

Differences of Zooplankton Development Along a Lake and a River Stretch of the River Spree (Germany)

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스프리 강 (독일) 내의 호수와 강 구획에서의 동물플랑크톤 성장의 차이. 김현우* · ¹주기재 · Norbert Walz (Institute of Freshwater Ecology and Inland Fisheries, Department of Shallow Lakes and Lowland Rivers, Muggelseedamm 301, D-12587 Berlin, Germany, ¹부산대학교 생물학과, 부산, 609-735)

동물플랑크톤의 성장률과 밀접한 상관 관계를 가지는 요인들에 대해 스프리 강 종류의 호수 및 강 구획 (호수 유입부 (S1), 호수 유출부 (S2), 호수 유출부 지점에서 21km 하류지점 (S3))에서 1999년 3월부터 11월까지 조사하였다. 총 동물플랑크톤 생체량은 S2지점에서 크게 증가하였고 S3에서 급격하게 감소하였다. 모든 조사지점에서 소형동물플랑크톤 (윤충류와 유생)의 개체수는 대형동물플랑크톤 (지각류와 요각류)의 개체수 보다 매우 높았다. 그러나, 대형동물플랑크톤의 생체량은 소형동물플랑크톤 생체량과 유사하거나 높았다. 대형 지각류 (*Daphnia cucullata*)는 조사지점 S2에서 우점한 반면, 조사지점 S1과 S3에서는 소형 지각류 (*Bosmina longirostris*)가 우점하였다. 주요 동물플랑크톤 군집의 성장률 (r_i in d^{-1})은 조사지점 S1 과 S2사이 (호수구획)와 S2와 S3사이 (강 구획)에서 매우 달랐다. 호수 구획 내에서의 성장률은 양성적인 유형을 나타낸 반면 강 구획 내의 성장률은 음성적인 양상을 나타내었다. 여러 환경 요인 중, 스프리강 종류지점에서는 수체의 잔류시간 (partial retention time: PRT, d^{-1}) 이 동물플랑크톤 군집구조의 특성을 결정짓는 가장 중요한 요인으로 사료된다.

Key words : Growth rates, Partial retention times, Lowland river, Cladocerans, rotifers

INTRODUCTION

Large lowland rivers tend to become highly eutrophic due to anthropogenic nutrient input (Marneffe *et al.*, 1996; Kim *et al.*, 1998). Moreover, high zooplankton abundances (Gosselain *et al.*, 1998; Lair *et al.*, 1999) are found in eutrophic lowland rivers when the long downward transportation allowed enough time for development. The influence of the partial retention time also increased the dominance of microzooplankton (mainly rotifers, see Walz and Welker, 1998) or

macrozooplankton and the total zooplankton biomass (Basu and Pick, 1996) in lowland river ecosystems. These hydrological changes of the river can be responsible for dramatic shifts in the community structure of zoo- and phytoplankton (Kim, 1999; Kim *et al.*, 2000).

Many studies on various aspects of river zooplankton dynamics have been conducted, including biotic interactions (Gosselain *et al.*, 1996; Kim *et al.*, 1999, Lair *et al.*, 1999) and abiotic interactions (Basu and Pick, 1997; Viroux, 1997, 1999). However, lowland rivers tend to show many forms of transitions between rivers and

