THE IMPACT OF ENVIRONMENTAL VARIABLES ON THE STRUCTURE OF CRUSTACEAN COMMUNITIES

Doctoral (PhD) Theses

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1 Introduction

The zooplankton of Lake Balaton are comprised mostly of Protozoa, Rotatoria, Crustacea as well as the larvae of Mollusca. Lower crustaceans, the subjects of our research are one of the most intensively studied groups of organisms inhabiting the lake. Nevertheless, a complex examination of the environmental factors affecting the distribution of planktonic crustaceans in different regions of the lake and within the water column has not yet been performed. A question of special interest may be how turbulent currents influence the life conditions of crustaceans in Lake Balaton, a water body uncommonly exposed to the agitating effect of the wind. The large surface area of Lake Balaton allows the wind to transmit a large amount of kinetic energy to the water. Due to the shallowness of the water (mean depth is 325 cm), only limited space is available for the dissipation of kinetic energy, therefore the water of the lake is usually highly turbulent. The effects of intensive water movements on the development and feeding of planktonic organisms have been extensively studied in seas and in lakes other than Lake Balaton (Rotschild & Osborn 1988; Mackas et al. 1993; Alcaraz et al. 1994; Kiørboe & Saiz 1995; Lagadeuc et al. 1997; Incze et al. 2001; Lewis & Pendley 2001; O´Brien 2002, O´Brien et al. 2004). However, studies of this type have not yet been conducted in Lake Balaton. Our objective was to study, at various water depths, the effect of turbulence (among other environmental parameters) on the ontogenesis, mortality and structure of the crustacean community constituting the zooplankton assemblage.

2 Objectives

The objectives of our research were to chart turbulence and environmental parameters in Lake Balaton, a shallow, hydrodynamically highly kinetic lake, and to study their effects on the structure and location of the zooplankton assemblage, on the developmental rate of the individual species and their various developmental stages. Our studies included sectors of the lake with divergent environmental properties, and laboratory experiments utilizing a wave generator were also performed. The following lines of research were pursued:

1. Analysis of the qualitative and quantitative characteristics of zooplankton in biotas of the lake with divergent kinetic properties (e.g. reed belt, littoral zone, open water);
2. Assessment of the effects of turbulence on the zooplankton assemblage of the lake as compared to the significance of other environmental parameters (e.g. temperature, water transparency);
3. 24-hour observation of the vertical migration of zooplankton under different turbulence conditions (in stormy and calm weather);
4. Studies on the effect of turbulence on the ontogenesis and mortality of various cladocerans and copepods in a laboratory experimental system.

3 Materials and Methods

3.1 Zooplankton sampling and processing of the samples

Zooplankton samples were taken at a weekly frequency, proceeding by 0.5-m increments from the surface down, at sites of various depths located in different basins of the lake, using a 50-cm-high, 34-l Schindler-Patalas sampler equipped with a plankton net of 60 μm mesh size. Each sample was concentrated to a volume of 100 ml, preserved with formaldehyde added to a final concentration of 3.5% and evaluated using a Zeiss-Opton inverted plankton microscope. 5-ml subsamples were taken from each sample, and a minimum of three parallel counts were made. Species were identified with the help of the identification guides of Gulyás & Forró (1999), Einsle (1993) and Flößner (2000). Organism densities are given in units of l^{-1}. A total of 119 samples were collected at the various sampling sites on the dates specified.

3.2 Studies on the spatial and temporal distribution of zooplankton in Lake Balaton

Zooplankton structure in Lake Balaton was studied on a weekly basis from April, 2006 to October, 2007 in various layers of the littoral zone in front of the Balaton Limnological Research Institute of the Hungarian Academy of Sciences (BLRI HAS) at three sites, namely in the reed belt (water depth 55 cm), and in a distance of 25 m (water depth 220 cm) and 200 m (water depth 330 cm) therefrom. In addition, the structure of zooplankton communities was also studied on a monthly basis in various depths at the following 5 sampling sites located along the longitudinal axis of Lake Balaton: Keszthely (water depth 310–330 cm), Szigliget (400–410 cm), Zánka (430–440 cm), Tihany (410–430 cm) and Siófok (430–460 cm).

