

**BALTICA Volume 25 Number 1 June 2012 : 77–86****Pelagic patterns along the Nemunas River–Curonian Lagoon transition,
south–eastern Baltic Sea**

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Abstract The aim of this study was to reveal the patterns of structural and quantitative alterations of the plankton communities along the Nemunas River–Curonian Lagoon transition of the south-eastern Baltic Sea. Authors hypothesised the influence of the different phases of the seasonal plankton development (Bacillariophyceae vs. Cyanobacteria dominance) on the response of plankton communities due to hydrodynamic forcing. In order to assess spatial patterns of physical forcing, we used sediment grain size distribution data as a proxy for hydrodynamic regime. Zooplankton and phytoplankton communities in the Nemunas River were sampled to obtain a point of reference for their structure and seasonal dynamics. The changes in sediment grain size distributions, quantitative and structural alterations in zooplankton communities, as well as structural trends in phytoplankton communities were detected in the Nemunas River–Curonian Lagoon transition area. However, the expected abundance trend was not observed in the phytoplankton community, even during the Cyanobacteria–dominated period. Despite the observed gradient of the sediment structure along the river–lagoon transition, the expected value of the sediment characteristics for the pelagic conditions was not statistically proved.

Keywords *Plankton communities • River-lagoon transition • Sediment structure • Curonian Lagoon • Lithuania*

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INTRODUCTION

Physical forcing in lagoons and estuaries is generally related to hydrodynamic features, forming temporally and spatially variable environmental conditions and, subsequently, creating a continuum of communities from river to the sea (Attrill, Rundle 2002). River delta is supposed to be a boundary, forced by abrupt changes in current velocity and in the physical sense, the location of river–lagoon transition also could be easily traced by the changes in sedimentation processes (Pasternack, Brush 2002). Moreover, sedimentary features in the river deltas are widely used to reflect, e.g., changing current regime, wave action, coastal

human activity or even development of benthic communities (Longhitano, Colella 2007; Yang *et al.* 2008; Yamashita *et al.* 2009).

Plankton community–level response to the hydrodynamics has several specific features. Generally, currents and mixing of water column are limiting factors for plankton development, restricting mainly large species with comparatively long generation time (e.g. Welker, Walz 1999; Mortazavi *et al.* 2000). Diatoms and green algae usually dominate the phytoplankton in large rivers, whereas large Cyanobacteria can increase significantly in areas where currents are reduced (Reynolds, Descy 1996; Leland 2003). River zooplankton is also dominated by small fast–growing organisms:

rotifers, bosminids and juvenile copepods (Pace *et al.* 1992, Akopian *et al.* 2002).

The Curonian Lagoon (Fig. 1) is a shallow eutrophic water body connected to the south-eastern Baltic Sea in its northern part and influenced by frequent non-periodic wind-driven brackish water (up to nearly 8 PSU) inflows (Gasiūnaitė *et al.* 2008). The southern and central parts of the lagoon are freshwater due to the Nemunas River discharge, reaching up to 6800 m³/s during the spring flood period (Razinkovas *et al.* 2008) and averaging 22 km³/year, or 96 % of the annual runoff to the lagoon (Ferrarin *et al.* 2008). The structure and dynamics of lagoon plankton communities are typical for eutrophic waters. Phytoplankton is dominated by

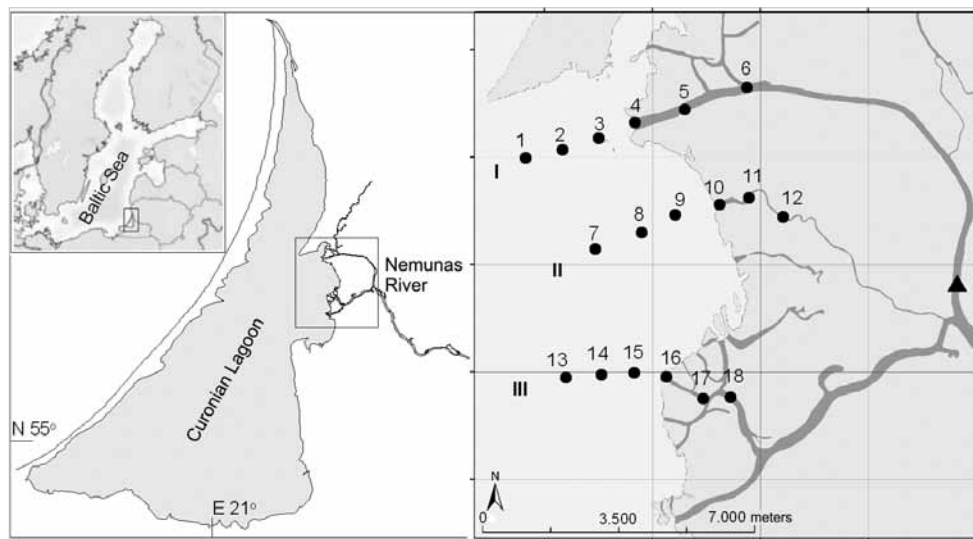


Fig. 1 Study area. Circles mean plankton and sediment sampling stations along the river-lagoon transition; triangle – seasonal plankton sampling station in the Nemunas River. Compiled by A. Razinkovas-Baziukas.

diatom *Stephanodiscus hantzchii* during the spring, whereas Cyanobacteria (mostly *Aphanizomenon flos-aquae*) blooms usually start at the end of June. Cyanobacteria representatives co-dominate together with diatoms until the end of vegetation season (Gasiūnaitė *et al.* 2005; Pilkaitytė, Razinkovas 2007). Cyclopoids are dominating in the spring and autumn zooplankton community throughout the lagoon; large *Daphnia* spp. appeared in the early summer and are followed later by small-bodied *Chydorus sphaericus* (Gasiūnaitė, Razinkovas 2004).

