ACTA ZOOLOGICA BULGARICA
Acta zool. bulg., 65 (2), 2013: 225-231

Spatial and Diurnal Distribution of Cladocera in Beds of Invasive *Vallisneria spiralis* and Open Water in Heated Lake

Elżbieta Bogacka-Kapusta, Andrzej Kapusta

Department of Ichthyology, Inland Fisheries Institute in Olsztyn, Oczapowskiego 10, 10-719 Olsztyn, Poland;
E-mails: ela@infish.com.pl, kasta@infish.com.pl

Abstract: The aim of this study was to analyze the changes in the composition and richness of Cladocera in the littoral zone of a lake dominated by the exotic macrophyte species *Vallisneria spiralis* L., 1758. The research on the diurnal spatial distribution of Cladocera in the patches of *Vallisneria spiralis*, and in comparison, in the open water zone situated between the macrophyte stands, was carried out in July and August 2004 in Lake Licheńskie (central Poland). The *Vallisneria* habitat was characterized by a great variability in water temperature and oxygen content. In both habitats, the abundance and species richness of Cladocera were higher in July than in August. The density and biomass of cladocerans were higher in the *Vallisneria* habitat than the open water area. The diel pattern of Cladocera density and biomass distribution in July indicates its use of *V. spiralis* as a daytime refuge from zooplanktivorous fish.

Key words: heated water, macrophytes, shallow lakes, species richness, *Vallisneria spiralis,* zooplankton

Introduction

Aquatic plant beds play an important role in the shaping of zooplankton assemblage structures (Van Donk, Van de Bund 2002, Kuczyńska-Kippen, Nagengast 2006). Zooplankton distribution in lakes is affected by various factors, among which the environmental conditions often plays an important role. In shallow lakes, zooplankton undergoes diel horizontal migrations (DHM) into the vegetated areas. Daytime hours are spent in or near macrophytes, which serve as a refuge from predators. At night, zooplankton migrates back towards the pelagic zone (Burks *et al.* 2002). The littoral zone is quite diverse. This is especially advantageous to plankton organisms that feed on periphyton, which find herein an abundant supply of food. For this reason, the presence of plankton organisms is closely associated with macrophytes (Balayla, Moss 2003).

Lake Licheńskie is a key element of a power plant cooling system. Extensive plant growth in the lake littoral zone reduces lake water circulation rates as well as its ability to cool water from the power plants. It is also a factor in the ecological changes that are taking place in the lake. Effects of water heating and increased flow rates on production, species richness, population structure, and the fertility of zooplankton found in the pelagic zones of lakes were a subject of long-term and divers studies (Hillbricht-Ilkowska, Zdanowski 1978, Hillbricht-Ilkowska *et al.* 1988, Tunowski 2009). Over the past few years, studies on the littoral zone zooplankton community were conducted. Paturej *et al.* (2007) reported effects of littoral heterogeneity and high temperature on the zooplankton. A high species richness of rotifers inhabiting the alien plant were determined by

Ejsmont-Karabin (2011), and Ejsmont-Karabin, Hutorowicz (2011).

Vallisneria spiralis (Hydrocharitaceae) is a non-native species in Poland. It has been found in the lake since the early 1990s (Hutorowicz *et al.* 2006). The high temperatures of water in the lake were one of the most important reasons for the rapid invasion of *V. spiralis* in the littoral (Hutorowicz 2006). It has a rather simple morphology and therefore it is not expected to offer much differentiated substrates for the littoral zooplankton community (Ejsmont-Karabin, Hutorowicz 2011). The aim of the current study was to determine the species richness and abundance of the cladocerans in two littoral habitats in a heated lake.

Materials and Methods

Lake Licheńskie (52º18'N, 18º20'E) is a shallow eutrophic lake (mean depth of 4.5 m) with a surface area of 147.6 ha, situated near Konin, central Poland. Since 1958, it has been heated with cooling waters discharged from the Pątnów and Konin power plants (Stawecki *et al*. 2007). Lake Licheńskie has the highest water temperature of the five lakes that comprise the cooling system. Mixing processes in the lake take place from top to bottom beginning in early spring through to late autumn. The northern and southern parts of the lake are heated to a lesser degree and can freeze during harsh winter conditions (Stawecki *et al*. 2007). The littoral zone of Lake Licheńskie is dominated by *V. spiralis* (Hutorowicz 2006).