3.3 Studies on the diurnal migration of zooplankton

In the year 2003, two 24-hour experiments were carried out in front of the Limnological Institute, at a distance of approximately 800 m from the lakeshore (water depth 270–280 cm), in calm, bright weather. Measurements were made at 12, 15, 19, 23, 3, 7, 10, 13 and 15 o'clock on 4-5 August and 25-26 August. Turbulence was not yet measured in 2003.

In 2007, samples were taken and turbulence measurements performed at 17, 19, 3:30, 6:30, 11 and 14:30 o'clock on 18-19 August, at 2 sampling/measuring sites. The 2007 study was scheduled on the basis of the weather forecast in order to have the opportunity to observe the effect of a predicted, incoming strong wind on the vertical structure of zooplankton in Lake Balaton. The strong wind struck after 20 o'clock on the evening of 18 August. The study also included turbulence measurements in the various water layers. The methods used for sampling, sample processing and turbulence measurement were identical with those applied for weekly sampling. In 2007, withdrawal of two samples at one sampling site failed due to stormy weather. Based on data in the literature (Entz & Sebestyén 1942; Ponyi & Tamás 1964; Ponyi & H. Péter 1986), the samples obtained in the course of the 24-hour experiment were used for studying the vertical migration of *Daphnia cucullata x galeata* and *Eudiaptomus gracilis*. The prevailing mean residence depth (MRD; Armengol & Miracle 2000) characteristic of zooplankton populations was determined:

$$MRD = \frac{\sum (N_i \times d_i)}{\sum N_i}$$

where N_i is the organism concentration measured in the *i*-th depth and d_i is the depth of the *i*-th sample. The MRD value identifies the imaginary centre of the population: it indicates the depth where the bulk of the population resides at a given time.

3.4 Environmental variables studied

Parallel with zooplankton sampling, the following parameters were studied with the help of a Horiba U-10 water analyzer: water depth, temperature, conductivity, pH. Water transparency was determined using a Secchi disk. Furthermore, turbulence was measured in the various water layers. Values of wind velocity to be used for calculations of the turbulent kinetic energy dissipation rate and the Kolmogorov length were obtained from the Observatory of the National Weather Service, Siófok.

3.4.1 Turbulence measurement

Turbulence measurements were carried out spatially and temporally parallel with zooplankton sampling, using a three-dimensional Sontek Acoustic Doppler Velocimeter (ADV).
In the course of the measurements the emitter-sensor unit of the device was mounted on a 5-m pole with a spade equipped with a heavy ferrule attached to its end. The appropriate distance of the emitter/sensor unit from the lakebed and from the pole was maintained by a sliding metal arresting mechanism. After having fixed the emitter/sensor unit at the point of the pole corresponding to the desired depth, the pole was vertically thrust into the sediment from the boat. Measurements of 10 min at 50 Hz were made in every 50 cm of the water column, parallel with zooplankton sampling.

Turbulence was characterized by the root mean square of 3-D turbulent velocity fluctuations (RMS-turbulence) and expressed in units of cm s^{-1} (Tennekes & Lumley 1972; Reynolds 1992).

$$RMS[Vx'] = \sqrt{(V_x')^2} = \sqrt{\frac{\sum V_x^2 - \left(\sum V_x\right)^2 / n}{n-1}}$$

The 3-D velocity/frequency data were evaluated with WinADV software.

Turbulent kinetic energy dissipation rates and Kolmogorov length scales at various wind velocities and water levels were calculated according to Tennekes & Lumley (1972) and MacKenzie & Leggett (1993).

