ostracods. Külköylüoğlu and Dügel (2004) and Külköylüoğlu (2005) stated that species with similar ecological requirements had similar phenology, showing how important it is to take into account the role of environmental factors while discussing phenological diversity. According to Rieradevall and Roca (1995), the lowest numbers of *Candona neglecta* coincided with the end of summer and the beginning of autumn, when water temperature was the highest. The maximum densities of this species were recorded in winter. Small peaks also appeared in spring and at the end of autumn. A similar result was obtained in this study with the peak in autumn, but it should be remembered that no research was conducted in winter. According to CCA analysis, *Candona neglecta* is strongly negatively correlated with increasing temperature, which confirmed its environmental requirements. Furthermore, the species is strongly positively correlated with ammonia nitrogen content, TDS, conductivity and visibility (Fig. 4). According to Meisch (2000), *Candona candida* produces one generation a year; larvae appear in spring and reach sexual maturity in autumn and winter. In the present study the two peaks of density of adult individuals in spring and in autumn may be regarded as proof that the period of mass occurrence of adult individuals in river habitats is prolonged over the spring period. Earlier larval stages of the order *Candona* were identified here as the juvenile Candoninae. The share of juvenile Candoninae was high in spring, which confirmed Meisch's (2000) report that the larvae occurred in spring. According to the present study, *C. candida* shows no strong correlation with any of the studied environmental factors (Fig. 4). Hiller (1972) reported abundant adults of *F. levanderi* from autumn (October) to spring; rare adults of both sexes were found until mid-June. He concluded that this species was a winter form producing one generation per year. This agrees with results obtained in the present study: the maximum density of adults occurred in autumn, the minimum in summer, and

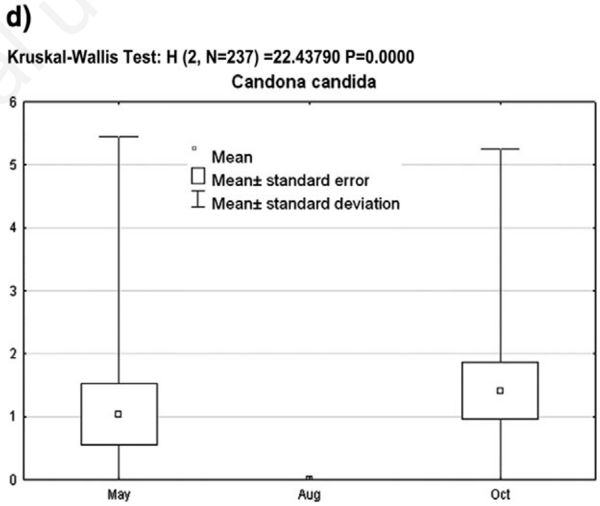

Fig. 3d. Continued from previous page.

in winter no research was conducted. This study shows that F. *levanderi* has the same environmental requirements as *C. neglecta* (Fig. 4). Hiller (1972) collected adults of *Pseudocandona compressa* from April to October, noting maximum density in May and June, and Mallwitz (1984) reported a high number of adults from June to September, with the peak in August. These remarks are not contradictory to the results obtained in the present study, with the maximum density of adults noted in May and a still rather high result in August. According to the present study, *P. compressa* does not show a strong correlation with any of the studied environmental factors (Fig. 4). The life cycle of *Ilyocypris monstrifica* is poorly known. The species has been collected in the summer only (Meisch, 2000). To some extent those data coincide with the data obtained in the present study: the maximum density of adults was noted in summer, but the species occurred throughout the whole study period. In the present study, *Ilyocypris monstrifica* showed a strong positive correlation with phosphate and nitrate contents, and a negative correlation with dissolved oxygen, hardness and pH. It did not show a strong correlation with respect to temperature (Fig. 4). Meisch (2000) admitted that the life cycle of *Ilyocypris decipiens* was poorly known and conjectured that it was a summer form, which has been definitely confirmed by results obtained in the present study. In the present study the species shows a