The study was carried out in July and August 2004, in the shallow part of the lake. The samples were collected from two sites: 1) the *V. spiralis* (VS) habitat, and 2) a macrophyte-free area (BR). Sampling was carried out eight times within a 24-hour cycle. Zooplankton samples were collected five times (5 L volume of each sample) using a Patalas sampler. The samples were concentrated with a 60-μm plankton net and fixed immediately with Lugol's solution and 96% ethyl alcohol. The cladocerans in the samples were analyzed to species level following Flössner (1972). Moreover, water temperature (± 0.1°C) and dissolved oxygen content (± 0.1 mg O_2 dm^{-3}) were measured at each sampling site. Species biomass was estimated using length-weight equations (Bottrell *et al*. 1976).

The zooplankton data were transformed using ln(x+1) to stabilize any variances. ANOVA were used to analyze water temperature and oxygen content data for the two habitats studied in July and August. Tukey's test was used in *post-hoc* analysis. The Mann-Whitney test was used to compare the species richness, density, and biomass of the two habitats. Pearson's correlation analysis was used for testing the associations between the time of day, water temperature, oxygen content and total density or total biomass as well as the abundance of the five most numerous species. Statistical analyses were performed with Statistica 8.0 (StatSoft, Tulsa, Oklahoma).

Result

Environmental conditions

Significant spatial (VS-BR) and temporal variations (July-August) in water temperature were observed in the littoral zone of Lake Licheńskie ($P < 0.05$). Significantly higher water temperatures were recorded in July than in August ($P < 0.05$). The lowest water temperature in July was recorded at 03:00 hours in the VS habitat (25.4°C). Water temperatures increased starting at 06:00 hours and reached the highest levels in both habitats at 15:00 hours (27.7°C). In August, water temperatures were slightly higher in the BR habitat (24-hour mean of 24.4°C) than in the VS habitat (24-hour mean of 23.8°C).

Water oxygen content varied significantly between July and August ($P < 0.05$), but no significant differences were observed between the two habitats analyzed ($P > 0.05$). Oxygen content in the water was significantly higher in July than in August. The lowest oxygen content in July was noted at 03:00 hours in the VS habitat (6.7 mg O_2 dm^{-3}) and at 06:00 hours in the BR habitat (8.0 mg O_2 dm^{-3}). Oxygen content was shown to rise during the daytime hours, with the highest levels recorded in the VS habitat at 15:00 hours (22.7 mg O_2 dm^{-3}) and in the BR habitat at 18:00 hours (17.7 mg O_2 dm^{-3}). A similar trend was noted in August but only in the VS habitat. Dissolved oxygen content increased starting at 06:00 and peaked at 12:00 (13.7 mg O_2 dm^{-3}). Dissolved oxygen content remained constant throughout the day and night in the BR habitat at approximately 7.0 mg O_2 dm^{-3}.

Cladocera composition

A total of 18 species of Cladocera (Table 1) were identified in the littoral zone of Lake Licheńskie

Table 1. Mean (±SD) Cladocera density (ind dm^{-3}) in the *V. spiralis* habitat (VS) and the sandy littoral habitat (BR) in Lake Licheńskie in July and August.

	VS	BR	P
Acroperus harpae (Baird, 1835)	8.2 (± 7.1)	1.6 (± 2.8)	0.001
Alona rectangula Sars, 1862	0.8 (± 2.3)	0.2 (± 0.7)	ns
Alonella exigua (Lilljeborg, 1853)	0.4 (± 0.9)	0	ns
Alonella nana (Baird, 1843)	0.1 (± 0.3)	0.1 (± 0.3)	ns
Bosmina longirostris var. *typica* (Müller, 1785)	20.9 (± 19,5)	7.1 (± 9.5)	0.009
Bosmina longispina Leydig, 1860	2.9 (± 4.1)	0.7 (± 0.9)	0.001
Bosmina longispina var. *seligoi* Leydig, 1860	3.8 (± 6.9)	2.2(± 4.1)	ns
Ceriodaphnia quadrangula (Müller, 1785)	78.0 (± 105.3)	13.1 (± 18.3)	0.001
Chydorus sphaericus (Müller, 1785)	3.0 (± 4.0)	1.9 (± 4.1)	ns
Diaphanosoma brachyurum (Liévin, 1848)	66.4 (± 95.1)	21.4 (± 25.4)	0.001
Graptoleberis testudinaria Sars, 1862	1.7 (± 1.8)	0.1 (± 0.3)	0.001
Leptodora kindti (Focke)	0	0.2 (± 0.7)	ns
Leydiga quadrangularis (Leydig, 1860)	0.1 (± 0.3)	0.1 (± 0.3)	ns
Moina micrura Kurz, 1874	0	0.1 (± 0.3)	ns
Monospilus dispar Sars, 1862	0	0.1 (± 0.5)	ns
Peracantha truncata (Müller, 1785)	0.4 (± 0.7)	0	ns
Pleuroxus aduncus (Jurine, 1820)	37.2 (±43.4)	10.7 (± 24.0)	0.028
Scapholeberis mucronata (Müller, 1785)	0.3 (± 0.7)	0	ns
Sida crystallina (Müller, 1776)	20.9 (± 30.4)	2.2 (± 4.8)	0.001