Turbulent kinetic energy dissipation (ε, m^2 s^{-3}) was calculated using the mean water depths (Z) and the wind velocities (W) of the sampling sites (MacKenzie & Leggett 1993):

$$\varepsilon = \left(\left(\frac{\rho a}{\rho w}\right) C_D\right)^{\frac{3}{2}} \times \left(\frac{W^3}{0{,}4\, z}\right) \times \left(\frac{1\, W\, m^{-3}}{0{,}001\, m^2 s^{-3}}\right) = \left(6{,}045 \times 10^{-6}\right) \frac{W^3}{z}$$

Values of wind velocity (W) were the following: 0.5, 1, 2, 4, 8, 16 and 32 m s^{-1}. For mean water depth, the mean depths of the sampling sites were used, namely 0.5, 2.2, 3.3, 4, 4.3 and 4.45 m. Air density (ρa) was 1,2 kg m^{-3}, water density (ρw) was 998 kg m^{-3}, the drag coefficient between the water surface and the wind (C_D) was 0.0015 and the von Karman constant was 0.4.

Turbulent kinetic energy dissipation rates at mean depths of the sampling sites were also calculated by Taylor's equation (Luettich & Harleman 1990):

$$\varepsilon = A \times RMS^3\; l^{-1}$$

where RMS is RMS-turbulence measured by the ADV, the value of the constant A was assumed to be 1 and that of the local length scale (l) was taken as 25 cm, which is the average wave height in Lake Balaton (G.-Tóth et al. 2011).

The Kolmogorov length scale ($ή_k$, mm) was calculated from the dissipation rate (ε) and kinematic viscosity (ν = 1.1 10^{-6} m^2 s^{-1}) according to Tennekes and Lumley (1972):

$$\eta_k' = \left(\frac{\nu^3}{\varepsilon}\right)^{\frac{1}{4}}$$

3.5 Turbulence generator experiments

In order to model the effect of turbulence on zooplankton under laboratory conditions, we had a turbulence generator similar to that described by O'Brien (2004) designed and constructed at the Institute of Applied Mechanics of the University of Pannonia, Veszprém.

In the period between October, 2006 and September, 2007, nine series of experiments, each lasting for 18–21 days were carried out in a 64 x 64 x 96-cm experimental water aquarium equipped with the turbulence generator. A calm aquarium was used as control. The water aquariums were filled to a depth of 80 cm with water from Lake Balaton; the water was allowed to settle for 24 hours, and the mineral sediment settled was carefully removed by suction. The plastic grid (mesh size 5.8 x 5.8 cm) of the turbulence generator driven by a Giovanni electromotor oscillated in the upper layer of the water, at a frequency of 1,033 s^{-1} and with an amplitude of either 5 or 10 cm. Prior to the experiments, turbulence generated at both amplitudes was charted in the aquarium with a 3D Acoustic Doppler Velocimeter at 10 cm depth increments, along the points of an imaginary cubic grid with the points located in a distance of 10–20 cm from each other. Based on the preliminary measurements, operation with an amplitude of 10 cm was found to show the best fit with the characteristics of turbulence in Lake Balaton, and was chosen for the experiments. Thus the values of RMS-turbulence, the calculated energy dissipation rate and the Kolmogorov length scale along the aquarium's water column coincided with the corresponding parameters of Lake Balaton water of medium kinetism.

The energy dissipation rate (ε, m^2 s^{-3}) of the turbulent water aquarium was estimated on the basis of the equation formulated for containers agitated by oscillating grids (O'Brien et al. 2004), in distances of 10 cm from the lowermost grid position:

$$\varepsilon = \frac{1}{\beta}\left(\frac{2C_1^2 + C_2^2}{3}\right)^{\frac{3}{2}} \frac{M^{\frac{3}{2}} S^{\frac{9}{2}} f^3}{Z^4}$$

where the values of constants are ß = 0.1; $C_1 = 0.18 \pm 0.04$; $C_2 = 0.22 \pm 0.05$; the mesh size of the grid is M = 6 cm, stroke length is S = 0.1 m, the frequency of oscillation is f = 1.033 s^{-1} and Z is the distance from the grid (m).

Turbulent energy dissipation rate according to Taylor's equation was calculated as described for the field measurements, with the mesh size of the oscillating grid (5.8 cm) given as the diameter of the largest eddies.

The Kolmogorov length scale ($\acute{\eta}_k$) was calculated from the turbulent energy dissipation rate and the kinematic viscosity, as described for the field measurements.

