Article

Development of crustacean plankton in a shallow, polyhumic reservoir in the first 20 years after impoundment (northeast Poland)

Andrzej Górniak[1]* and Maciej Karpowicz

Department of Hydrobiology, Institute of Biology, University of Białystok, Białystok, Poland

** Corresponding author: hydra@uwb.edu.pl*

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Abstract

Multiannual changes of structure and biomass of crustacean zooplankton were studied in the shallow, lowland, polyhumic Siemianówka Reservoir on the upper Narew River in northeast Poland. High ammonium and soluble reactive phosphorus ion availability for phytoplankton, low water transparency, and high dissolved oxygen concentration resulted in humoeutrophication and caused an intensive development of summer cyanobacteria. We compiled and analyzed long-term (1993–2011) crustacean zooplankton community data and chlorophyll *a* concentrations. Zooplankton biomass and structure in the summer were related to the intensity of the cyanoprokaryota blooms. As chlorophyll *a* concentration increased, crustacean zooplankton biomass decreased and smaller crustacean species dominated the zooplankton structure. Large species of crustaceans (*Daphnia longispina*, *D. magna*, and *Eudiaptomus graciloides*) disappeared from the reservoir after filamentous cyanobacteria dominated the phytoplankton. Long-term studies suggest that phytoplankton with strong dominance of filamentous cyanobacteria shape the crustacean community but are probably an insignificant food source for the crustacean zooplankton in the Siemianówka Reservoir.

Key words: crustacean zooplankton, cyanobacteria, long-term, lowland reservoir

Introduction

Since the construction of the Siemianówka Reservoir in northeast Poland in 1990, phytoplankton has been permanently dominated by potentially toxic cyanobacteria. Ten years after the reservoir was created, restoration activities through biomanipulation were implemented to remove large amounts of planktivorous and benthivorous fish and increase stocking of piscivores. Despite ongoing conservation activities, the phytoplankton continues to be strongly dominated by filamentous cyanobacteria (Grabowska 2005), which are poor-quality food for zooplankton and can affect cladoceran life history (Lampert 1978, Vanni and Lampert 1992). Cyanobacterial filaments are difficult to digest, which causes Daphniidae to decrease their feeding activity (Porter and McDonough 1984, Gliwicz and Boavida 1996), retard their somatic growth, and produce fewer eggs (Lampert 1988, Gliwicz 1990). As a consequence, large zooplankton may starve during cyanobacterial bloom, and other food sources such as bacteria, flagellates, and small ciliates may become important.

Small zooplankton species are better competitors for filamentous cyanobacterial resources (DeMott and Kerfoot 1982). Large filamentous species such as *Anabaena* sp. and *Planktothrix* sp. are not suitable food for crustacean zooplankton due to morphology (Burns 1968). Although short filaments may be a reasonable source of nutrition, long filaments may inhibit zooplankton feeding. Laboratory experiments revealed that body growth of large *Daphnia* species (*Daphnia magna* and *D. longispina*) ceased at a relatively lower concentration of filaments than in smaller *D. cucullata* (Gliwicz 1990). Cladoceran zooplankton growing in high filament densities fail to control algal blooms (Dawidowicz et al. 1988, Chen and Xie 2003).

This study presents long-term crustacean zooplankton dynamics in a shallow polyhumic reservoir with strong dominance of filamentous cyanobacteria, a situation that

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is rare in the field but well-studied in laboratory experiments. We also assessed the effect of biomanipulation of mass removal of cyprinids on crustacean communities. Long-term observation of zooplankton structure elucidates the function and behavior of this ecosystem. Zooplankton represent an important trophic level and deciding factor for the flow of matter and energy; their biomass can vary widely both seasonally and year to year due to alterations in food sources, predator–prey interaction, and environmental conditions (Sommer et al. 1986). Understanding the relationships among zooplankton assemblages, cyanoprokaryota blooms, and reduced fish stocks is important for the development of ecological tools used in management techniques and environmental restoration of shallow eutrophic reservoirs (Ghidini et al. 2009).