in July and August. The number of taxa identified in both habitats was the same (15), but the species composition was different. Greater Cladocera species richness was detected in both habitats in July than in August ($P < 0.05$).

Diel Cladocera density and biomass fluctuated differently for the two habitats analyzed and in both months. Higher Cladocera density and biomass were noted in July than in August ($P < 0.05$). The density of cladocerans was higher in the VS than in the BR habitat during the research period ($P < 0.05$). The highest Cladocera densities in the VS habitat in July were recorded at 21:00 hours (596 ind. dm^{-3}) and between 09:00 and 15:00 hours (Fig. 1). Opposite pattern was recorded in BR habitat, with the highest density at both 06:00 and 18:00 hours (142 and 208 ind. dm^{-3}, respectively). Changes in Cladocera density and biomass followed a very different pattern during the second month of the study (Fig. 1). In August, the highest Cladocera densities were recorded at night ($P <0.05$). The density of cladocerans was five times lower during daytime hours (09:00 – 15:00 hours) than at night in both habitats.

The highest Cladocera biomass in the VS habitat in July were recorded between 09:00 and 15:00 hours (18.9 mg dm^{-3}, on average) and at 21:00 hours (15.4 mg dm^{-3}) (Fig. 1). Cladocera biomass in the BR habitat was the highest at 15:00 (7.1 mg dm^{-3}). In August, in both studied habitats, Cladocera biomass was lower during the daytime than at night time and was seven times lower in the VS habitat (on average 0.27 mg dm^{-3}) and over tenfold lower in the BR habitat (on average 0.08 mg dm^{-3}).

Dominant species variation

The three most abundant species in both habitats in July were *Ceriodaphnia quadrangula* (O.F. Müller) (34.1% – VS and 25.1% – BR), *Diaphanosoma brachyurum* (Liévin) (27.6% – VS and 31.0% – BR), and *Pleuroxus aduncus* (Jurine) (16.4% – VS and 20.7% – BR). Diel changes in the density of these species in the two habitats studied followed similar patterns (Fig. 2). The decrease in the density of cladocerans found at 06:00 and at 18:00 in the VS habitat was accompanied by a corresponding increase in BR. During the daytime the largest *C. quadrangula*, *D. brachyurum*, and *P. aduncus* densities in the VS habitat were recorded at 09:00 and at 12:00 hours, while the Cladocera density in the BR habitat was the lowest at the same time.

In August, the composition of the dominant species changed. The density of the plant-associated species, a previously dominant type among the Cladocera, decreased substantially in both habitats. The new dominant species comprised the open water such as the filter-feeders *Bosmina longirostris* var.

Table 2. Pearson's correlation coefficients for zooplankton density, biomass, and density of *C. quadrangula*, *D. brachyurum*, *P. aduncus*, *B. longirostris* var. *typica* and *B. longispina* var. *seligoi* versus time of day, oxygen content, and water temperature in the VS and BR habitats for July and August. Values with an asterisk are statistically significant (P < 0.05).