Artificial lights was on for 12 hours in the aquarium in daytime, while it was in dark during the night. The experimental temperature was 16–25°C. The water aquarium was populated with zooplankton from Lake Balaton, collected with a trawl-net and adapted in 50-l plastic barrels for 1–2 days. In addition to the turbulent water aquarium, another aquarium measuring 75 x 75 x 100 cm was set up for use as a control aquarium, which was populated with a corresponding, proportional amount of zooplankton. Dead zooplankton were removed by suction from the bottom of the aquariums s prior to the commencement of the experiment. To feed zooplankton, a laboratory-grown mixed green algal suspension of *Selenastrum capricornutum* and *Chlamydomonas reinhardti* (algal density: 7–8 x 10^6 individuals l^{-1}) was added to both aquariums every two days. Zooplankton samples were withdrawn from both the experimental and the control aquariums every two days, using a 60-μm mesh size vertical plankton net that filters the entire water column. On each sampling, 8 litres of water were filtered, whose zooplankton content was concentrated in the stainless steel funnel (volume 175 ml) of the sampler. 10 ml of the sample thus obtained was preserved in 70% ethanol, and the rest was returned into the aquarium. Three parallel samples were taken each time. Zooplankton were counted in a Zeiss-Opton inverted plankton microscope. The concentration of available algae was checked on a regular basis by direct counting in the inverted microscope. Furthermore, water conductivities and dissolved oxygen contents in the two aquariums were also regularly monitored. The concentration of dissolved oxygen was in the range of 60–91% (control aquarium) and 70–95% (experimental aquarium), and conductivity was around 760 μS cm^{-1}. For the evaluation of the results of the nine experiments performed, the absolute number of organisms (individual species and larval stages) (organism l^{-1}) and the ratio of these numbers measured in the experimental and control aquariums were considered.

4 Theses

1. In our studies on environmental parameters, significant differences were identified between values of Secchi transparency and turbulence among the basins of different depths of Lake Balaton. The transparency of the water was found to decrease from East to West in the basins of the lake. The highest values of RMS-turbulence were measured in the Szigliget and the Keszthely basins. RMS-turbulence was around 1.1–1.5 cm s^{-1} in the absence of wind and waves, and 1.5–3 cm s^{-1} at a wind velocity of 100–200 cm s^{-1} and in the presence of the resulting gentle wave activity. At a wind velocity of 400–600 cm s^{-1} and in the presence of the resulting surface wave activity, an RMS-turbulence of 4–13 cm s^{-1} was recorded. Examination of the turbulence distribution of water columns of different depths revealed that the water in front of the reed belt as well as water measuring about 2 m in depth are readily stirred up, and there exists no layer with relatively low turbulence among the layers with different depths that would be favourable for the zooplankton assemblage to inhabit. The agitating effect of the wind is less pronounced in the case of water columns of 3–4.4 m depth, and highly different turbulence values are established in the individual water layers, allowing stratification of zooplankton assemblages. Based on the two methods of assessment, values of energy dissipation rate varied in the range of 1.70×10^{-7} – 3.60×10^{-1} m^2 s^{-3} and 2.4×10^{-4} – 2.5×10^{-3} m^2 s^{-3}, respectively, and proved to be significantly higher in shallow water than in the deeper regions of the lake. The outstanding values observed at the Szigliget and Keszthely sampling sites attest that these regions of Lake Balaton are especially exposed to the agitating effect of turbulence. In Lake Balaton, a lake with a mean water depth of 3.25 m and a large surface area, there is little space available for the dissipation of wind-generated energy. Kolmogorov length scales based on the energy dissipation rates calculated using the two different methods fell into the range of 0.25–0.42 mm and 0.15–0.27 mm, respectively. The diameter of the smallest eddies is much smaller and the value of turbulent shear forces much larger than in deeper lakes or in the sea. Since the average size of zooplankton in Lake Balaton is in the range of 0.25–2.5 mm, the data reveal that the Kolmogorov length scale in Lake Balaton, while constantly varying as a function of water depth and wind velocity, often coincides with the size of plankton organisms.

Based on data in the literature, the size of plankton organisms in a given water body may not exceed the diameter of the smallest turbulent currents spreading downward from the surface, because shear tension would otherwise damage sensitive plankton organisms. According to the Kolmogorov length scales resulting from our calculations, turbulence in Lake Balaton often creates an unfavourable environment for the zooplankton assemblage.