Study site

The Siemianówka Reservoir (SR; 52°55′N, 23°50′E) was constructed in 1990 on the upper Narew River. SR lies in a peaty forest catchment in northeastern Poland near the state border with Belorussia. The basin is free of any great sources of pollution, but the waters feeding the impoundment are rich in mineral and organic products of soil organic matter decomposition. The morphometric parameters of the reservoir (maximum area 32.5 km^2, maximum capacity 79.5 km^3, mean depth 2.5 m) reflect its lowland character. The highest water inflow and water levels were observed in spring. The mean water residence time is ~4–6 months. Water quality in SR varied according to different seasons but always indicated a eutrophic to hypertrophic level (Górniak and Jekatierynczuk-Rudczyk 1998).

Development of cyanobacterial blooms has been a regular phenomenon in the SR from its first years of existence. Phytoplankton has been permanently dominated by the potentially toxic cyanobacteria *Planktothrix*, *Aphanizomenon*, *Dolichospermum*, and *Microcystis* (Grabowska 2005, Wołowski and Grabowska 2007). From 1996, phytoplankton blooms have been more intense and frequently consist of filamentous algae. The dominance of cyanobacteria in phytoplankton was observed from the beginning of May to the end of October with a maximum mainly in August. Since 2005, phytoplankton has been strongly dominated by the filamentous cyanobacteria *Planktotrix agardhii* and by genus *Anabeana* (Grabowska and Pawlik-Skowrońska 2008, Grabowska and Mazur-Marzec 2011).

Ten years after SR was created, restoration activities through biomanipulation began. Total fish biomass was reduced by 50% and water area was reduced. Restoration did not involve any chemical or physical manipulations. One of the most important restoration consequences was the reduction in soluble reactive phosphorus and inorganic nitrate concentration (Górniak et al. 2006a). This man-made lake has been studied intensively for 20 years, offering extensive datasets on hydrology, chemistry, hydrophysical parameters, phytoplankton, and zooplankton. Water quality and phytoplankton were described earlier (Górniak and Grabowska 1996, Górniak et al. 2002, 2006a, Grabowska 2005).

Material and methods

Crustacean samples were collected monthly from the deepest station near the dam (Fig. 1) in quadruplicate from depths of 0, 2, 4, and 6 m. These samples were pooled, filtered through a 40 μm plankton net, fixed with 4% formalin, and analyzed under a microscope after sedimentation. For each zooplankton sample, we counted a minimum 200 individuals and made 10 length measurements for each species. Mean values of the animal length were used to estimate the dry weight of planktonic crustaceans by applying the equations after Balushkina and Winberg (1979).

Long-term and seasonal changes in the crustacean zooplankton were tested with ANOVA ($p < 0.05$). To visualize seasonal patterns for the individual species or taxa, we used box-and-whisker plots depicting the average, median, and interquartile range for each month aggregated. Crustacean zooplankton to 2004 was described in details earlier (Górniak and Chocian 1999, Smakulska and Górniak 2004). Chlorophyll *a* concentration was determined using the spectrophotometric method. Samples were filtered on GF/C filters and extracted with boiling 90% ethanol (Lorenzen 1967).

Results

Quantitative and qualitative changes of summer crustacean zooplankton in the first 20 years of the Siemianówka Reservoir

We recorded 51 Crustacea species, including 33 species of Cladocera, 17 species of Cyclopoida, and 1 Calanoida. Most of these species were single records or accidental species, and only a few were common, including *Daphnia cucullata*, *Diaphanosoma brachyurum*, *Bosmina longirostris*, *Bosmina coregoni*, *Chydorus sphaericus*, and *Mesocyclops leuckarti* (Fig. 2). In the first years after reservoir impoundment (1993–1996), summer crustacean zooplankton was characterized by high biomass (Fig. 3), and the community structure was dominated by large herbivorous species from the family Daphniidae, with a low proportion of small cladocerans from families Chydoridae and Bosminidae (Fig. 2). The genus *Daphnia*

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was dominated by *D. cucullata*, but *D. longispina* and *D. magna* were also noted. The main copepod species were *Mesocyclops leuckarti* and *Eudiaptomus graciloides*.