	Density	**Biomass**	***C. quadrangula***	***D. brachyurum***	***P. adunctus***	***B. longirostris* var. *typica***	***B. longispina* var. *seligoi***
July							
Time of day (VS)	0.038	0.129	0.218	0.138	0.101	-0.516	-0.631
Oxygen (VS)	0.023	0.263	0.111	0.165	0.410	-0.668	-0.431
Temperature (VS)	0.143	0.340	0.248	0.280	0.403	-0.736*	-0.439
Time of day (BR)	0.131	0.089	0.126	0.136	0.308	-0.316	-
Oxygen (BR)	0.495	0.474	0.379	0.281	0.597	-0.076	-
Temperature (BR)	0.170	0.2053	0.266	0.218	0.176	-0.370	-
August							
Time of day (VS)	-0.124	-0.209	0.619	0.739*	-	-0.793*	0.152
Oxygen (VS)	-0.790*	-0.758*	0.177	0.053	-	-0.826*	-0.261
Temperature (VS)	-0.373	-0.126	0.087	-0.090	-	-0.733*	0.355
Time of day (BR)	-0.151	-0.201	0.367	-0.113	-	-0.346	-0.322
Oxygen (BR)	-0.493	-0.436	-0.425	-0.589	-	0.126	-0.736*
Temperature (BR)	-0.021	0.111	0.333	0.008	-	-0.036	-0.191

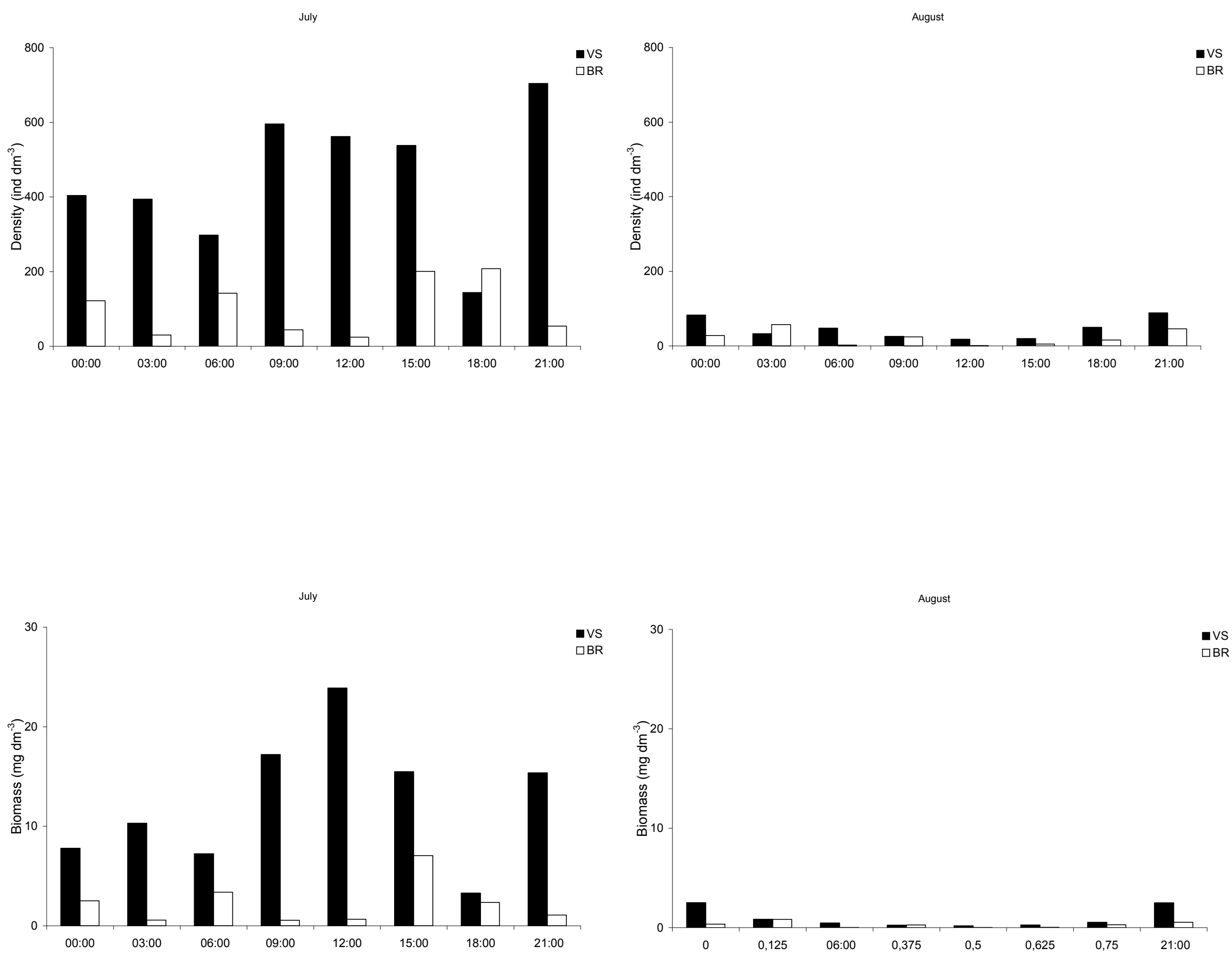

Fig. 1. Cladocera density and biomass in the littoral zone of Lake Licheńskie in the *V. spiralis* habitat (VS) and the sandy littoral habitat (BR) in July and August.