2. Zooplankton density decreased along the lake from the Western towards the Eastern basins. The distribution of planktonic crustaceans as a function of water depth showed individual characteristics specific for each species and developmental stage. The ratio of nauplius larvae was nearly twofold in the littoral zone as compared to that in open water. The opposite tendency was observed in the case of Cladocera species: their ratio in open water was about threefold relative to that recorded in the littoral zone. No uniform tendency was observed for copepods – the case of each species was different. The abundance of *Eudiaptomus gracilis* was lower in the littoral zone than in open water. There was no significant difference between the percentage ratios of cyclopoids recorded at the individual sampling sites.
3. According to our analysis, in addition to the seasonal and spatial effect, secondary factors influencing the structure and density of the zooplankton assemblage were turbulence, water depth, the time of day, Secchi transparency, water temperature and the presence of predatory zooplankton species. The significance of the factors enumerated may be highly different for each of the individual planktonic groups. The seasonal pattern of water temperature data showed a close correlation with changes in zooplankton density. In the case some of Cladocera species (e.g. *Alona affinis*, *Diaphanosoma brachyurum*), different developmental stages and egg-laying females, the determining factors were month and time of day. The effect of the presence of the predatory species *Cyclops vicinus* and *Leptodora kindtii* was negligible as compared to that of the other environmental parameters. The group affected the most by Secchi transparency was cladocerans. Water temperature affected two crustacean groups, namely Cladocera species and *Mesocyclops leukarti*.
4. Zooplankton organisms exhibited diverse sensitivities towards the impact of turbulence. Among filter feeders, turbulence had a significant effect on the ontogenesis, mortality and localization of Cladocera species and, to a smaller extent, of the copepod *Eudiaptomus gracilis*.

Based on the data in the pertinent literature, the reasons underlying this phenomenon may be the negative effect of sediment resuspended by increasing turbulence on the efficiency of feeding on the one hand and destruction by shear tension on the other.

5. 24-hour field observations reveal that *Daphnia cucullata x galeata* and *Eudiaptomus gracilis* perform daily vertical migration in calm weather, in the course of which they withdraw into the deeper water layers during the day and are distributed evenly along the water layers at night. According to our results, disintegration of the vertical stratification of zooplankton in Lake Balaton starts in the RMS-turbulence range of 3–3.5 cm s^{-1} and, as suggested by the ratio of windy days in the area, is a common phenomenon in the lake. The distribution of zooplankton in the various water layers differed at sampling sites of different depths: in relatively deep water the animals were distributed relatively evenly, whereas in shallow water the bulk of zooplankton was localized in the middle 100–150 cm water layer.
6. Our laboratory experiments attest that turbulence has a strong impact on the species composition and the mortality of zooplankton in Lake Balaton even at a low suspended material content. Comparison of the zooplankton populations of the turbulent and control aquariums revealed that the crustacean group most sensitive to the unfavourable effects of turbulence are cladocerans.

5 References

Alcaraz M., Saiz E., Calbet A. (1994): Small-scale turbulence and zooplankton metabolism: Effects of turbulence on heartbeat rates of planktonic crustaceans. Limnology and Oceonography 39: 1465-1470.

Armengol X., Miracle M. R. (2000): Diel vertical movements of zooplankton in lake La Cruz (Cuenca, Spain). Journal of Plankton Research 22: 1683-1703.

Einsle U. (1993): Crustacea, Copepoda: Calanoida und Cyclopoida, Gustav Fischer Verlag Stuttgart Jena New York.

Entz G., Sebestyén O. (1942): A Balaton élete, Királyi Magyar Természettudományi Társulat, Budapest.

Flöβner D. (2000): Die Haplopoda und Cladocera Mitteleuropas. Backhuys Publishers, Leiden.

Gulyás P., Forró L. (1999): Az ágascsápú rákok kishatározója 2. bővített kiadás, Környezetgazdálkodási Intézet.