The latest study on the spatial variation in the residence time in the Curonian Lagoon (Ferrarin *et al.* 2008) points toward abrupt changes in hydrological conditions between the River channels and avandelta. Therefore, it was expected distinct structural and quantitative alterations of the plankton communities along the river-lagoon transition. The influence of the different phases of the seasonal plankton development (Bacillariophyceae versus Cyanobacteria dominance) on the response of plankton communities to the hydrodynamic forcing was hypothesised. To identify the

location of the hydrodynamic transition, we used the data on sediment grain size distribution as a proxy for hydrodynamic regime. Zooplankton and phytoplankton communities in the Nemunas River were sampled to obtain a point of reference for their structure and seasonal dynamics.

MATERIAL AND METHODS

Sampling and sample analysis

Plankton communities and bottom sediments were sampled along three approx. 7 km length transects (18 stations in total, Fig. 1, A). The mean depth of main channels in the Nemunas Delta varied from 2–3 m (II and III transects, Fig. 1) to 4–5 m (I transect, Fig. 1). The avandelta is 3–4 km wide and very shallow (0.5–1.5 m), characterised by high sedimentation rates of fine grained material and followed by a steep slope towards the depths of 2.5–3 m typical for the central lagoon (Žaromskis 1999).

Bottom sediments were sampled on July 18, 2001 using Van-Veen grab. Sieving method was used for sediment grain size analysis, since all samples contained more than 10% of particles with grain size exceeding 0.05 mm. Samples were dried and sorted by sieving shaker *Fritch Analyzette 3*. Analysis of sediments with silt and clay particles was made from wet samples by using water-mechanical method (Petelin 1967). For further analysis the sediment particles were classified to size classes according to Wentworth (1922) modified by Folk (1965). The median diameter (Md) was calculated according to the method of Trask (1930).

In order to reveal the pattern of spatial changes in phyto- and zooplankton communities along the river delta-lagoon transition, we sampled the same 18 stations (I-III transects, Fig. 1, A) on July 18 and August 17, 2001. Additionally, phyto- and zooplankton was sampled every 2 weeks at a single station in the Nemunas River (Fig. 1) from April to September 2002. Published data (Gasiūnaitė, Razinkovas 2004; Olenina 1997; Gasiūnaitė *et al.* 2005) were used as points of reference for the lagoon plankton communities' structure and seasonal dynamics.

Phytoplankton was sampled using a 1 L bathometer from 1m depth and fixed with 2 % formaldehyde

solution. Taxonomic composition was determined and cell density was counted according to HELCOM recommendations (HELCOM 1998). Zooplankton was collected from 1m depth using a 10 L bathometer. At each sampling station 20 litres of water were filtered through a 100 µm mesh net and fixed with 4 % formaldehyde solution. All plankton crustaceans excluding nauplii were identified and counted.

Statistical data analyses

The ordination of samples by multi-dimensional scaling (MDS) based on Bray-Curtis similarity coefficient (Clarke, Warwick 1997) used to evaluate the pattern of structural and quantitative changes in bottom sediments as well as phyto- and zooplankton communities along the river-lagoon transition. Sediment samples were analysed according to the relative share of different grain size classes. Phytoplankton samples were described according to the relative abundance of Cyanobacteria, Bacillariophyceae, Chlorophyceae and one cumulative group containing the rest of the phytoplankton species. The relative abundance of genus *Daphnia*, *Chydorus*, *Bosmina*, adult and juvenile Cyclopoida and a cumulative group of the rest of zooplankton species was used for crustacean zooplankton analysis. Cyanobacteria/Bacillariophyceae and Copepoda/Cladocera ratios for plankton communities were calculated as indicators of structural river-lagoon gradients.

Multivariate redundancy analysis (RDA) was applied as a tool to evaluate the relationships between environmental characteristics and structure of plankton communities. Depth sediment median diameter Md, total abundance of phytoplankton and total abundance of zooplankton Md were selected as explanatory variables; relative abundance of Cyanobacteria, Bacillari-

ophyceae, Chlorophyceae, Copepoda and Cladocera – as response variables. Paired *t*-test was applied to evaluate the differences in means. Statistical analysis was done by BROD GAR 2.7.2. (Highland Statistics Ltd) and PRIMER 5 (PRIMER-E Ltd.) statistical packages.

RESULTS

Sedimentation patterns

The multi-dimensional scaling (MDS) ordination of sediment samples according to grain size reveals consistent changes in sediment structure along the river-lagoon transition (Fig. 2). The sediments in distributary channels were predominately composed of medium (58 to 82% in stations 4; 5; 6; 12 and 18) and fine (48 to 71% in stations 10; 11; 16; 17) sand with the mean grain size 0.29 ± 0.08 mm (Table 1). Generally, the coarsest sediments indicating the most active hydrodynamic conditions were found in the northernmost channel (transect I; Fig. 1). Fine sand dominated in all lagoon stations (60 to 90%) except 1; 7 and 8, characterised by very fine sand (67 to 88%). Mean sediment grain size in the lagoon stations was 0.15 ± 0.06 mm.

