ISSN 1995-4255, Contemporary Problems of Ecology, 2017, Vol. 10, No. 6, pp. 632–639. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © V.P. Semenchenko, M.D. Moroz, E.A. Sysova, T.P. Lipinskaya, 2017, published in Sibirskii Ekologicheskii Zhurnal, 2017, No. 6, pp. 708–716.

Effects of Common Carp (*Cyprinus carpio*) and Bream (*Abramis brama*) on the Structure of the Littoral Community in a Mesotrophic Lake (Mesocosm Experiments)

V. P. Semenchenko*, M. D. Moroz, E. A. Sysova, and T. P. Lipinskaya
Scientific and Practical Center for Bioresources, National Academy of Sciences, Minsk, 220072 Belarus
**e-mail: semenchenko57@mail.ru*

Received December 6, 2016; in final form, March 28, 2017

Abstract—The effect of common carp and bream on hydrochemical parameters, abundance, and structure of phyto-, zooplankton, and macrozoobenthos has been studied in semienclosed mesocosms installed in the littoral zone of a mesotrophic lake. Significant differences in the biomass of different algal groups in mesocosms with fish in respect to the control were established only for diatoms and were not found for other phytoplankton groups. Common carp had a greater effect on the abundance of large zooplankton species (*Diaphanosoma brachyurum*) compared to bream. The abundance of the small *Bosmina longirostris* increased in mesocosms both with bream and common carp. The macrozoobenthos biomass reduced at higher rates in mesocosms with common carp than in those with bream, with the strongest effect of common carp on mayfly larvae. The differences between the consumption of chironomid and oligochaete larvae were not established in mesocosms with common carp. Bream mainly affected the larvae of mayflies and oligochaetes and, to a lesser degree, the chironomid larvae.

Keywords: common carp, bream, phytoplankton, zooplankton, macrozoobenthos

DOI: 10.1134/S1995425517060117

The common carp *Cyprinus carpio* Linnaeus, 1759 is the most invasive species in waterbodies of Europe and United States. The introduction of the species may cause drastic changes in the ecosystem, especially in shallow lakes (Weber and Brown, 2009). The introduction of common carp may be one of the main reasons for biodiversity loss in waterbodies (Zambrano et al., 2001).

Common carp may have direct or indirect impacts on the ecosystems. The direct effect is associated with its strong impact on zoobenthos and macrophytes; the indirect effect is associated with its burrowing activity, which causes sediment resuspension, thus decreasing water transparency and releasing nutrients (Breukelaar et al., 1994, Matsuzaki et al., 2007).

Despite numerous studies on the effect of common carp on lake communities (Tapia and Zambrano, 2003; Koehn, 2004; Lougheed et al., 2004; Vilizzi et al., 2015; etc.), the problem of the comparative analysis of the impact of common carp and aboriginal fish species on lake ecosystems have been poorly studied.

MATERIALS AND METHODS

The studies were conducted in July (July 2–25, 2014) in the mesotrophic shallow Lake Obsterno (Republic of Belarus, 55°37′26.55″ N, 27°21′30.18″ W) (area 9.89 km^2, average depth 5.3 m, and transparency 5.0 during the experiment). Bream is a common species in the lake and is recorded in catches; common carp is absent (Shevtsova et al., 1986).

Mesocosms were installed at a depth of 1.5 m in the lake littoral at a distance of 60 m from the shore. Mesocosms were parts of the clean littoral enclosed with a net with a 5-mm mesh size. The area of enclosures was 9 m^2. Such a semienclosed type of mesocosms demonstrates, to a greater degree, the impact of fish on different communities when compared to completely enclosed mesocosms, as they do not accumulate a considerable amount of substances excreted by fish. It should be noted that phytoperiphyton fouling development on nets delayed water exchange in the mesocosms.

A total of three variants of mesocosms were installed: three control, three with common carp (*Cyprinus carpio* Linnaeus, 1759), and three mesocosms with bream (*Abramis brama* Linnaeus, 1758) (Fig. 1).

Age of common carp 2+, body length 30–32 cm; age of bream 7+, body-length range from 27 to 30 cm. The number of fish was five specimens in a mesocosm; the total weight was about 4.5 kg in a mesocosm. Other fish species were absent in the mesocosms.