The long-term dataset of the crustacean plankton in the SR revealed 2 noteworthy changes, both with respect to the mean abundances and to the relative contribution of the main taxa or species. First, after 1996 the crustacean biomass decreased significantly (Fig. 3), and in subsequent years cyanobacterial blooms became more intense. Zooplankton community structure also started to change, resulting in a decreased proportion of large species from genus *Daphnia* and a gradual increase of small species from families Chydoridae and Bosminidae (Fig. 2). After the phytoplankton became dominated by cyanobacteria, 3 large species, *Daphnia longispina*, *D. magna*, and *Eudiaptomus graciloides* disappeared from the SR. Long-term analysis revealed a significant reduction of *D. cucullata* body length in subsequent years.

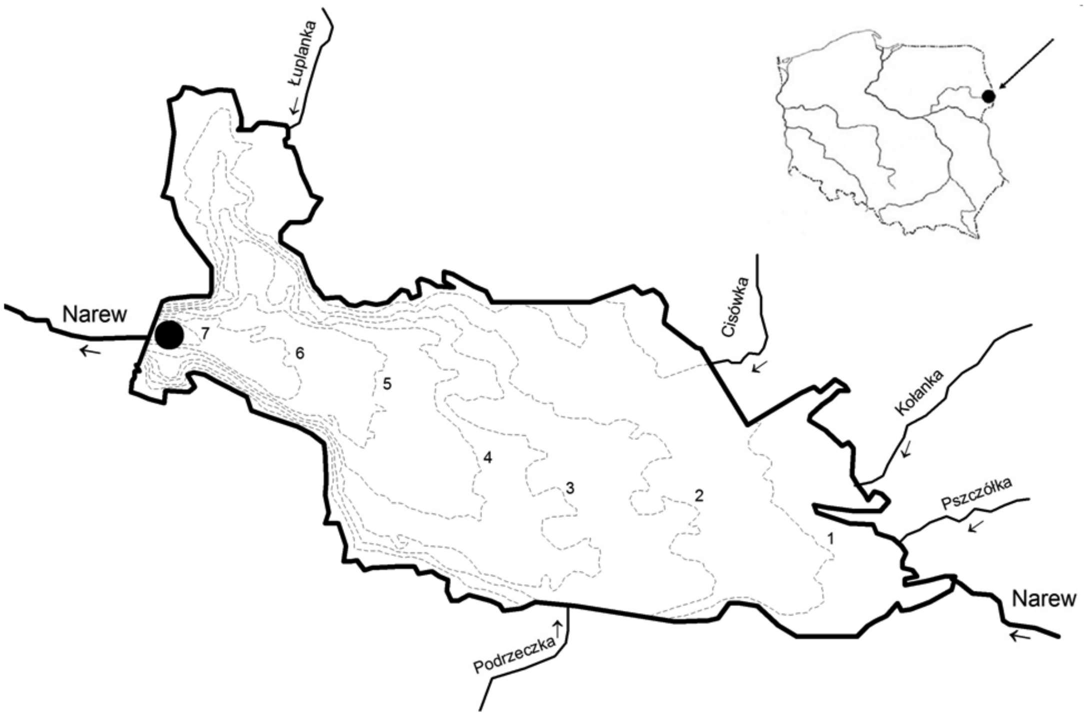

Fig. 1. Siemianówka Reservoir (SR) bathymetry and location of the sampling station.