Seasonal dynamics of the plankton communities

Bacillariophyceae (mostly Centrales and Penales) dominated the Nemunas River phytoplankton community from April up to mid of July (50.8 ± 16.4 % of total phytoplankton density; A, Fig.3). Chlorophyceae composed 36.7 ± 8.1 % of total abundance during May–September period. The Cyanobacteria dominance was observed only in August (approx. 46.8 ± 0.4 % of total

Table 1 Depth and grain size composition of bottom sediments (in %) at each sampling station.

Station No.	Depth, m	Fraction, mm							Md, mm	Sediment class
		>1	1-0.5	0.5-0.25	0.25-0.125	0.125-0.063	0.063-0.004	<0.004		
1	3.1		9.84	1.54	12.27	66.99	8.46	0.9	0.082	Very fine sand
2	3.2			12.44	63.99	15.92	6.94	0.71	0.168	Fine sand
3	2.4		0.73	51.93	45.17	1.7	0.47		0.254	Medium sand
4	4.4		0.22	69.03	28.47	1.92	0.36		0.32	Medium sand
5	2.9		4.53	82.81	11.57	0.79	0.3		0.329	Medium sand
6	2.5		4.92	73.33	21.16	0.41	0.18		0.33	Medium sand
7	3.3			0.34	6.14	87.69	5.83		0.076	Very fine sand
8	2.5		0.1	0.35	10.27	85.82	3.46		0.078	Very fine sand
9	1		0.02	0.97	60.46	38.07	0.48		0.13	Fine sand
10	1.8		1.22	32.23	59.11	4.8	2.64		0.198	Fine sand
11	2.9		1.9	45.73	49.02	2.92	0.43		0.246	Fine sand
12	3.0	5.46	31.36	57.96	3.63	1.34	0.25		0.449	Medium sand
13	2.25		1.28	3.53	91.85	3.18	0.16		0.174	Fine sand
14	3.35		1.4	11.94	68.36	14.99	2.49	0.82	0.171	Fine sand
15	2.3		0.04	2.56	90.51	6.86	0.03		0.174	Fine sand
16	2.3		0.07	25.35	71.86	2.15	0.57		0.222	Fine sand
17	3.8		0.75	21.95	48.32	24.68	4.3		0.176	Fine sand
18	3.2	0.7	4.97	62.71	29.14	2.01	0.47		0.304	Medium sand

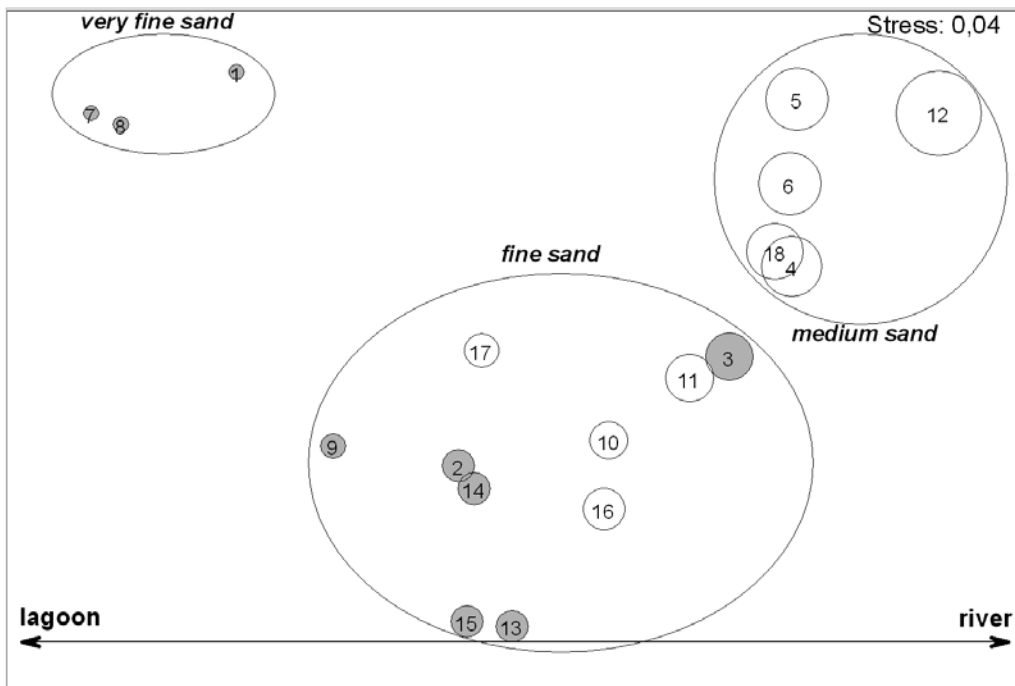


Fig. 2 MDS ordination for sediment grain size distribution along the river-lagoon gradient. Size of the circles indicates mean grain size of the sediments, ranging from 0.08 to 0.45 mm. Open circles represent river, filled – lagoon stations. River–lagoon gradient and dominant sediment types are indicated. Compiled by Z.R. Gasiūnaitė and S. Gulbinskas.