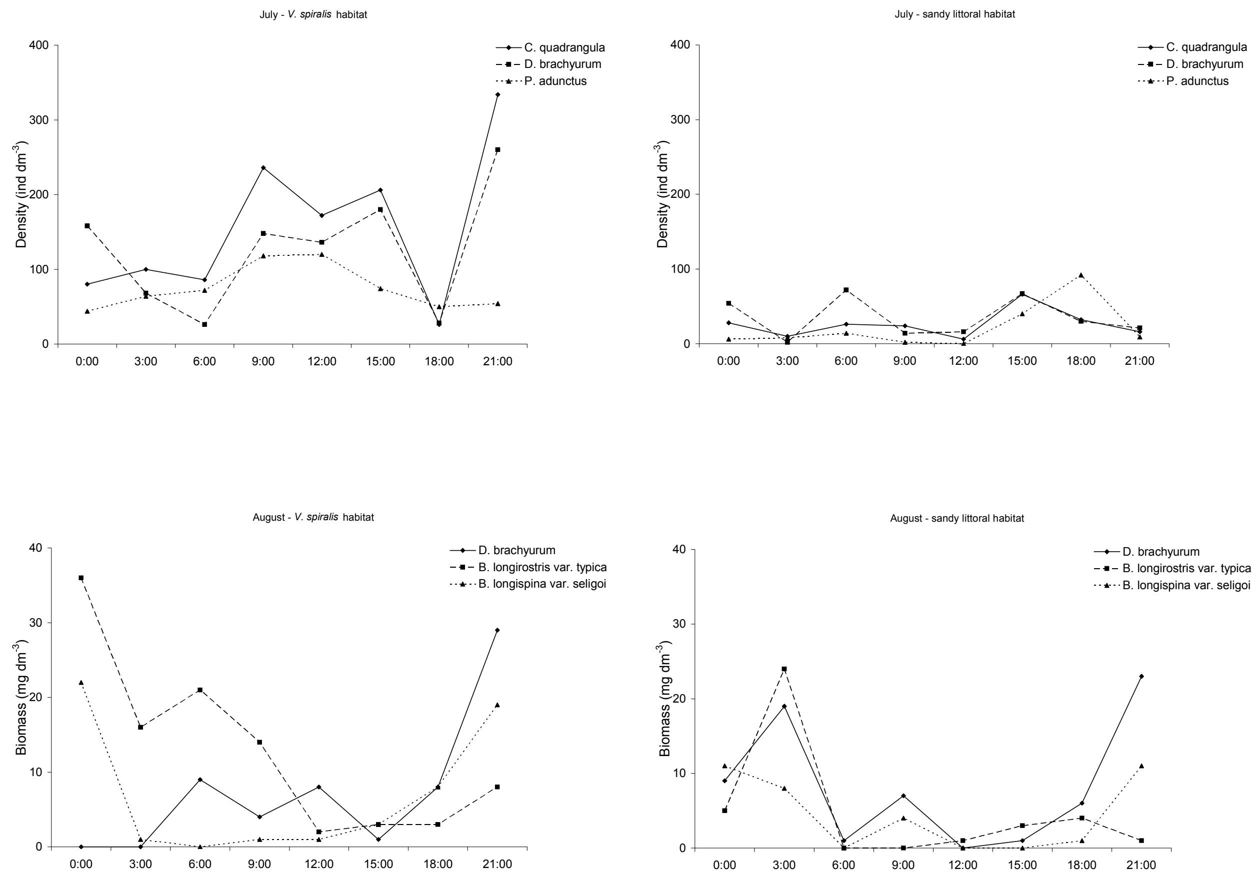

Fig. 2. Changes in the density and biomass of dominant Cladocera species in the littoral zone of Lake Licheńskie in the *V. spiralis* habitat and the sandy littoral habitat in July and August.

typica (O.F. Müller) (28.1% – VS; 21.2% – BR), *Bosmina longispina* var. *seligoi* Leydig (15.0% – VS; 19.5% – BR), and *D. brachyurum* (16.1% – VS and 36.9% – BR). The density of the species mentioned was lower during the day (09:00 – 15:00 hours) than at night (18:00 – 03:00 hours) in both habitats.