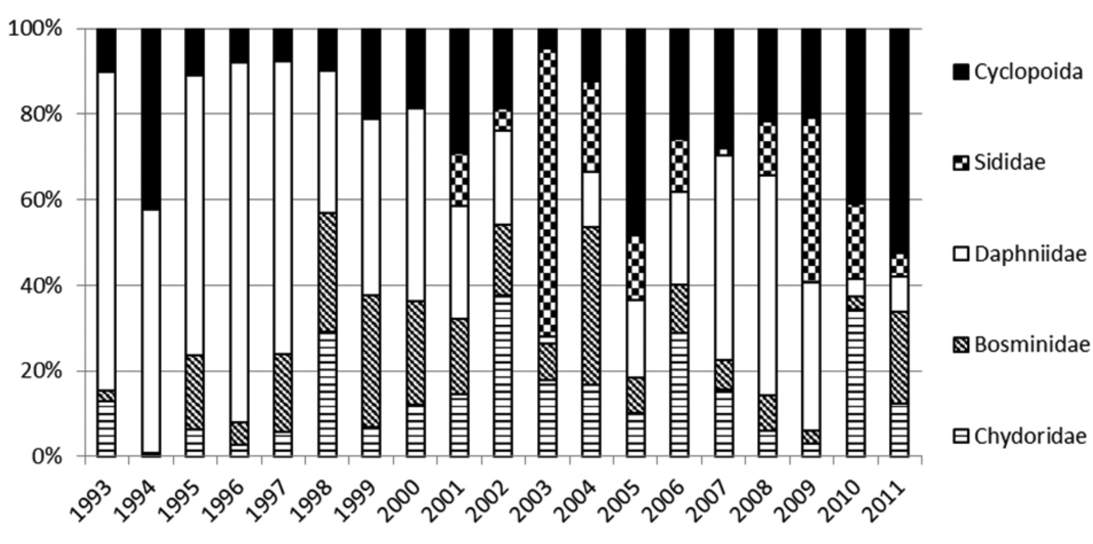

Fig. 2. Long-term summer contribution of dominant crustacean zooplankton taxa in the Siemianówka Reservoir.

The second remarkable change took place during restoration process when biomass of crustacean dropped significantly (Fig. 3). After the restoration process, *Diaphanosoma brachyurum* appeared in the reservoir (Fig. 2), and total biomass of crustacean zooplankton systematically increased (Fig. 3) with a larger proportion of Cyclopoida and Daphniidae (Fig. 2).

Long-term quantitative and qualitative changes of crustacean zooplankton in the SR were strongly related with cyanoprokaryota development. Zooplankton biomass was negatively correlated with the concentration of chlorophyll *a* (Fig. 4). High concentration of chlorophyll *a* coincided with the replacement of large cladocerans by the smaller species (Fig. 5A and B).

Seasonal dynamics of crustacean zooplankton

Winter zooplankton in SR were less numerous, consisting of juvenile forms of Cyclopoida and single individuals of small Cladocera like *Chydorus sphaericus* and *Bosmina longirostris*. The crustacean zooplankton biomass increased from April, mainly due to the development of Cyclopoida (Fig. 6). During second part of May, intense growth of *Bosmina longirostris* (i.e., up to 62.32 mg L^{-1} biomass and 4153 ind. L^{-1} density) was often observed (Fig. 6). The population of *B. longirostris* then dramatically declined at the end of June and was replaced by *Bosmina coregoni* from July to September.

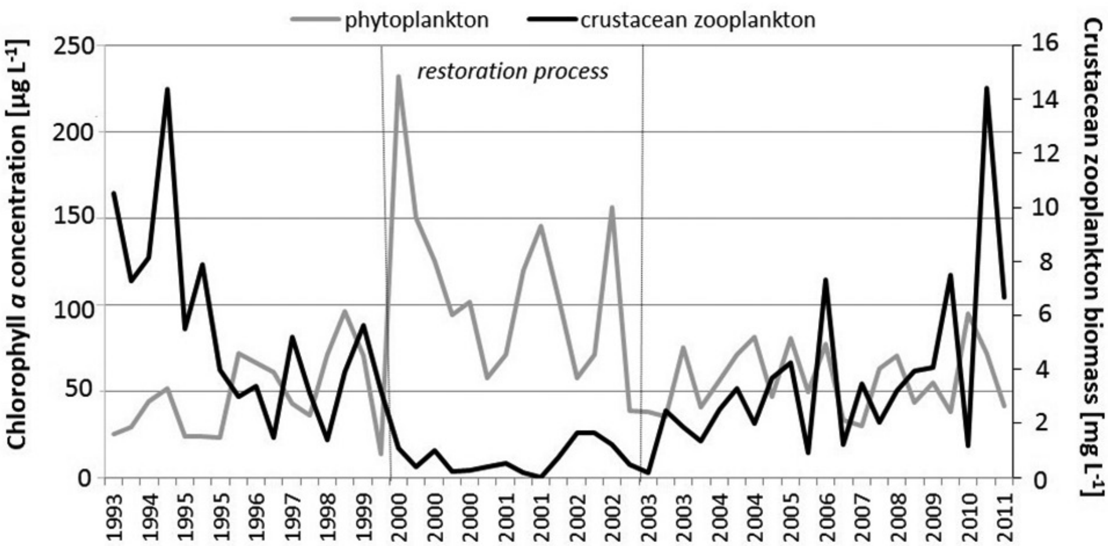

Fig. 3. Long-term summer (Jul–Aug) crustacean zooplankton biomass (mg L^{-1}) and chlorophyll *a* concentration (µg L^{-1}) in the Siemianówka Reservoir.