Mean phytoplankton density was 7026 ± 2394 and 23039 ± 8430 thousand cells l^{-1} in July and August respectively. The representatives of Bacillariophyceae (Centrales, Fragilariaceae, *Nitzschia* spp.) dominated in July; the Cyanobacteria/Bacillariophyceae ratio was very low in all stations (0.06 ± 0.07). In August Cyanobacteria (*Aphanizomenon flos-aquae*, *Oscillatoria* spp.) and Bacillariophyceae (Centrales, *Stephanodiscus*) shared the dominance. The MDS revealed two groups of samples, characterised respectively by

density). Cyanobacteria/Bacillariophyceae ratio varied from 0.1 to 0.8 during all study period. The highest overall phytoplankton abundance was observed in May–August. Two density maximums were typical for Nemunas River zooplankton (B, Fig. 3) and copepods dominated the community over the year (75.8 ± 14.1 % of total density). Copepoda/Cladocera ratio varied from 1.5 to 7 except some occasions in spring when cladocerans were absent.

Spatial distribution of the plankton communities

The overall phytoplankton abundance during both sampling periods did not show a clear trend along the river–lagoon gradient (Figs 4 and 5; A and B in Fig. 6).

high (8.9 ± 3.8) and low (0.5 ± 0.4) Cyanobacteria / Bacillariophyceae ratio (B in Fig. 6). The first was typical for Lagoon stations, the second – for river distributaries and lagoon stations situated closer to the River mouths. Average values of the Cyanobacteria /Bacillariophyceae ratio in these groups differed significantly (*t*-test, $p < 0.01$).

Zooplankton abundance in both sampling cases increased along the river–lagoon gradient (Figs 4 and 5; B and C in Fig. 6). Mean zooplankton abundance varied from 7 ± 3 and 4 ± 3 ind l^{-1} in riverine samples to 115 ± 81 and 166 ± 91 ind l^{-1} in lagoon samples (July and August respectively). Cyclopoida copepodites, *Daphnia* spp. and *Bosmina* spp. dominated in July in the lagoon.

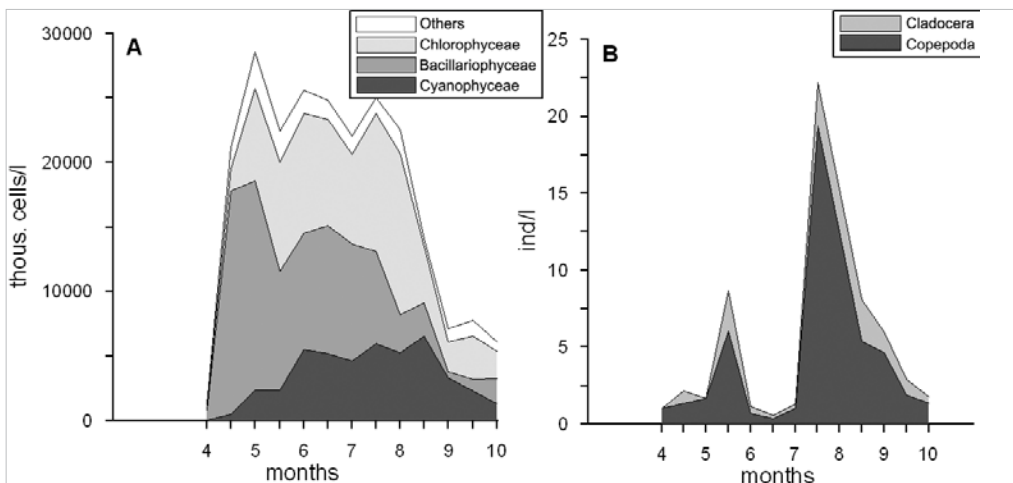


Fig. 3 Seasonal changes in phytoplankton (A) and zooplankton (B) community structure in the Nemunas River. Compiled by Z.R. Gasiūnaitė and R. Pilkaitytė.

High Copepoda/Cladocera ratio (2.1 ± 1.2) was typical for river channels, low (0.4 ± 0.2) – for the lagoon. In August zooplankton was dominated by juvenile copepod stages in the river and adults in the lagoon (*Mesocyclops*, *Eucyclops* and *Eudiaptomus*; Copepoda/Cladocera ratio: 2.1 ± 1.2), except 3, 7 and 15 stations,