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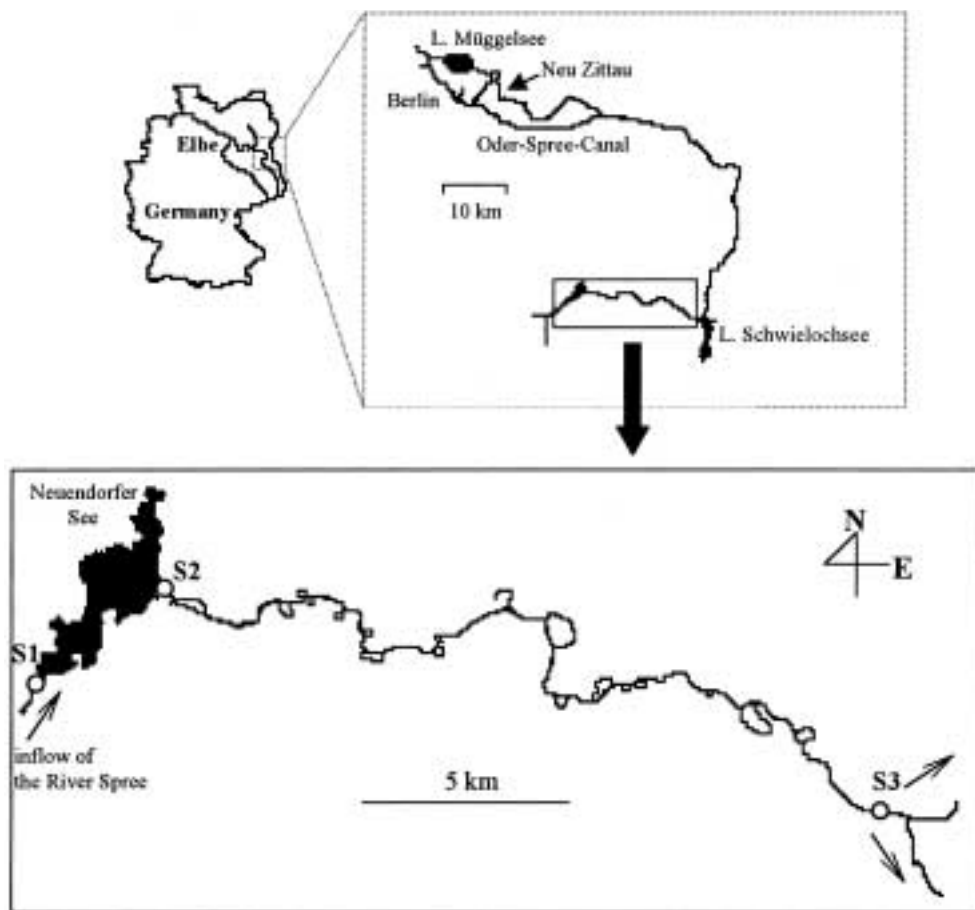


Fig. 1. Map showing the study site (S1: Leibsch, S2: Alt-Schadow, S3: Trebatsch).

lakes. Even though a number of field studies were carried out in shallow lakes (Jeppesen *et al.*, 1997) and lowland rivers (Gosselain *et al.*, 1994), a few of them covered both habitat types within one system. Due to the limited number of zooplankton dynamics studies in such river systems, a question remains what is the relative importance of zooplankton community in such river systems and which factors are most strongly related to zooplankton growth rates. Thus, the aim of the present paper is to elucidate what is the reason for this expected difference between microzooplankton (mainly rotifers) and macrozooplankton (cladocerans and copepods) in the different parts of a lowland river system.

MATERIALS AND METHODS

General description of the River Spree

The River Spree rises in the Lusatian Moun-

tains at 580 m above mean sea level near Neugersdorf (Czech Republic) and flows northwards through Saxony and Brandenburg. It travels 397 km before joining the Havel, a tributary of the Elbe, in Berlin. Municipal, industrial, and agricultural sewage flowed into the Spree after partial and mechanical reduction treatment until 1992. Meantime the situation is much better. The Spree divides into many branches of the inland delta of the Spreewald before it broadens naturally into several shallow lake basins (Fig. 1). It drains of a total area of about 10,000 km².

Between these widened river stretches the Spree flows, often meandering, with a mean velocity of 0.5 ~ 0.6 m s⁻¹. The range between annual minimum (10.1 m³ s⁻¹) and maximum runoff (29.2 m³ s⁻¹, both averages, 1976 ~ 1992, near Neu Zittau) is relatively small, with minimum discharge in summer and maximum discharge in early spring.

The width of the lower Spree (without flushed

lakes and canals) varies between 25 and 40 m with mean depths of 1.5–2.5 m (Köhler, 1994).

Study sites and sampling

The three sampling stations were selected above and below Neuendorfer See. Station 1 (Leibsch) was in the inflow of the River Spree to the Neuendorfer See, Station 2 (Alt-Schadow) was ca. 100 m after the outflow of the lake, and Station 3 (Trebatsch) at the end of a 21 km downstream stretch (Fig. 1). From March to November of 1999, samples were collected in biweekly intervals. Water samples were collected at 0.5 m depth with a 3.4 l Ruttner Sampler (Limnos^{TN}), placed in 20 l sterile polyethylene bottles, and kept in the shade at ambient temperatures until returned to the laboratory, within 3 hrs of collection.