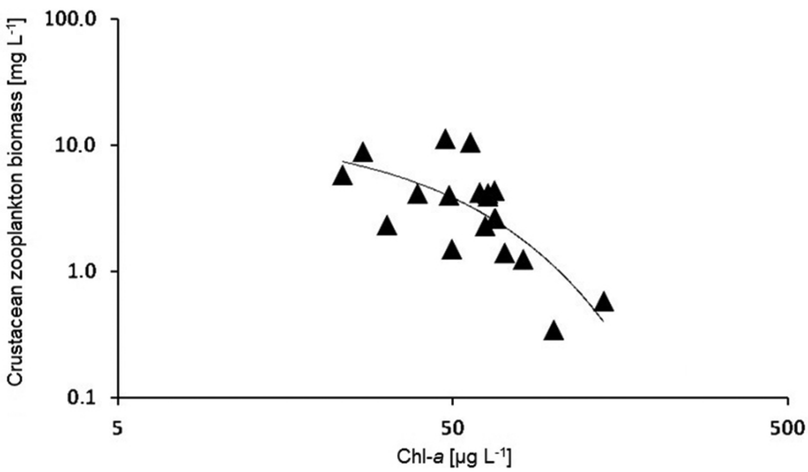

Fig. 4. Relationship between summer chlorophyll *a* (Chl-*a*) concentration and total biomass of crustacean zooplankton in the Siemianówka Reservoir. $y = 13.3\ e^{-0.025x}$, $r^2 = 0.53$, $p < 0.01$.

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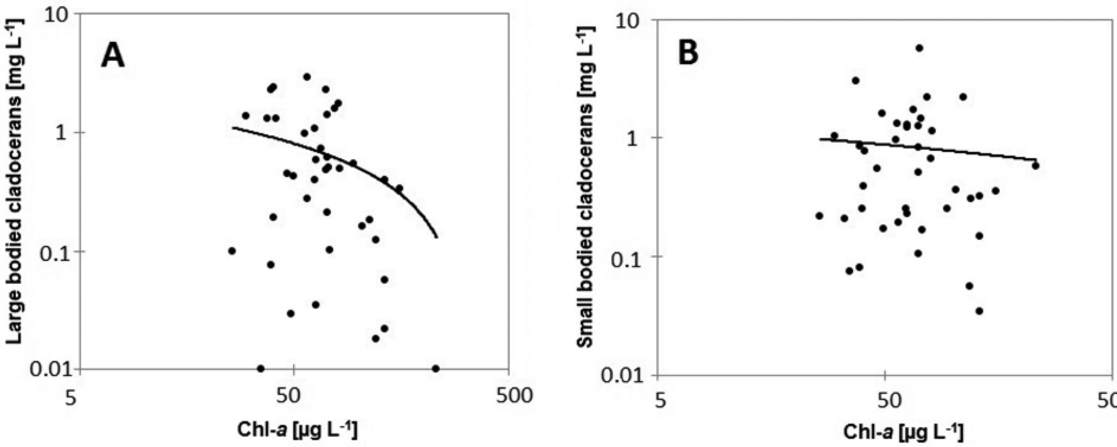

Fig. 5. Regression between summer chlorophyll *a* (Chl-*a*) concentration (µg L^{-1}) and crustacean zooplankton biomass (mg L^{-1}) in the Siemianówka Reservoir (2003–2011). (A) large-bodied cladocerans ($y = 1.043e^{-0.016x}$, $r^2 = 0.172$, $p < 0.01$) and (B) small-bodied cladocerans ($y = 0.629e^{-0.040x}$, $r^2 = 0.018$, $p < 0.01$).