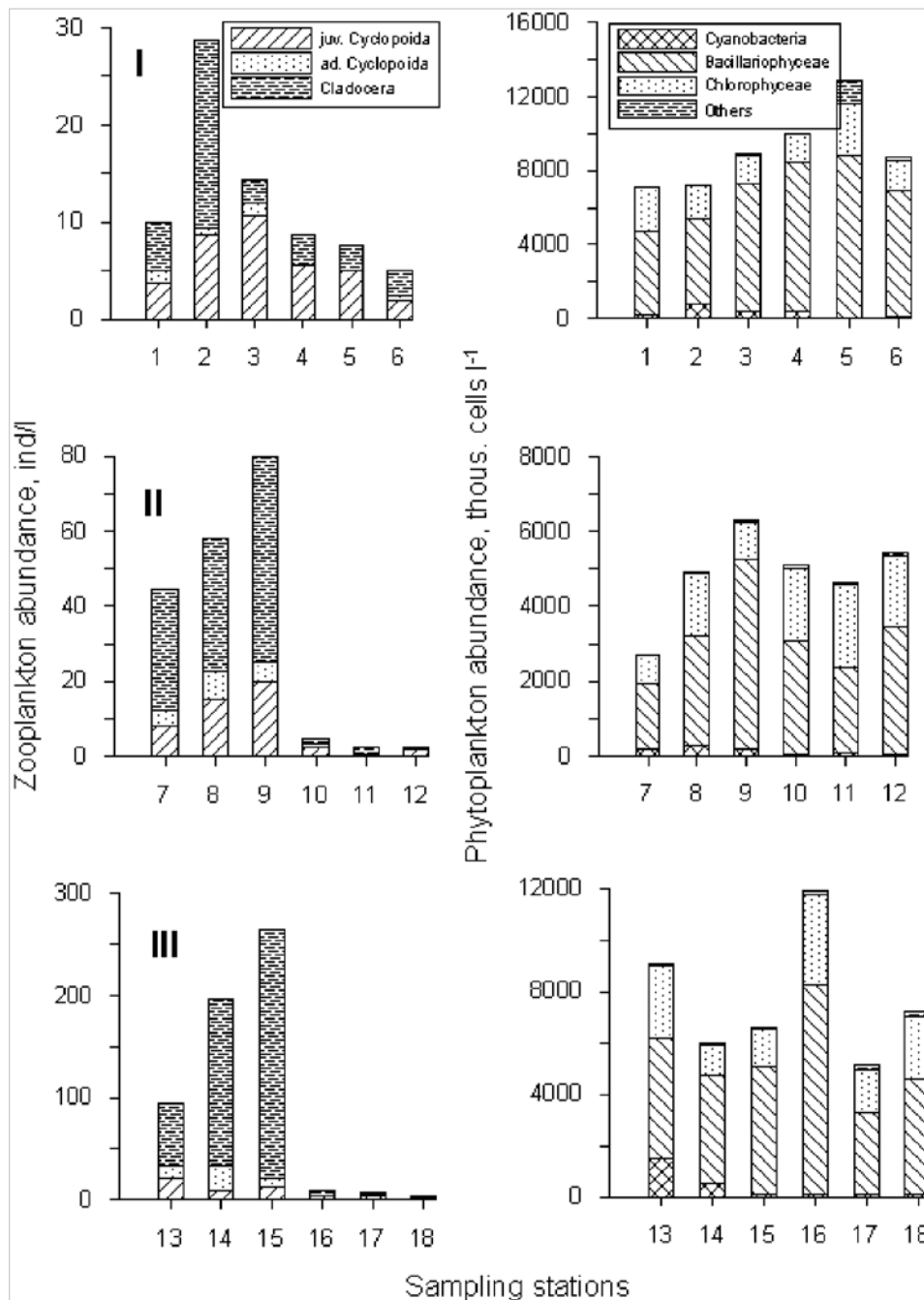


Fig. 4 Zooplankton and phytoplankton community structure along the river–lagoon transition, 18 July, 2001. Transects (I–III) are indicated as in Fig. 1. Compiled by Z.R. Gasiūnaitė and R. Pilkaitytė.

characterised by the dominance of *Daphnia* and *Chydorus* (Copepoda/Cladocera ratio: 0.8 ± 0.1). Average values of the Copepoda/Cladocera ratio in these groups differed significantly (t -test, $p < 0.01$).

The results of the multivariate redundancy analysis (RDA) were shown in Fig. 7. The explanatory variables described 38% of the variability in July and total zooplankton abundance was the significant predictor. Positive correlation was observed between the total zooplankton abundance and relative abundance of both

Cladocera and Cyanobacteria. Sediment median diameter was positively related to the relative abundance of Copepoda (Fig. 7, A). The explanatory variables are responsible for 58% of the variability in August. The significant predictor was total zooplankton abundance, which was positively correlated to the relative abundance of Cyanobacteria. Sediment median diameter was positively correlated to the relative abundance of Cladocera, Bacillariophyceae and Chlorophyceae (Fig. 7, B).