Statistically significant correlations (Table 2) were identified in the VS habitat between *D. brachyurum* density and time of day and *B. longirostris* var. *typica* density and time of day. A statistically significant correlation between *B. longirostris* var. *typica* density and water temperature was noted in the VS habitat. The correlation between *B. longirostris* var. *typica* density and oxygen content in the VS habitat was strong, although not statistically significant ($r = -0.668$, $P = 0.07$). Statistically significant correlations were noted between total Cladocera density and oxygen content in the VS habitat and between total Cladocera biomass and oxygen content. In the VS habitat, a statistically significant correlation was identified between *B. longirostris* var. *typica* density and oxygen content and water temperature (Table 2). In the BR habitat, a strong correlation was noted between oxygen content and *B. longispina* var. *seligoi* density.

Discussion

Macrophytes play an important role in the shaping of the structure of littoral heterogeneity, while species diversity leads to the formation of heterogeneous micro-habitats that support different types of zooplankton assemblages (Balayla, Moss 2003, Kuczyńska-Kippen, Nagengast 2003). The presence of large macrophyte-covered areas leads to greater habitat diversity compared to that of open waters, and this has a positive impact on zooplankton biomass growth (Wang *et al*. 2009). Unlike open waters, the mosaic of littoral habitats supports a very diverse zooplankton community (Kuczyńska-Kippen, Nagengast 2006). The development of macrophytes reduces water through-flow which helps the process of zooplankton development (Basu *et al*. 2000). In many lakes, zooplankton organisms undergo DHM into macrophytes (Burks *et al*. 2002). Cladocera species, which can find optimum habitat conditions in the open water zone during the day, often seek refuge from predators among macrophytes (Kairesalo *et al*. 1998) even though the food conditions there may be less favorable (Kuczyńska-Kippen 2008). Refuge effectiveness is at its maximum in the summer after dense stands of macrophytes develop in lakes (Burks *et al*. 2001, Balayla, Moss 2003). Crustaceans seek refuge among macrophytes during the daytime in response to especially large numbers of zooplanktivorous fish (Rybak, Węgleńska 2003). Plant-associated cladocerans are less exposed to predators than those living in open waters since they are less visible to fish. The effectiveness of macrophytes as a refuge for zooplankton depends on the associated assemblage of predatory macroinvertebrates and fish among the plants (González Sagrario, Balseiro 2010). Sometimes submerged macrophyte beds do not represent a refuge for zooplankton in lakes where predators are numerous among the plants.

In the summer of 2004, 92% of the littoral zone of Lake Licheńskie was covered with plant assemblages dominated by *V. spiralis* (Hutorowicz 2006), and such a level of dominance by this exotic species in the littoral zone limited the presence of other macrophyte species. Consequently, this could have led to reduced habitat diversity and species richness within the zooplankton community (Paturej *et al*. 2007). The current study indicated that neither of the habitats analyzed varied in terms of species richness. They did vary in terms of taxonomic composition that stemmed from the different habitat preferences of the taxa identified. The large predatory pelagic cladocerans *Leptodora kindti* (Focke) were not found in the VS habitat, nor were the warm-water species *Moina micrura* Kurz or the mesotrophic species *Monospilus dispar* Sars, which live near sediments (Duigan, Birks 2000). No plant-associated species were identified in the BR habitat such as the stenothermic species *Peracantha truncata* (O.F. Müller), *Alonella exiqua* (Lilljeborg), which prefers mesotrophic waters, or *Sida crystallina* (O.F. Müller). The latter two species live in the littoral zone of lakes and ponds, preferring habitats covered with macrophytes from the genus *Myriophyllum*, *Ceratophyllum*, *Elodea*, *Potamogeton*, and *Nymphae*. Large populations of *S. crystallina* can be found on stones and detritus as well as on *Chara* meadows as deep as 5 m or more (Flössner 1972). Paturej *et al*. (2007) analyzed zooplankton density and diversity in Lake Licheńskie in 2001-2002 and reported that *S. crystallina* was noted only occasionally.