During summer, biomass of larger cladocerans increased from families Daphniidae and Sididae (Fig. 6); however, summer crustacean zooplankton biomass was negatively correlated ($r^2 = 0.53$, $p < 0.05$) with the intensity of the cyanoprokaryota blooms expressed by chlorophyll *a* concentration (Fig. 4) due to limited development of large bodied cladocerans (*Daphnia cucullata* and *Diaphanosoma brachyurum*) at high densities of filamentous cyanoprokaryota (Fig. 5A). Small zooplankton species are more competitive feeding at high concentrations of cyanobacteria (Fig. 5B); larger cladocerans do not feed selectively, and longer algal filaments clog their filtering apparatuses. High concentration of chlorophyll *a* also resulted in a significant reduction of *D. cucullata* body size (Smakulska and Górniak 2004).

In autumn a marked decrease in total zooplankton biomass was observed (Fig. 6), and *D. brachyurum* disappeared from the reservoir (Fig. 6). A notable shift was observed in the dominance of family Bosminidae from *Bosmina coregoni* to *Bosmina longirostris*.

Discussion

Fish predation accompanied by dominance of cyanobacteria in phytoplankton were the main forces shaping zooplankton communities in the SR. Large-bodied herbivorous zooplankton developed in the first years of the reservoir, followed by a rapid decrease in zooplankton biomass due to dense fish stocks, resulting in an increased growth of algae dominated by cyanobacteria. The initial natural fish community in the SR was disturbed by stocking with carp (Górniak and Jekaterynczuk-Rudczyk 1998). The fish structure was strongly dominated by Cyprinidae (*Cyprinus carpio*, *Carassius gibelio*, *Rutilus rutilus*, and *Abramis brama*), and the fish biomass was about 928 kg ha^{-1} in 1994 and 628 kg ha^{-1} in 1995 (Wiśniewolski 2002).

Size-selective predation by Cyprinidae was a major factor in the structuring of zooplankton populations, resulting in the domination of small-sized zooplankton. Large-sized cladocerans tend to disappear in reservoirs with dense fish stocks (Seda and Kubecka 1997, Tallberg et al. 1999, Seda et al. 2000, Smakulska and Górniak 2004). The removal of fish in 2000–2003 released zooplankton from the pressure and slowly increased the proportion of larger cladocerans (*Diaphanosoma brachyurum* and *Daphnia cucullata*) and Cyclopoida, despite the dominance of cyanobacteria in phytoplankton.

The high density of filamentous cyanobacteria in SR affected crustacean communities. Large-bodied cladocerans were replaced by smaller cladocerans and copepods, as occurs in other eutrophic lakes of the temperate zone (Gliwicz 1969, Karabin 1985, Andronikova 1996). High density of cyanobacteria is mainly why the *Eudiaptomus graciloides* population did not rebuild, despite its constant presence in the tributaries of SR (Karpowicz and Górniak, unpubl.). This species has numerous chemoreceptors on its antennae and mouth parts used for food selection, and they are sensitive to the toxins produced by cyanobacteria (DeMott 1986).

Summer biomass of zooplankton was negatively correlated with the density of the cyanoprokaryota blooms in SR. High concentration of chlorophyll *a* was the limiting factor for development of large-bodied cladocerans. Larger cladocerans experience difficulty feeding in the presence of cyanobacteria because they do not feed selectively, and longer algae filaments clog their filtering apparatuses