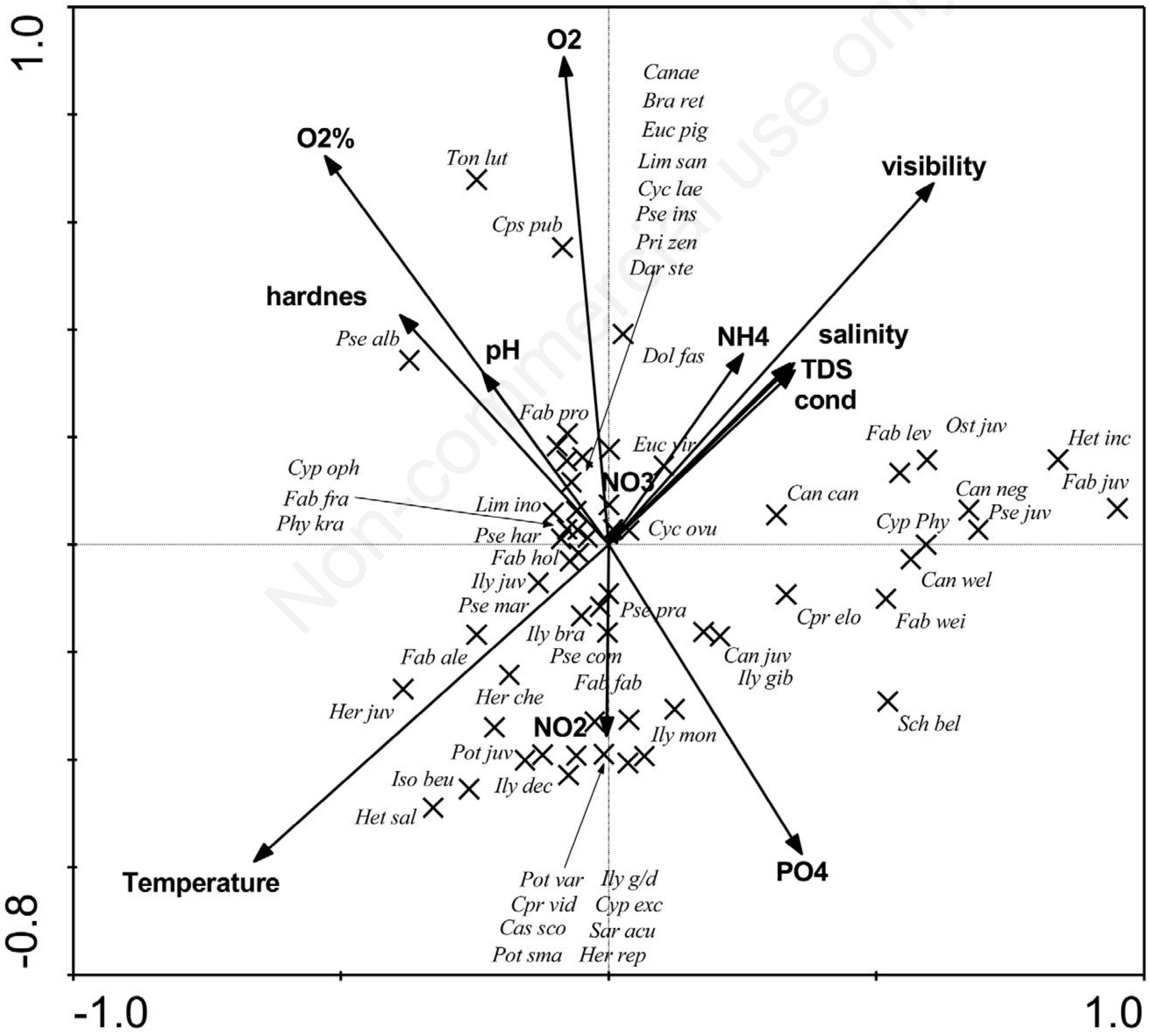

Fig. 4. The ordinance diagram for species and habitat variables in the system of two first axes of CCA for the samples from the studied stretch of the Oder River. Abbreviations explained in Tab. 1.

strong positive correlation with increasing temperature as well as phosphate and nitrate contents, and a negative correlation with dissolved oxygen, hardness and pH (Fig. 4). According to Meisch (2000), adults of *Ilyocypris bradyi* occurred throughout the whole year, which has been entirely confirmed in this study by the absence of statistically significant differences regarding the occurrence of this species in particular seasons. According to the present study, *I. bradyi* shows no strong correlation with any of the studied environmental factors, similarly to *P. compressa* (Fig. 4). In the case of *Bradleystrandesia reticulata* and *Cypris pubera*, which occurred in the river only in spring, reaching a comparatively high density, the results were convergent with data from literature. *Bradleystrandesia reticulata* is believed to be an early year form of mature females of *Cypris pubera* and is usually found from late May till June/July and disappears soon after (Meisch, 2000). Scharf (1988) reported that *Cypridopsis vidua* was very frequent in the warm season while the adults were rare in winter; the author encountered adults throughout the year, but found instars only in the summer time; those observations are identical with ours. With respect to environmental requirements *C. vidua* resembles *I. monstrifica* (Fig. 4). Hiller (1972) found numerous individuals of *Potamocypris variegata* from June to October, and larvae were the most abundant in August or in October. On the other hand, Külköylüoğlu and Dügel (2004), found the species from July to October. Meisch (2000) suggested that the species could belong to summer forms. Data provided by the above mentioned authors confirm the status that the species has been given in the present study. In terms of environmental requirements, this species has similar properties as *I. monstrifica* and C. *Vidua* (Fig. 4). Meisch (2000) believed that *Potamocypris smaragdina* was a summer form, confirming data given by Nüchterlein (1969) and Hiller (1972), as well as data presented in this study. With respect to its environmental requirements, the species is similar to *I. monstrifica*, *C. vidua* and *P. variegata* (Fig. 4).