Limnological variables and Chl. *a* concentration

Chemical analyses of the water samples were carried out after filtration through Sartorius cellulose nitrate membrane filters (0.45 µm). Soluble reactive phosphorus (SRP) was determined using VARIAN-photometer CARY 1E with the ammonium molybdate method according to DIN EN 1189. Total phosphorus (TP) was determined as SRP after digestion with H₂O₂ and H₂SO₄ at 170°C. Total nitrogen (TN) was measured using TN-Aanalyzer (Abimed®). Ammonia was determined using the indolphenol blue method according to *Ausgewählte Methoden der Wasseruntersuchung* (1986). Nitrate was measured using the ion chromatographic method according to DIN 38405-D19. Water temperature, dissolved oxygen (mg l⁻¹, % Sat.), and pH were measured using a WTW Oximeter EOT 196. For chlorophyll *a* (Chl. *a*) analysis, samples were filtered through Whatman GF/C fibre glass filters. The filters were extracted in 10 ml of boiling ethanol (90%, 78°C) and homogenized (Polytron, Kinematica, 45 seconds at 8000 r.p.m.). The determination of Chl. *a* concentration followed DIN 38412-L12.

Zooplankton sample collection, enumeration, and biomass (µg dry weight l⁻¹) determination

Zooplankton samples were taken by 3.4 l Ruttner sampler from 0.5-m depth. The screened zooplankton samples were fixed in 4% (final conc.) formalin. At least 100 individuals of one species were counted (100 and 400-fold magni-

fication) under a compound microscope (Ergaval, Carl Zeiss, Jena), normally several hundreds. Zooplankton taxa were identified to genus or species (except for juvenile copepods) using as references Koste (1978), Flössner (1972), and Einsle (1993). Crustaceans biomass (µg dry weight l⁻¹) was estimated using length-weight regressions published by Balushkina and Winberg (1979), Bottrell *et al.* (1976), and McCauley (in Downing and Rigler, 1984). Formulas of Ruttner-Kolisko (1977) were modified according to actual length relationships of rotifers in River Spree to determine rotifers biomass (µg dry weight l⁻¹).

Hydrological data and partial retention time (day)

The water discharge volumes (Q; m³ d⁻¹) were obtained from the regional water authorities (Landesumweltamt Brandenburg) based on daily water gauge measurements at sampling stations. The mean theoretical partial retention time, *t* (d), of water in a distinct river stretch, *s* (m), is given by equation (1) as

$$t = A s/Q \quad (1)$$

where *A* (m²) was the estimated sectional area of the river minus dead-zones based on numerous depth profiles.

Growth rates (*r_t* in d⁻¹) in relation to the theoretical partial retention time

Growth rates (*r_t*) of major zooplankton populations can be estimated by equation (2) as

$$r_t \text{ (d}^{-1}\text{)} = \ln b - \ln b_0/t \quad (2)$$

where *b*₀ and *b* are the biomasses of the population at the beginning and at the end of the river stretch, respectively (Talling and Rzoska, 1967).

RESULTS

Hydrologic regime and limnological variables

In the River Spree basin, the annual discharge cycle was typical for this region in North-East Germany, a transition zone between maritime and continental climate. The peak discharge occurred in the wet season (March to April and November to December), while low discharge was maintained during summer and fall season (Fig. 2A). The discharge changed dramatically