G.-Tóth L., Parpala L., Balogh Cs., Tátrai I., Baranyai E. (2011): Zooplankton community response to enhanced turbulence generated by water-level decrease in Lake Balaton, the largest shallow lake in Central Europe. Limnology and Oceanography 56: 2211-2222.

Incze L. S., Hebert D., Wolff N., Oakey N., Dye D. (2001): Changes in copeod distributions associated with increased turbulence from wind stress. Marine Ecology Progress Series 213: 229-240.

Kiørboe T., Saiz E. (1995): Planktivorous feeding in calm and turbulent environments, with emphasis of copepods. Marine Ecology Progress Series 122: 135-145.

Lagadeuc Y., Boulé M., Dodson J J. (1997): Effect of vertical mixing on the vertical distribution of copepods in coastal waters. Journal of Plankton Research 19: 1183-1204.

Lewis D. M., Pedley T. J. (2001): The influence of turbulence on plankton predation strategies. Journal of Theoretical Biology 210: 347-365.

Luettich R. A., Harleman D. F. (1990): A comparison between measured wave properties and simple wave hindcasting models in shallow water. Journal of Hydraulic Research 28: 299-308.

Mackas D. L., Sefton H., Miller C. B., Raich A. (1993): Vertical habitat partitioning by large calanoid copepods in the oceanic subarctic Pacific during spring. Progress in Oceanography 32: 259-294.

MacKenzie B. R., Leggett W. C. (1993): Wind based models for estimating the dissipation rates of turbulent energy in aquatic environments: empirical comparisons. Marine Ecology Progress Series 94: 207-216.

O'Brien K. (2002): The effect of turbulent mixing on vertical distribution and biomass of phytoplankton populations, PhD. Thesis, Centre for Water Research, University of Western Australia, Crawley, 6009 Australia.

O´Brien K. R., Meyer D. L., Waite A. M. Ivey G. N., Hamilton D. P. (2004): Disaggregation of *Microcystis aeruginosa* colonies under turbulent mixing: laboratory experiments in a drid-stirred tank. Hydrobiologia 519: 143-152.

Ponyi J., Tamás G. (1964): Napszakos változások vizsgálata a tihanyi Belső-tó fito- és zooplanktonjában. Állattani Közlemények 51: 105–124.

Ponyi J., H. Péter I. (1986): Az *Eudiaptomus gracilis* (G. O. Sars) napszakos vertikális vándorlása a Balatonban, Állattani Közlemények 73: 69-77.

Reynolds C. S. (1992): Turbulent Intensity and dissipation rate. In: Giller, P.S., Hildrew, A.G. and Raffaelli, D.G. (Eds): Aquatic ecology, scale, pattern and process. The 34th Symposium of the British Ecol. Soc. Univ. Coll. Cork. Blackwell Sci. Publ. Oxford, London, Edinburgh, Boston, Melbourne, Paris, Berlin, Vienna.

Rotschild B. J.,. Osborn T. R (1988): Small scale turbulence and plankton contact rates. Journal of Plankton Research 10: 465-474.

Tennekes H., Lumley J. L. (1972): A first course in turbulence. The MIT press, Cambridge, Massachusetts 1-310.

6 Cumulative Data of Scientific Activity

6.1 Publications

Baranyai E., Forró L. (2004): Rekonstruált szikes tavak Cladocera és Copepoda faunájának összetétele, szezonális dinamikája és összefüggése a vízkémiai paraméterekkel. 2. Szünzoológiai Szimpózium, Budapest, 12-13.

Baranyai E., Forró L., Herzig A. (2004): Artenzusammensetzung und saisonale Dynamik der Cladocera- und Copepoda-Fauna in künstlichen Natrongewässern. Archives des Sciences, IF: 0,261.

Baranyai E., Forró L. (2006): Cladocera-Copepoda fauna kapcsolata a fizikai-vízkémiai paraméterekkel rekonstruált szikes tavakban. Hidrológiai Közlöny 86 (6): 42-44.

Baranyai E., G.-Tóth L. (2007): Az egyes zooplankton fajok és fejlődési stádiumaik viszonya a könnyen felkeveredő Balaton turbulenciájával. Hidrológiai Közlöny 87 (6): 14-17.