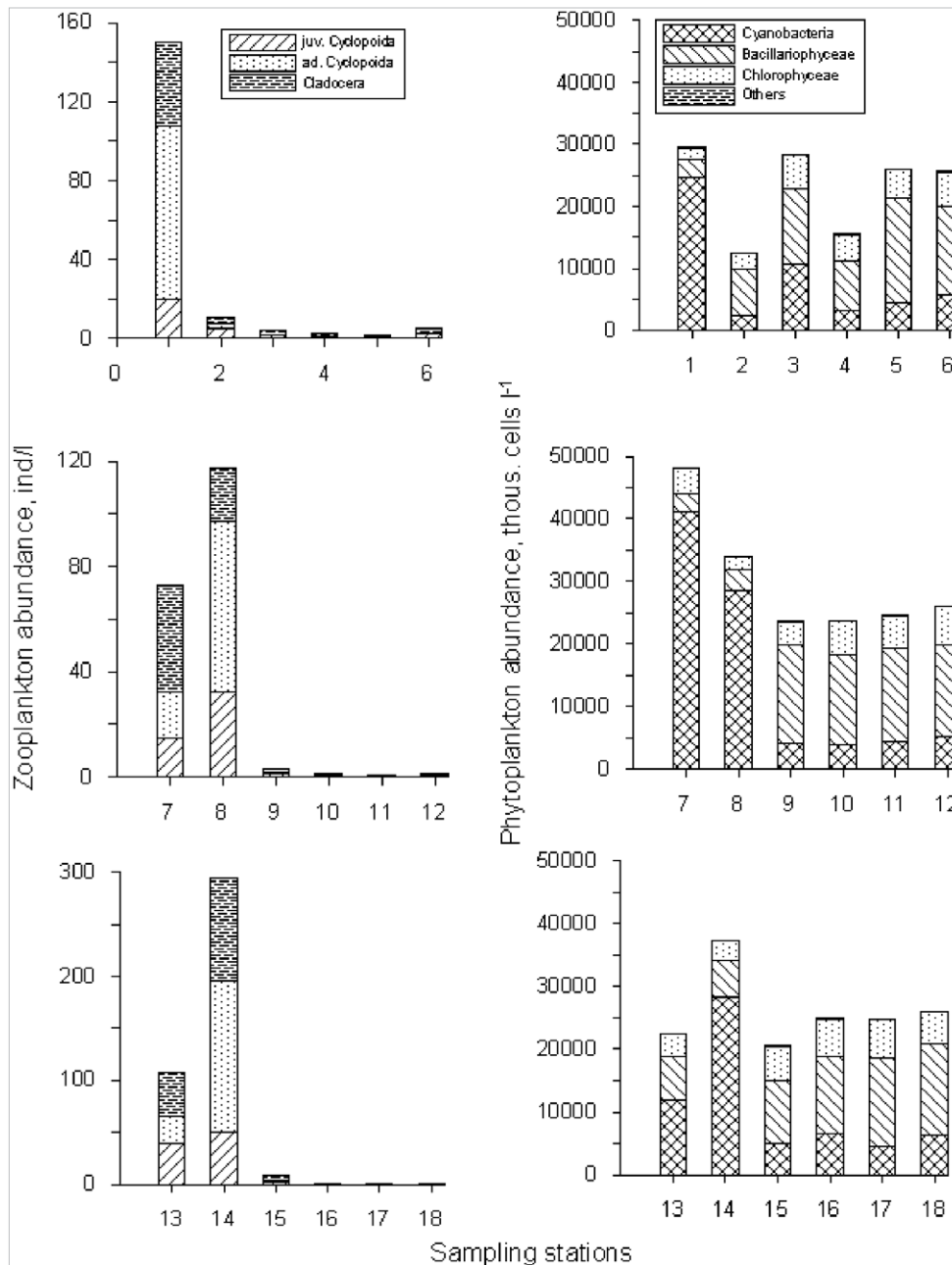


Fig. 5 Zooplankton and phytoplankton community structure along the river-lagoon transition, 17 August, 2001. Transects (I–III) are indicated as in Fig. 1. Compiled by Z.R. Gasiūnaitė and R. Pilkaitytė.

DISCUSSION

Clearly pronounced changes in sediment grain size distribution along the Nemunas River–Curonian Lagoon transition (Fig. 2) suggest spatially consistent narrow hydrodynamically forced barrier *sensu* Emelyanov (2005). According to the long-term data of Nemunas River discharge (Jakimavičius, Kovalenkoviėnė 2010) we could also expect temporal consistency of this river–lagoon boundary for all summer season. Structural and quantitative response of the characteristics of plankton communities to the hydrodynamic forcing at the river–lagoon transition, in turn, could be defined by the dominant groups of organisms both in the lagoon and river.

Typically, diatoms dominate in March–May phytoplankton community of the Curonian Lagoon (up to 70% of total phytoplankton density), Cyanobacteria are the most abundant in June–September (up to 80% of total density), Chlorophyceae constitute up to 50% during April–October. The Cyanobacteria/Bacillariophyceae ratio is 0.01–0.7 in spring, increase to 1–3.5 in summer and sometimes exceeds 40. The highest total phytoplankton abundance is typical for May and July–September (Pilkaitytė, Razinkovas 2007; Pilkaitytė 2007). Filamentous Cyanobacteria abundance in the Lagoon in July–September varied from 1270 to 413500 thous. units l^{-1} (Olenina 1997). Cladocerans generally dominate in the Lagoon from June to September (up