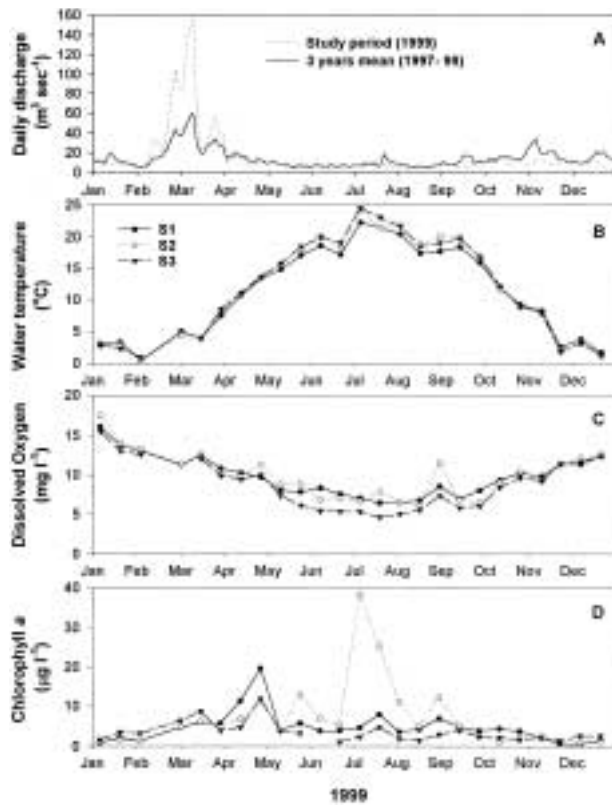


Fig. 2. Changes in the daily discharge at Alt-Schadow during 1997~1999 (A) and selected limnological parameters (B: Water temperature, C: Dissolved Oxygen, D: Chlorophyll *a*) at 3 stations (S1: Leibsich, S2: Alt-Schadow, S3: Trebatsch).

between February and March (Discharge_{max}: 140 ~ 150 m³ sec⁻¹), and was higher compared with that of other years (Fig. 2A). The rising-water period in the spring was brief, and high discharge was maintained only for several weeks. During April–December of 1999, daily discharge was very low (less than 20 m³ sec⁻¹). From May to mid July the discharge was lower than 10 m³ sec⁻¹.

Water temperatures followed the expected seasonal trends (Fig. 2B), with the maximum temperature recorded in the middle of July (25°C at S3). A water temperature < 1°C was recorded only in February. The ranges of dissolved oxygen were 5.0~18.0 mg l⁻¹ (Fig. 2C), and the mean percent saturation was not over 100% (Table 1). In spring and summer, low oxygen levels were maintained with values less than 10 mg l⁻¹ and 80%, especially less than 70% saturation at S3. Dissolved oxygen (mg l⁻¹ and % saturation) was high, over 10 mg l⁻¹ and with an 80% saturation during winter and fall season. Annual means of

Table 1. Means and standard errors of limnological parameters at 3 stations in the River Spree (Jan. ~ Dec. 1999, n = 25). SRP: soluble reactive phosphorus, DO: dissolved oxygen, TN: total nitrogen, TP: total phosphorous.

	Unit	S1	S2	S3
Temperature	°C	11.4±1.40	11.8±1.41	12.3±1.59
pH		7.6±0.02	7.7±0.04	7.6±0.03
DO	mg l ⁻¹	9.7±0.51	9.9±0.46	8.7±0.64
DO	% sat.	86±2.21	89±3.22	77±3.22
Chl. <i>a</i>	µg l ⁻¹	4.7±0.79	6.9±2.07	3.4±0.50
TN	mg l ⁻¹	1.90±0.18	1.76±0.21	1.76±0.18
TP	µg l ⁻¹	63±3.11	71±4.11	73±3.64
Nitrate-N	mg l ⁻¹	1.40±0.18	1.18±0.24	1.24±0.19
Ammonia-N	mg l ⁻¹	0.18±0.02	0.23±0.02	0.17±0.01
SRP	µg l ⁻¹	16±1.26	19±2.58	31±3.40

Chl. *a* concentrations were less than 10 mg l⁻¹ (Fig. 2D), and similar at all stations (Table 1). However, along the studied segment, Chl. *a* concentration was seven or eight fold higher in S2 than in both S1 and S3 during the summer season. The pH remained between 7.2 and 8.2 along the entire stretches of the sampling stations and there was no distinct spatial variation in nutrients (Table 1).

Zooplankton biomass (µg dry weight l⁻¹) and community structure

There was a substantial variation in total zooplankton biomass and of major parts of the zooplankton community along the flowing stretch in River Spree (Fig. 3). The differences in total zooplankton biomass between S2 and both of S1 and S3 were significant (ANOVA, $p < 0.01$, $n = 19$). The annual mean of total zooplankton biomass at S2 was high (122±28 µg dw l⁻¹; mean±s.e., $n = 19$), while that of total zooplankton biomass generally was low at both stations (S1: 26±2.6 µdw l⁻¹, S3: 13±1.8, respectively). The relative rotifer biomass consisted of more than 38% of the total zooplankton biomass at both stations (S1: 46%, S3: 38%) and less than 30% at S2. Among the macrozooplankton biomass, cladoceran biomass was approximately 8-fold higher than the biomass of cyclopoid copepodids. Especially, cladoceran biomass at S2 was higher than that of at both S1 and S3 (Fig. 3).