Three species were dominant in July in both of the habitats: *C. quadrangula*, *P. aduncus*, and *D. brachyurum*. The first two species are typical of littoral environments (Flössner 1972). They favor conditions featuring dense plant patches with floating leaves that are rich in detritus. *D. brachyurum* despite the fact that they normally inhabit pelagic waters, even so, they can be found in large numbers in plant habitats. Their numbers tended to decline in the morning (06:00) and the evening (18:00) in the VS habitat and increase in the vegetation-free habitat at the same times. The changes in *C. quadrangula*, *P. aduncus*, and *D. brachyurum* population patterns identified suggest the use of *V. spiralis* as a refuge from zooplanktivorous fish during both day and night. At dawn and dusk, when fish are most active in the littoral zone (Kapusta, Bogacka 2006), the zooplankton species migrate to the BR habitat. While zooplanktivorous fish feed throughout the pelagic zone at night, *C. quadrangula* and *D. brachyurum* find refuge in the VS habitat.

In August, the dominant species in both habitats were those that are commonly found in open waters in eutrophic lakes: *B. longirostris* var. *typica*, *B. longispina* var. *seligoi*, and *D. brachyurum*. In both of the habitats analyzed the densities of these species were the lowest during the day and the highest in the evening and at night. At the point of contact between the littoral and open water environments, cladocerans tend to intermingle and migrate horizontally (Burks *et al*. 2002, Romare *et al*., 2003).

The predatory behavior of zooplanktivorous fish and the use of macrophytes as a refuge play an important role in the shaping of medium-scale patterns of zooplankton migration and population dynamics (Balayla, Moss 2003). Research on cladoceran diel migration patterns in the littoral zone of Lake Licheńskie has shown that plankton organisms are capable of adapting to life among macrophytes, and this type of adaptability plays an important role in cladoceran migration patterns and population dynamics. The large Cladocera density noted in the VS habitat suggests that the invasive *V. spiralis* plays an anti-predatory function in Lake Licheńskie. At the same time, the degree of homogeneity noted in the lake littoral zone can limit the diversity of zooplankton to some extent. A littoral zone that is diverse in terms of taxonomic composition provides more types of habitats for more types of zooplankton taxa. In Lake Licheńskie, a lake that is quite homogeneous in terms of littoral macrophytes, the zooplankton has a limited choice between two types of habitats, that of *V. spiralis* and the open water zone.

Acknowledgments: The study was supported with funding from Project S-009 of the Inland Fisheries Institute in Olsztyn, Poland.

References

Balayla D. J., B. Moss 2003. Spatial patterns and population dynamics of plant-associated microcrustacea (Cladocera) in an English shallow lake (Little Mere, Cheshire). – *Aquatic Ecology,* **37**: 417-435.

Basu B. K., J. Kalff and B. Pinel-Allou 2000. The influence of macrophyte beds on plankton communities and their export from fluvial lakes in the St Lawrence River. – *Freshwater Biology*, **45**: 373-382.

Bottrell H. H., A., Duncan, Z. M. Gliwicz, E. Grygierek, A. Herzig, A. Hillbricht-Ilkowska, H. Kurasawa, P. Larsson and T. Weglenska 1976. A review of some problems in zooplankton production studies. – *Norwegian Journal of Zoology*, **24**: 419-456.

Burks R. L., E. Jeppesen and D. M. Lodge 2001. Littoral zone structures as Daphnia refugia against fish predators. – *Limnology and Oceanography*, **46**: 230-237.

Burks R. L., D. M. Lodge, E. Jeppesen and T. L. Lauridsen 2002. Diel horizontal migration of zooplankton: costs and benefits of inhabiting the littoral. – *Freshwater Biology*, **47**: 343-365.

Duigan C. A., H.H. Birks 2000. The late-glacial and early – Holocene palaeoecology of cladoceran microfossil assemblages at Kråkenes, western Norway, with a quantitative reconstruction of temperature changes. – *Journal of Paleolimnology*, **23**: 67-76.

Ejsmont-Karabin J. 2011. Does invasion of *Vallisneria spiralis* L. promote appearance of rare and new rotifer (Rotifera) species in littoral of the lakes heated by power station (Konin Lakes, W. Poland)? – *Polish Journal of Ecology*, **59**: 201-207.

Ejsmont-Karabin J., A. Hutorowicz 2011. Spatial distribution of rotifers (Rotifera) in monospecies beds of invasive *Vallisneria spiralis* L. in heated lakes. – *Oceanological and Hydrobiological Studies*, **44**: 71-76.