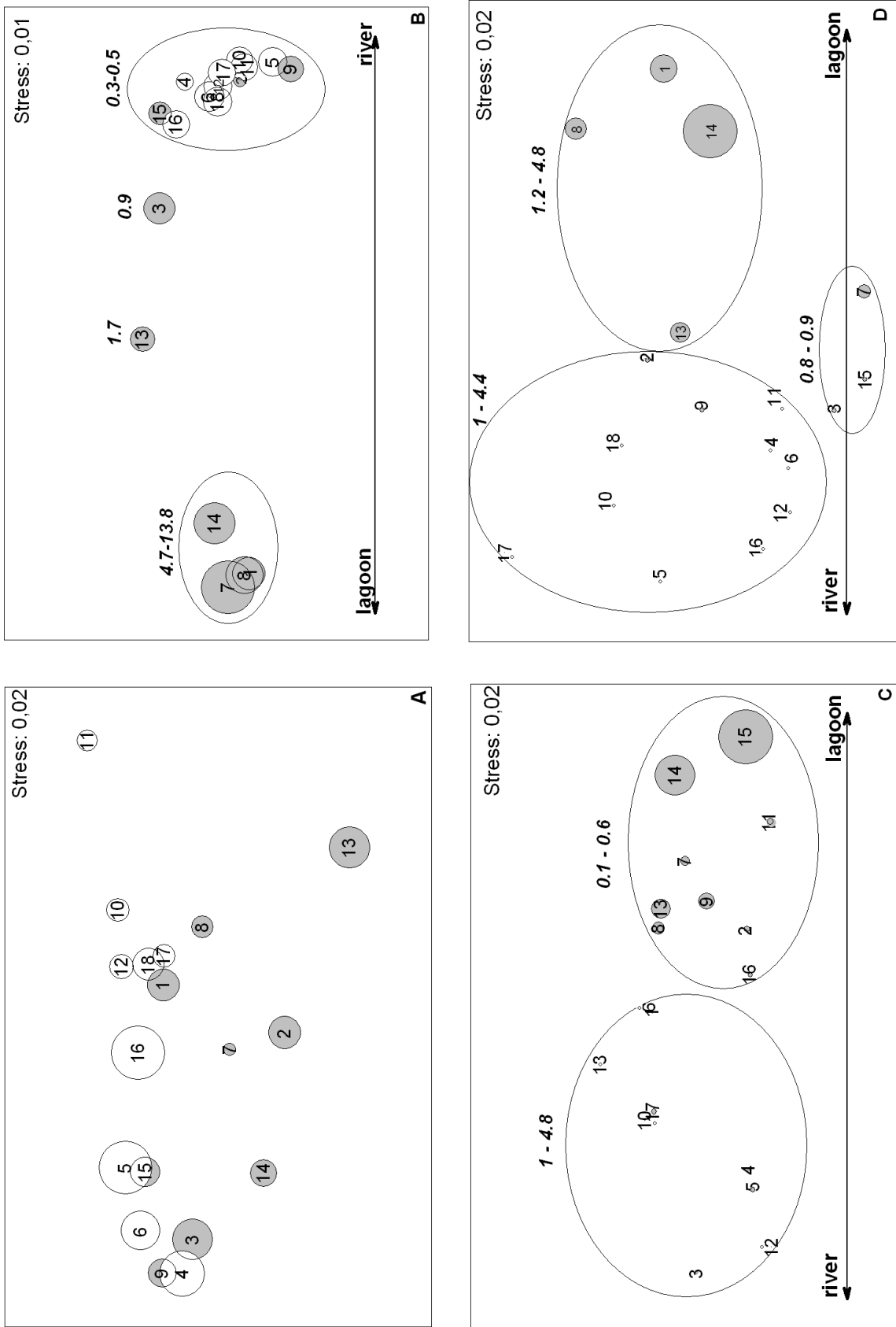
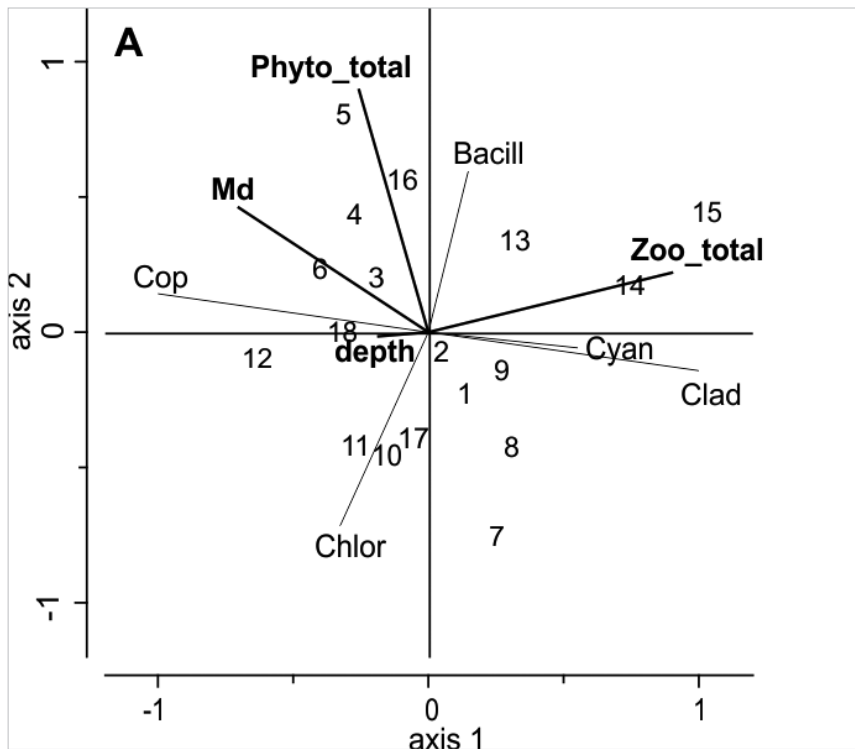


Fig. 6 MDS ordination for phytoplankton and zooplankton community structure along the river-lagoon transition. A – phytoplankton, 18 July, 2001; B – phytoplankton, 17 August, 2001; C and D – zooplankton at 18 July, 2001 and 17 August, 2001 respectively. Cyanophyta/Bacillariophyta and Copepoda/Cladocera ratio indicated under each group of samples. Size of the circles shows abundance of plankton organisms, ranging from: A – 2690-12840 thous. cells l⁻¹; B – 12440-48190 thous. cells l⁻¹; C – 3-270 ind l⁻¹; D – 1-240 ind l⁻¹. Open circles represent river, filled – lagoon gradient is indicated. Compiled by Z.R. Gasiūnaite.



abundance in the Lagoon is roughly 10 times higher than observed in the Nemunas River (Gasiūnaitė, Razinkovas 2004; Gasiūnaitė *et al.* 2005). Therefore, both sampling occasions along the river-lagoon gradient coincide with the expected Cyanobacteria and Cladocera dominated period in the lagoon communities.

The seasonal changes in the river plankton communities follow different scheme. The variation of main taxonomic groups' ratios (Cyanobacteria/Bacillariophyceae for phytoplankton and Copepoda/Cladocera for plankton crustaceans) is markedly lower in the River throughout the seasons and could be explained by different adaptations of the species to the running water conditions (*e.g.* Reynolds, Descy 1996; Welker, Walz 1999; Piirsoo 2001). Consequently, we could predict the pattern of plankton changes along the River–Lagoon transition, suggesting quantitative differences for phytoplankton throughout the year and well expressed structural changes during the Cyanobacteria–dominated period in the Lagoon (June–October). Clear shift in abundance could be characteristic all year round for zooplankton, while the gradient in community structure could be observed during Cladocera–dominated period in June–August.