However, it turned out that the dynamics of occurrence of certain species investigated in the present study contradicted data from literature. Unfortunately, the species discussed below showed no strong correlation with any of the studied environmental factors (Fig. 4). Thus, they were not useful for considering phenological variability. According to Ranta (1979), the peak of abundance of *Darwinula stevensoni* took place in late summer and in autumn with a second, smaller peak in spring, and the minimum in summer. On the other hand, Rieradevall and Roca (1995) reported high densities in fall and winter, declining during spring, with a small peak in midsummer. According to the present study, the species reached its peak in spring. Martens and Tudorancea (1991) stated that the species avoided parts of the lake in Lake Zwai, in Ethiopia, where temperatures rose to a high level. According to Meisch (2000), *Cypria ophtalmica* could be found throughout the year. Rieradevall and Roca (1995) reported high densities of this species in late summer and early autumn, which is not concurrent with results obtained in the present study: according to the present research, the maximum took place in spring. According to Hiller (1972), the populations of *Physocypria kraepelini* remained constant in size throughout the year, which stands in conflict with data obtained in the present study where a clear peak of density occurred in spring. According to Sywula (1977) and Jungwirth (1979), both adults and juveniles of *Limnocythere inopinata* were reported to occur throughout the whole year, and thus Meisch (2000) classified it as a permanent form, with the peak of abundance taking place from May to September, which does not entirely agree with the results of the present study, according to which the maximum density was reported in May. It is interesting to note that all density models obtained by us which conflicted with data from literature referred to situations, where the maximum density occurred in spring. This points out to the fact that during that period the conditions in the river are very favourable in comparison to other seasons, as confirmed by the results of environmental factors (Tab. 3). However, even in Oder River summer no oxygen deficits took place, and the minimal values in respective seasons amounted to 10.04 in spring, 6.7 in summer, and 9.9 mg m^{-3} in autumn. Examples from literature discussed above referred to lakes and ponds where oxygen deficits occurred, especially in summer. Thus, differences noted between those habitats and river habitats regarding ostracod densities might be due to differences between habitat types. Another important factor affecting the occurrence of the Ostracoda is the access to organic detritus, which is the main source of their diet beside algae and bacteria (Meisch, 2000). In non-river habitats there are usually excessive amounts of accumulated organic material, but in rivers, due to constant movement of waters and changes in water level washing out of organic matter is more probable than its accumulation (Szlauer-Łukaszewska, 2013). When the organic matter content was high, ostracod populations presented higher densities and were more diverse (Benzie, 1989; Martens and Tudorancea, 1991; Szlauer-Łukaszewska, 2013). During summer and autumn, when ostracod densities were the lowest, the water level rose several times, resulting in partial washing out of organic matter from the groyne fields and could also directly remove some of the fauna itself (Szlauer-Łukaszewska, 2008).

CONCLUSIONS

Statistically significant differences regarding the structures of ostracod assemblages during the vegetation season were determined for a number of taxa, as well as density and the evenness index. Seasonal changes in the occurrence of the Ostracoda were strongly reflected by their general density, reaching the maximum in spring and the minimum in autumn.

Five models of density dynamics were determined. *Limnocythere inopinata* and *Physocypria kraepelini* were dominant species throughout the whole vegetation season. Apart from that, juvenile Candoninae dominated in spring, *Cypridopsis vidua* dominated in summer, whereas *Candona neglecta, C. vidua* and juvenile *Pseudocandona* dominated in autumn. In the case of *Darwinula stevensoni*, *Cypria. ophtalmica*, *Physocypria kraepelini*, and *L. inopinata*, models of seasonal occurrence differed from those known from subject literature.

The observed changes in the dynamics of Ostracoda density resulted from environmental factors. Temperature, visibility, and dissolved oxygen content were among factors which most strongly affected the structure of ostracod assemblages. Statistically significant differences noted between the seasons in the case of a majority of studied environmental factors confirmed the above thesis.

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