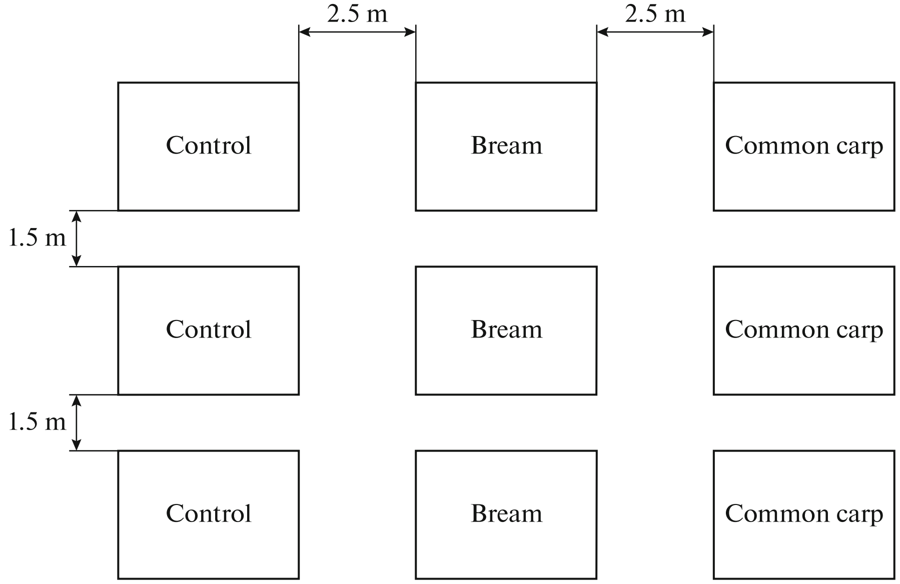

Fig. 1. Scheme of location of experimental mesocosms in the lake.

After the installation of the mesocosms, samples were collected in a random way once every 4–5 days in each mesocosm for 20 days, and the following parameters were determined:

(i) concentration of dissolved phosphorus, nitrate, and nitrite ammonium after water filtration through a 1.0-μm filter using a HANNA 8300 multiphotometer (HANNA Instruments, Germany). The concentrations were not determined at the moment of mesocosm installation in view of a possible error due to water being stirred up.

(ii) samples for phytoplankton counts were collected with a Ruthner bathometer. The numbers of algal cells were counted in a Fuchs–Rosenthal chamber under a Micros MC300 microscope at 360 × 1000 magnification. The biomass of algae was determined by the volume method (Sun and Lui, 2003).

(iii) abundance of zooplankton was determined when dragging the net (mesh size 40 μm) from the bottom to the surface in two replicates.

(iv) macrozoobenthos was taken with a Petersen dredge in two replicates. Macrozoobenthos samples were washed onto a sieve (0.5 mm mesh size) and the abundance and biomass of particular groups of organisms (wet weight, including mollusks) were determined by weighing on a WT-50 torsion balance with an accuracy of 0.1 mg.

During the experiment, water temperature in mesocosms ranged from 20 to 24°C, 260–280 μS, pH 8.3–8.5.

Phytoplankton and zooplankton were fixed in 2% formaldehyde; macrozoobenthos was fixed in 70% alcohol. The results are presented as mean values for each variant of experiments.

The data were analyzed for normal distribution with the Shapiro–Wilk test (Real Statistics Resource Pack, using Excel) and for equality of variance with Levene's test. Two-way ANOVA (RStudio) was used to evaluate the significance of the effect of common carp and bream on the studied parameters compared to control mesocosms.

RESULTS

A large number of floating aquatic plants (*Elodea canadensis*) on the surface were observed in the mesocosms with common carp 3 days after the beginning of the experiment, which indicates the intensive burrow-

Table 1. Concentrations of dissolved mineral phosphorus, nitrate, and ammonium nitrogen in the experiment