The sampling along the river–lagoon transition shows the absence of phytoplankton abundance trend (Figs 4 and 5) even during Cyanobacteria dominated period in August. Diatoms also could be responsible for the phytoplankton abundance trend in the transitional environments (Izaguirre *et al.* 2001), but this pattern was not observed in the Nemunas delta, when Bacillariophyceae dominated both in lagoon and river stations (July).

MDS analysis does not reveal a structural gradient along the river–lagoon transition in July (Fig. 6). In August nearly all phytoplankton samples fell into two distinct groups, dominated respectively by diatoms in river and lagoon stations, situated

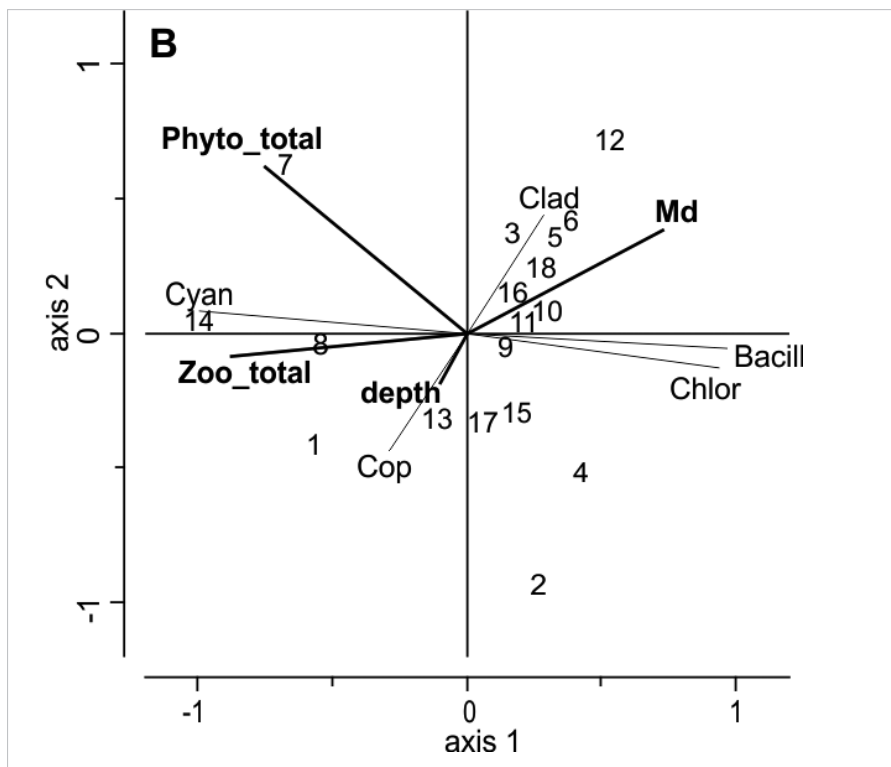


Fig. 7 RDA analysis for the river–lagoon transition at 18 July, 2001 (A) and 17 August, 2001 (B). Md – sediment median diameter; phyto_total – total abundance of phytoplankton; zoo_total – total abundance of zooplankton; Cyan – Cyanobacteria; Bacill – Bacillariophyceae; Chlor – Chlorophyceae; Cop – Copepoda; Clad – Cladocera. Compiled by Z.R. Gasiūnaitė and S. Gulbinskas.

to 90 %). The mean Copepoda/Cladocera ratio in the Lagoon varies from 20 to 50 in early spring, decreases to 2–11 in May, did not exceed 0.5 in summer and increases again to 1–3 in autumn; overall zooplankton

structural gradient along the river–lagoon transition in July (Fig. 6). In August nearly all phytoplankton samples fell into two distinct groups, dominated respectively by diatoms in river and lagoon stations, situated

closer to the channel mouths and by Cyanobacteria in more distant lagoon stations.

As expected, the total abundance of crustacean zooplankton community increased significantly towards the lagoon in both sampling cases (Figs 4 and 5). Cladocerans dominated in lagoon zooplankton in July and structural changes along the river-lagoon gradient were clearly expressed. Cyclopoids were prevalent in some Lagoon stations in August instead of expected dominance of cladocerans, namely *Chydorus sphaericus* (Gasiūnaitė, Razinkovas 2004); only three stations were dominated by cladocerans. Despite the similar Copepoda/Cladocera ratio, structural gradient was distinct since adult cyclopoids dominated in the Lagoon and juveniles – in the River.

Bottom sediment characteristics (sediment median diameter), however, were not among the significant predictors of the variability of plankton community structure along the river-lagoon transition; the best predictor in both sampling cases was the total abundance of plankton crustaceans.

CONCLUSIONS

The changes in sediment grain size distribution, quantitative and structural alterations in phytoplankton communities were detected in the Nemunas River – Curonian Lagoon transition area. Hydrodynamic gradient during the summer is strong enough to shape zooplankton community. Phytoplankton community structure is generally affected as far as turbulence-sensitive Cyanobacteria are dominating. However, the expected abundance trend was not observed in the phytoplankton community, even during the Cyanobacteria-dominated period. Despite the observed gradient of the sediment structure along the river-lagoon transition, indicative value of the sediment characteristics for the pelagic conditions was not statistically proved.

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