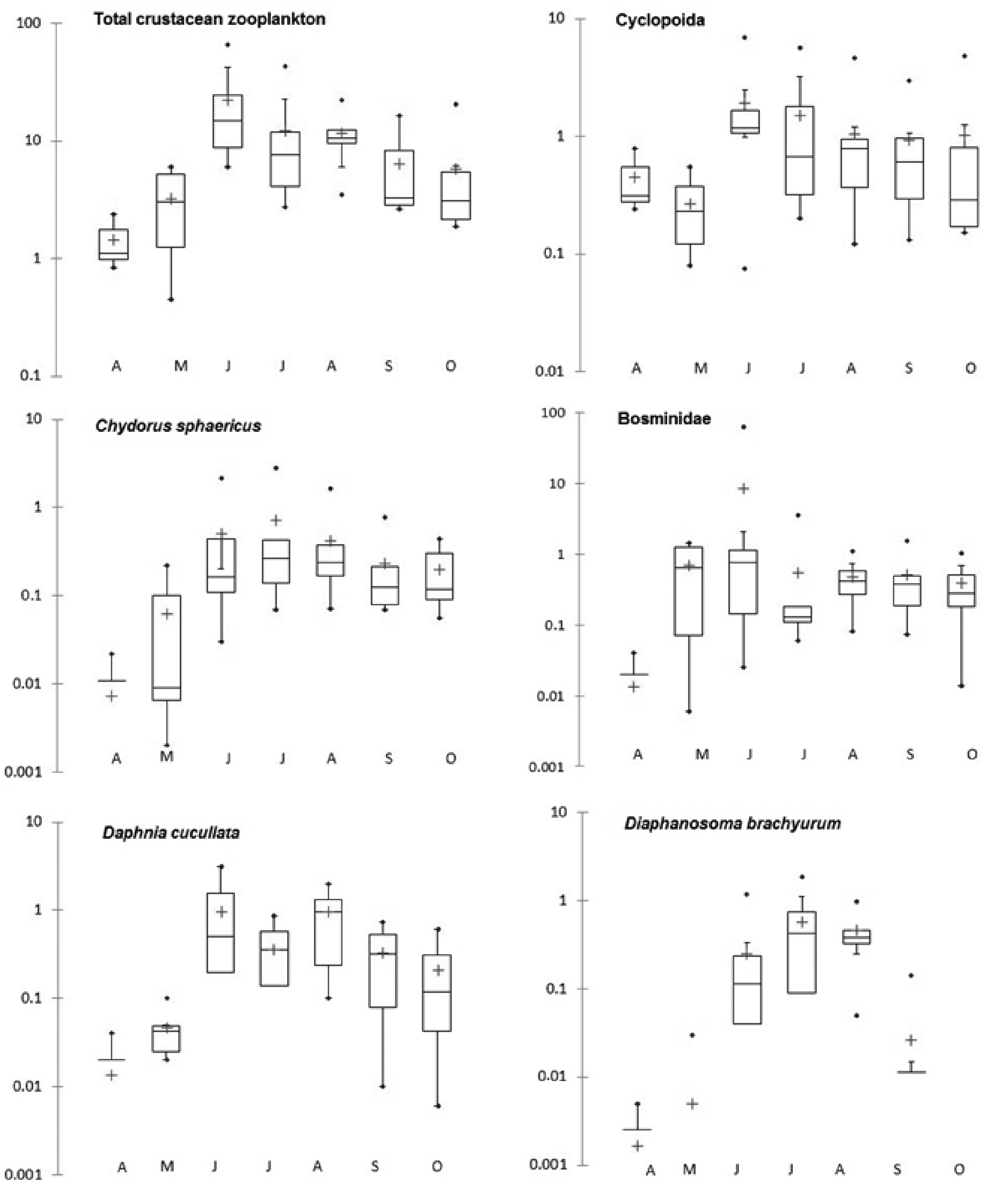

Fig. 6. Average monthly (Apr–Oct) variations in zooplankton biomass from 2003 to 2011 as box plots: means (crosses), median (horizontal line in middle of box), minimum and maximum (dots), interquartile range (box), and range (whiskers) for total crustacean zooplankton biomass (mg L^{-1}) and the dominant taxa or species biomass (mg L^{-1}).

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(Henning et al. 1991, Mayer et al. 1997, Cyr 1998, Donabaum et al. 1999). This hypothesis was confirmed in laboratory experiments in which an inverse regression relationship was observed; growth of larger *Daphnia* species was halted at relatively lower filament concentration than in smaller *D. cucullata* (Gliwicz 1990). The decreasing tendency of the mean body length and width of carapace of *Daphnia cucullata* was observed in SR before restoration. Factors such as food availability, fish predation, and exclusive presence of *D. cucullata* among Daphniidae were responsible for the changes in body size of zooplankton (Smakulska and Górniak 2004).

We observed similar morphological tendencies at seasonal and horizontal scales but with different densities of filamentous algae. Reduction in zooplankton body size cannot be explained by the fish predation pressure because total biomass of planktivorous fish decreased after the restoration process compared with previous years (Górniak et al. 2006b). The reduced carapace width of *Daphnia cucullata* suggests that feeding behaviors are inefficient and energetically costly because colonies and filaments that clog the filtering appendages are rejected with the postabdominal claw.

Long-term studies suggest that dominance of filamentous cyanobacteria in phytoplankton shapes the crustacean community but probably plays an insignificant role as a food source for the crustacean zooplankton in the SR.

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