G.-Tóth L., Parpala L., Baranyai E., P. Klein T. (2008): A zooplankton tömege és termelése 1999 és 2007 között a Balatonban. Hidrológiai Közlöny 88 (6): 58-61.

Baranyai E., G.-Tóth L. (2008): Kritikus turbulencia tartományok vizsgálata a balatoni zooplankton szempontjából. Hidrológiai Közlöny 88. (6): 18-21.

G.-Tóth L., Parpala L., Baranyai E., Balogh Cs. (2009): A turbulencia növekedés hatása a zooplanktonra a vízszint csökkenésekor. Hidrológiai Közlöny 89 (6): 12-14.

G.-Tóth L., B. Muskó I., Balogh Cs., Baranyai E., Parpala L., Szalontai K. (2009): A balatoni zooplankton struktúrája és funkciója 1999 és 2008 között. In: Bíró P., Banczerowsky J: A Balaton-kutatások fontosabb eredményei 1999-2009. Budapest: MTA, 2009. 82-96.

Baranyai E., G.-Tóth L., Homonnay Z. G. (2009): A balatoni zooplankton vertikális szerkezetének napszakos változása eltérő turbulencia viszonyok között. Hidrológiai Közlöny 89 (6): 9-11.

Baranyai E., G.-Tóth L. (2010): The influence of turbulence on vertical distribution of zooplankton in shallow, kinetic Lake Balaton (Hungary). Verhandlungen der

Internationale Vereinigung für Theoretische und Angewandte Limnologie 30 (10): 1505-1508.

G.-Tóth L., Parpala L., Baranyai E., B. Muskó I., Balogh Cs. (2010): A Dreissena lárvák tömegének változása a Balatonban (1999-2009). Hidrológiai Közlöny 90 (6): 29-31.

Baranyai E., G.-Tóth L., Vári Á., Homonnay Z. G. (2011): The effect of variable turbulent intensities on the distribution of zooplankton in the shallow, large Lake Balaton (Hungary), Knowledge and Management of Aquatic Ecosystems, 400: 07, IF: 0,304

G.-Tóth L., Parpala L., Balogh Cs., Tátrai I., Baranyai E. (2011): Zooplankton community response to enhanced turbulence generated by water-level decrease in Lake Balaton, the largest shallow lake in Central Europe. Limnology and Oceanography 56: 2211-2222, IF: 3,385

6.2 Presentations

Baranyai E., Forró L. (2004): Rekonstruált szikes tavak Cladocera és Copepoda faunájának összetétele, szezonális dinamikája és összefüggése a vízkémiai paraméterekkel. 2. Szünzoológiai Szimpózium, Budapest, márc. 8-9. Poster

Baranyai E., Forró L. (2005): Cladocera-Copepoda fauna kapcsolata a fizikai-vízkémiai paraméterekkel rekonstruált szikes tavakban. XLVII: Hidrobiológus Napok, október 5-7. Poster

Baranyai E., G.-Tóth L. (2006): Az egyes zooplankton fajok és fejlődési stádiumaik viszonya a könnyen felkeveredő Balaton turbulenciájával. XLVIII: Hidrobiológus Napok, október 4-6. Poster

Baranyai E., G.-Tóth L. (2007): Kritikus turbulencia tartományok vizsgálata a balatoni zooplankton szempontjából. XLIX. Hidrobiológus Napok, október 3-5. Poster

Baranyai E., G.-Tóth L. (2007): The influence of turbulence on the vertical distribution of zooplankton in the shallow lake Balaton (Hungary). 30th Congress of the International Association of Theoretical and Applied Limnology, August 12-18, Montreal (Canada). Poster

Baranyai E., G.-Tóth L. (2008): The effect of turbulence on zooplankton assemblages in shallow lake Balaton (Hungary). Shallow Lakes Conference, 2008. 11. 23-28. Punta del Este (Uruguay). Poster

Baranyai E., G.-Tóth L. (2008): A balatoni zooplankton vertikális szerkezetének napszakos változása eltérő turbulencia viszonyok között. L. Hidrobiológus Napok, október 1-3. Oral presentation