Zooplankton abundance and species

The seasonal variation of total zooplankton abundance was dramatic. High zooplankton

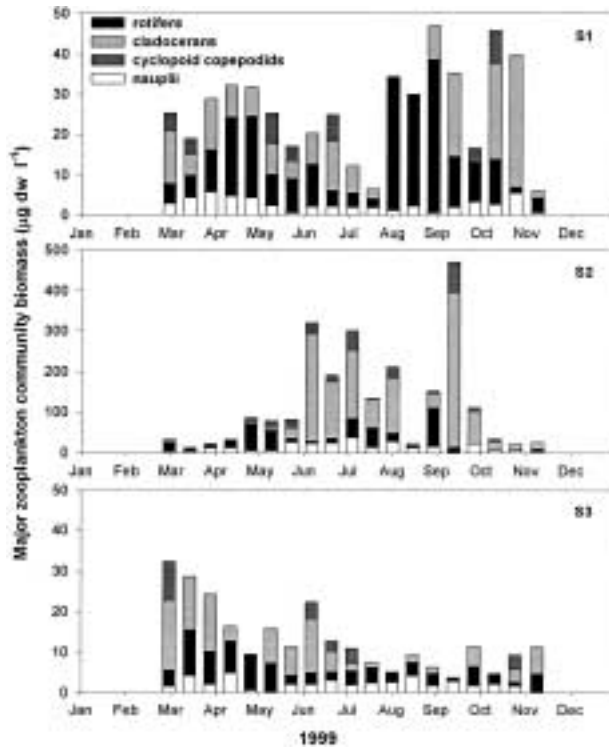


Fig. 3. Seasonal changes in major zooplankton community biomass ($\mu\text{g dw l}^{-1}$) at 3 stations (S1: Leibsch, S2: Alt-Schadow, S3: Trebatsch).

abundance was usually maintained during March to May and July to September 1999 in the River Spree. The seasonal pattern of rotifer variation was similar to that of total zooplankton abundance. The maximum zooplankton abundance was observed in early July and September at S2 ($N_{\text{max}}: > 1,500 \text{ ind. l}^{-1}$).

Of the rotifers, *Keratella* spp., *Synchaeta* spp., *Trichocerca* spp., and *Polyarthra* spp. were most numerous. *Keratella* spp. and *Synchaeta* spp. were the dominant rotifers. These rotifers occupied more than 60% of total rotifer abundance at all stations. *Polyarthra* spp. and *Trichocerca* spp. showed a remarkable difference in abundance patterns along the lake and river stretch of the River Spree. *Polyarthra* spp. (mainly *P. dolichoptera/vulgaris*) occupied more than 15% of total rotifer abundance at both S1 and S3, but was not as abundant at S2 (less than 5%). *Trichocerca* spp. occupied 6.7% of total rotifer abundance at S2, while *Trichocerca* spp. were scarce at both S1 and S3 with less than 2% of total rotifer abundance.