Flössner D. 1972. Krebstiere (Crustacea), Kiemen- und Blattfüßer (Branchiopoda), Fischläuse (Branchiura). VEB Gustav Fischer Verlag, Jena.

González Sagrario M. d. l. Á., E. Balseiro 2010. The role of macroinvertebrates and fish in regulating the provision by macrophytes of refugia for zooplankton in a warm temperate shallow lake. – *Freshwater Biology*, **55**: 2153-2166

Hillbricht-Ilkowska A., B. Zdanowski, 1978. Effect of thermal effluents and retention time on lake functioning and ecological efficiencies in plankton communities. – *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, **63**: 609-617.

Hillbricht-Ilkowska A., J. Ejsmont-Karabin and T. Węgleńska 1988. Long-term changes in the composition, productivity and trophic efficiency in the zooplankton community of heated lakes near Konin (Poland). – *Ekolgia Polska,* **36**: 115-144.

Hutorowicz A. 2006. *Vallisneria spiralis* L. (Hydrocharitaceae) in Lakes in the Vicinity of Konin (Kujawy Lakeland). – *Biodiversity: Research and Conservation*, **1-2**: 154-158.

Hutorowicz A., J. Dziedzic and A. Kapusta 2006. *Vallisneria spiralis* (Hydrocharitaceae) localities in Konin Lakes (Kujawy Lakeland). – *Fragmenta Floristica et Geobotanica Polonica*, **13**: 89-94. (In Polish).

Kairesalo T., I. Tátrai and E. Luokkanen 1998. Impacts of waterweed (*Elodea canadensis* Michx) on fish-plankton interactions in the lake littoral. – *Verhandlungen – Internationale Vereinigung für theoretische und angewandte Limnologie*, **26**: 1846-1851.

Kapusta A., E. Bogacka 2006. Diel variability in the occurrence of juvenile fish in the shallow littoral zone: do macrophytes impact the structure of fish assemblages? – *Archives of Polish Fisheries*, **14**: 301-308.

Kuczyńska-Kippen N. 2008. Spatial distribution of zooplankton communities between the Sphagnum mat and open water in a dystrophic lake. – *Polish Journal of Ecology*, **56**: 57-64.

Kuczyńska-Kippen N., B. Nagengast 2003. The impact of the spatial structure of hydromacrophytes on the similarity of rotifera communities (Budzyńskie Lake, Poland). – *Hydrobiologia*, **506-509**: 333-338.

Kuczyńska-Kippen N., B. Nagengast 2006. The influence of the spatial structure of hydromacrophytes and differentiating habitat on the structure of rotifera and cladoceran communities. – *Hydrobiologia*, **559**: 203-212.

Paturej E., E. Bogacka and A. Kapusta 2007. Abundance and diversity of zooplankton in the littoral of Lake Licheńskie. – *Archives of Polish Fisheries*, **15**: 356-367.

Romare P., S., Berg, T. Lauridsen and E. Jeppesen 2003. Spatial and temporal distribution of fish and zooplankton in a shallow lake. – *Freshwater Biology*, **48**: 1353-1362.

Rybak J. I., T. Węgleńska 2003. Temporal and spatial changes in the horizontal distribution of planktonic Crustacea between vegetated littoral zone and the zone of open water. – *Polish Journal of Ecology*, **51**: 205-218.

Stawecki K., J. Pyka and B. Zdanowski 2007. The thermal and oxygen relationship and water dynamics of the surface water layer in the Konin heated lakes ecosystem. – *Archives of Polish Fisheries*, **15**: 247-258.

Tunowski J. 2009. Zooplankton structure in heated lakes with differing thermal regimes and water retention. – *Archives of Polish Fisheries*, **17**: 291-303.

Van Donk E., W. J. Van de Bund 2002. Impact of submerged macrophytes including charophytes on phyto- and zooplankton communities: allelopathy versus other mechanisms. – *Aquatic Botany*, **72**: 261-274.

Wang G. X., L. M. Zhang, H. Chua, X. D. Li, M. F. Xia, and P. M. Pu 2009. A mosaic community of macrophytes for the ecological remediation of eutrophic shallow lakes. – *Ecological Engineering*, **35**: 582-590.

Received: 26.04.2012
Accepted: 06.12.2012