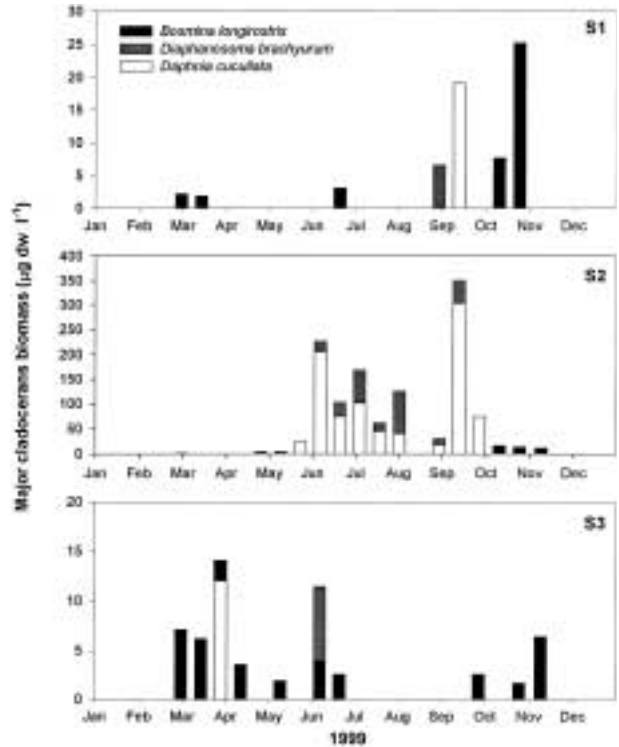


Fig. 4. Seasonal changes in the major cladoceran biomass at 3 stations (S1: Leibsch, S2: Alt-Schadow, S3: Trebatsch).

In cladocerans, *Bosmina longirostris*, *Daphnia cucullata*, and *Diaphanosoma brachyurum* accounted for more than 50% of the total cladoceran biomass at all stations (Fig. 4). *Bosmina longirostris* reached its peak in both spring and late-fall at all stations. The large-bodied cladoceran *Daphnia cucullata* was the most dominant cladoceran species and accounted for ca. 34% of the total cladoceran biomass at S2. Examining the seasonal succession of cladocerans, *Bosmina longirostris*, *Daphnia cucullata*, and *Diaphanosoma brachyurum* showed recognizable changes along the lake and river stretch of the River Spree (Fig. 4). *Bosmina longirostris*, after an initial growth phase (spring), showed a sharp decrease in mid-summer. Instead of small-bodied cladocerans, a great appearance of large-bodied taxa was observed from summer until early-fall. Its biomass increased to a maximum of $262 \mu\text{g dw l}^{-1}$, and $379 \mu\text{g dw l}^{-1}$ in both early-June and September, respectively (Fig. 4).

Partial retention time (d) and growth rates (r_i in d^{-1})

Hydrological conditions (partial retention time) were different at sampling stations. The relationships between partial retention time and Chl. *a* were found to be significantly correlated with zooplankton biomass at S2 and S3 (Table 2). At S1 major zooplankton groups and partial retention time were not significantly correlated except the nauplii. A relationship existed between Chl. *a* and the microzooplankton biomass (rotifers and nauplii) observed at S2 and S3, while there was no relationship between Chl. *a* and microzooplankton biomass at S1. The results show that in River Spree, zooplankton dynamics are explained mostly by partial retention time. On an annual basis, PRT (partial retention time) exerted a positive relationship with macrozooplankton (MACZ) biomass in the lake stretch ($r^2 = 0.313$, $p < 0.05$), while a negative relationship between both microzooplankton (MICZ) and macrozooplankton biomass and PRT was shown in the river stretch.

Patterns in growth rates of total zooplankton, cladocerans, and rotifers were greatly different between the lake and the river stretch during the study period. In the lake-like zone, growth rates generally were positive (Fig. 5A), while val-

Table 2. Pearson correlation coefficients between major zooplankton community biomass ($\mu g dw l^{-1}$) and Chl. *a* and partial retention time (day) at study stations (Mar. ~ Nov. 1999, $n = 19$).

A) S1

	ROT	CLA	COP	NAU	MICZ	MACZ	TOT
Chl. <i>a</i>	ns	ns	ns	ns	ns	ns	ns
PRT	ns	ns	ns	-0.558	ns	ns	ns

B) S2

	ROT	CLA	COP	NAU	MICZ	MACZ	TOT
Chl. <i>a</i>	0.498	ns	ns	0.606	0.669	ns	ns
PRT	ns	0.552	0.546	0.593	ns	0.560	0.617

C) S3

	ROT	CLA	COP	NAU	MICZ	MACZ	TOT
Chl. <i>a</i>	0.697	ns	ns	ns	0.602	ns	ns
PRT	-0.537	-0.550	ns	ns	-0.471	-0.499	-0.615

ns, not significant, $p > 0.1$, ROT-rotifers; CLA-cladocerans; COP-copepodids; NAU-nauplii; MICZ-rotifers+nauplii; MACZ-cladocerans+copepodids; TOT-total zooplankton biomass; PRT-Partial Retention Time (day)

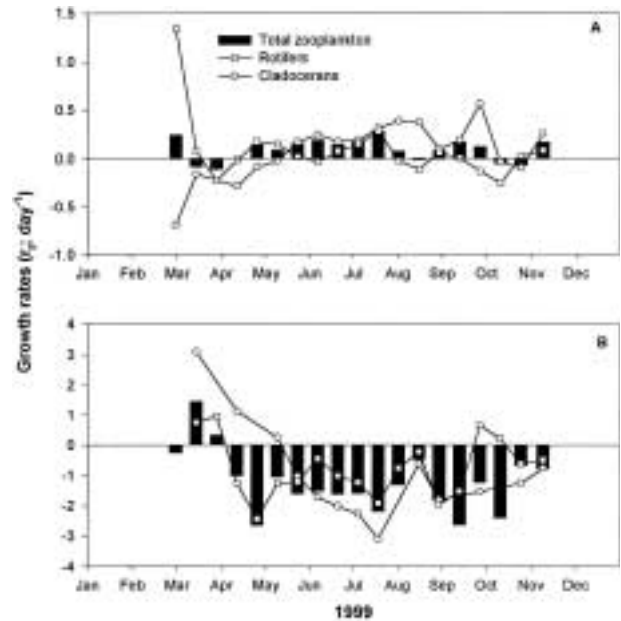


Fig. 5. Seasonal changes in growth rates (r_i , d^{-1}) of total zooplankton, rotifers, and cladocerans in relation to partial retention time between S1 and S2 (A) and S2 and S3 (B).

ues of growth rates were negative in the river stretch (Fig. 5B). In particular, the relationship between PRT and growth rate of cladocerans was found clearly to show an inverse pattern between the lake and river stretch (Fig. 6).

DISCUSSION

Spatial variations in zooplankton species composition and community biomass were distinct in the middle part of River Spree. Total zooplankton biomass increased toward the lake stretch (S2) and decreased in the river stretch (S3). Among the various parameters, partial retention time (PRT) was found to be more significantly correlated with zooplankton development in this river than to Chl. *a*. In particular, the lake stretch may create hydrologic conditions that are particularly favorable for zooplankton development at S2. In the lake, inter-relationship between macrozooplankton biomass and PRT was shown to be positively correlated, while microzooplankton biomass was not (Fig. 6). In contrast, negative relationships between zooplankton biomass (MICZ and MACZ) and PRT were detected in the river stretch. These relationships suggest that changes of zooplankton abundance

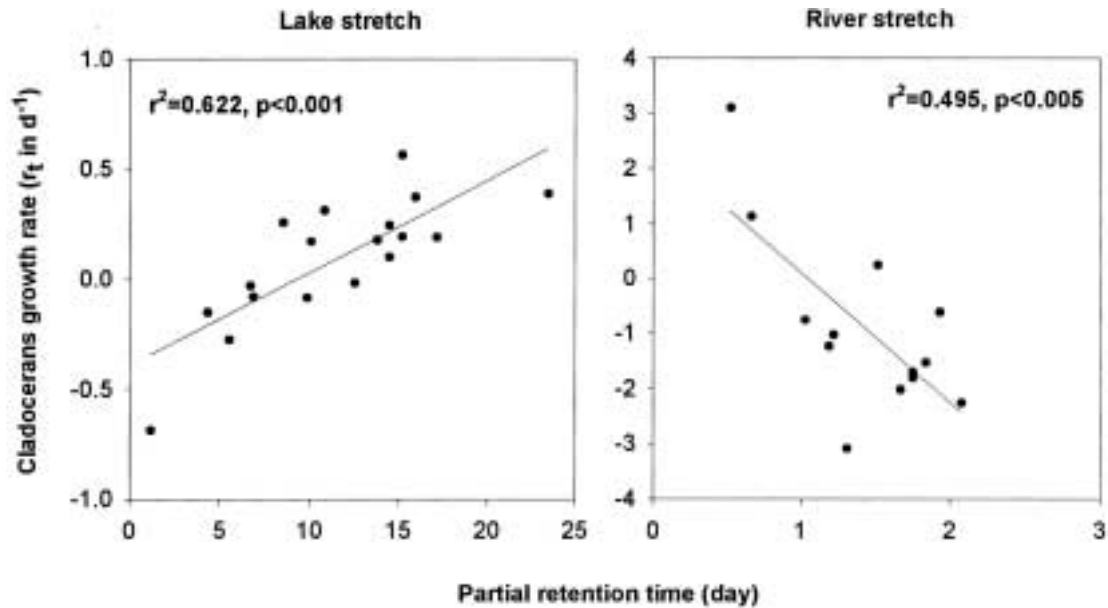


Fig. 6. Pearson correlation between partial retention time and total cladocera growth rates at the lake (S2) and river stretch (S3).

and biomass should be affected by hydrological parameters such as PRT.

The development of the zooplankton should be dependent on the limited time for growth in the lake stretch. For that reason, macrozooplankton is only able to develop at longer retention times in the lake stretch and its biomass could get higher values than of microzooplankton. In contrast, in the river stretch (at S1 and S3, mean PRT less than 3 days) such a 'time-limitation' recedes into the background, favouring the importance of other factors (Walz, 1993). We also consider that such factors affecting zooplankton dynamics in the river stretch of the River Spree is the benthic grazing by unionid and zebra mussels (*Dreissena polymorpha*). In the middle part of the River Spree, benthic filter feeders, especially *Dreissena polymorpha*, usually are highly present between S2 and S3 (mean density at S2: more than 4,000 ind. m^{-2} , personal benthic observations) and apparently they could have influenced zooplankton densities (Welker and Walz, 1998). We also found that zebra mussels at S2 highly grazed on *Keratella*, ciliates, and small size phytoplankton (less than 10 μm diameter) using laboratory grazing experiments, which were conducted on 3 occasions during late spring of 2000 (Kim and Walz, unpublished data).

The present study suggests again the impor-

tance of hydraulic conditions for zooplankton dynamics in eutrophic rivers. In the absence of nutrient limitation, discharge has a profound influence on plankton dynamics. At most of all sampling dates the growth rates of total zooplankton were positive in the lake zone. But, negative growth rates were maintained for all major zooplankton communities in the river reach. Although there were not much data available, the changes of growth rates for microzooplankton and macrozooplankton in the river systems were reported and a schematic illustration for the changes of the population dynamics in rotifers was established (Welker and Walz, 1998). In this study the mean growth rates of rotifers in the lake and river reach was ca. 0.2 d^{-1} and $-1.5 d^{-1}$, respectively ($n = 5$) (Welker and Walz, 1998), which showed a similar pattern compared to our results (0.08 d^{-1} and $-1.37 d^{-1}$, respectively, $n = 19$). We also observed that growth rates of macrozooplankton followed the same patterns of rotifer's growth rates.

ABSTRACT

Factors most strongly related to zooplankton growth rates were studied along a lake and a river stretch in the middle part of the lowland River Spree. The study was conducted at the

lake inflow (S1), the lake outflow (S2), and at the end of a 21 km stretch of the outflow (S3) from March to November of 1999. Total zooplankton biomass increased significantly at S2 and then sharply decreased at S3. The abundance of microzooplankton (rotifers and nauplii) was strongly higher than macrozooplankton (cladocerans and copepodids) at all stations. However, macrozooplankton biomass ($\mu\text{g dw l}^{-1}$) was similar or much higher than microzooplankton biomass. Large-bodied cladocerans (*Daphnia cucullata*) dominated at S2 while small-bodied cladocerans (*Bosmina longirostris*) dominated at S1 and S3. Patterns in growth rates (r_t in d^{-1}) of the major zooplankton community were greatly different between S1 and S2 (lake stretch) and between S2 and S3 (river stretch). In the lake, growth rates generally were positive, while values of growth rates were negative in the river stretch. Among the environmental variables considered, partial retention time (PRT, d^{-1}) seemed to play the most important role in determining characteristics of the zooplankton community structure in the middle part of River Spree.

ACKNOWLEDGMENTS

This study was supported by Korean Science and Engineering Foundation (grant for Post-doc. 1999 Program to Dr. H.W.K.). We thank the Chemistry Laboratory of the IGB for nutrient analyses, and Bernd Schütze for help on sampling excursions. The Landesumweltamt Brandenburg-Wasserwirtschaftsamt Cottbus kindly made the hydrological data of the Spree available.

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