Date		Control	Common carp	Bream
July 7	PO_4	0.84 ± 0.20	0.78 ± 0.22	0.64 ± 0.01
July 14		0.98 ± 0.87	0.82 ± 0.14	0.92 ± 0.63
July 19		1.59 ± 1.16	1.25 ± 0.51	1.46 ± 0.32
July 25		1.79 ± 0.83	1.93 ± 0.47	1.96 ± 0.35
July 7	NO_3	0.07 ± 0.12	0.10 ± 0.13	0.12 ± 0.0
July 14		0.10 ± 0.10	0.09 ± 0.12	0.07 ± 0.06
July 19		1.43 ± 0.57	0.84 ± 0.23	0.61 ± 0.0
July 25		0.03 ± 0.06	0.04 ± 0.06	0.03 ± 0.06
July 7	NH_4	0.30 ± 0.04	0.27 ± 0.06	0.28 ± 0.05
July 14		0.49 ± 0.18	0.42 ± 0.11	1.10 ± 0.04
July 19		0.23 ± 0.13	0.22 ± 0.01	0.21 ± 0.03
July 25		0.22 ± 0.03	0.22 ± 0.09	0.20 ± 0.0

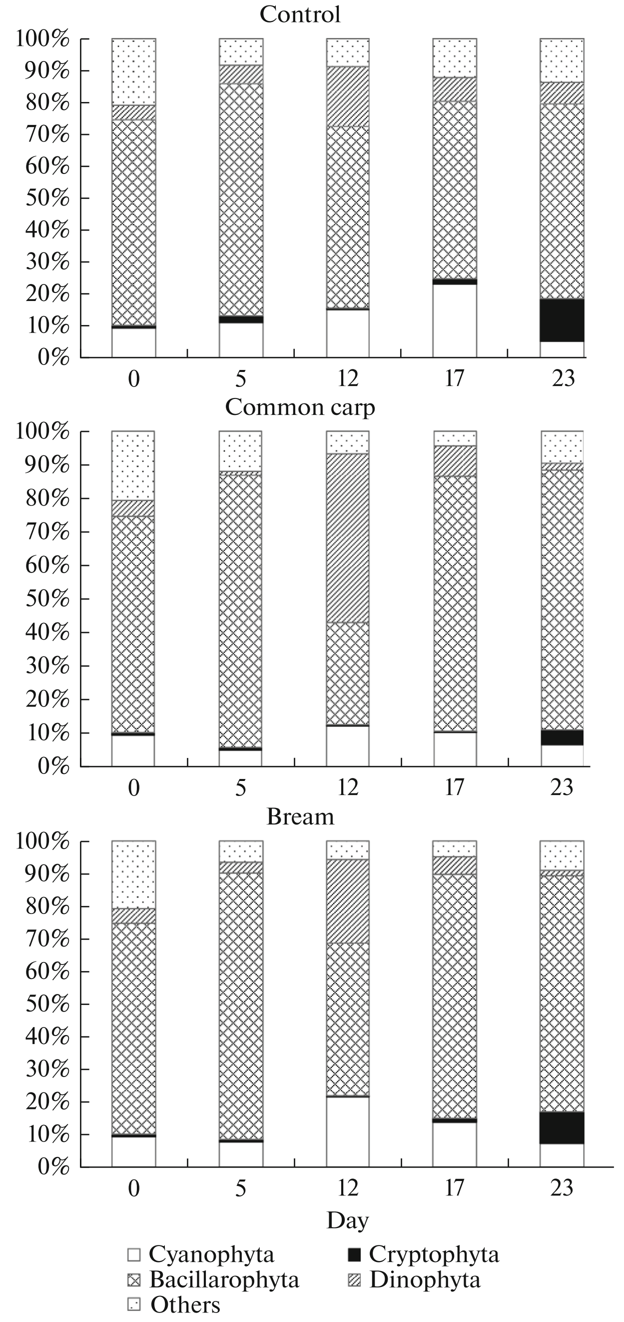

Fig. 2. Change in the ratio of different algae divisions in the course of the experiment. Others, Chrysophyta, and Euglenophyta.

Table 2. Results of an analysis of variance (ANOVA) of the effect of common carp and bream on the abundance of *D. brachyurum* and *B. longirostris* in mesocosms

	df	Sum sq	Mean sq	*F* value	*P* value
		Carp			
Diaphanosoma	7	67.48	9.640	4.23	0.00804
Bosmina	7	31. 99	4.57	6.572	0.00091
		Bream			
Diaphanosoma	7	43.28	6.183	2.37	0.0722
Bosmina	7	23.88	3.411	2.167	0.0948

ing activity of carp. No such phenomenon was observed in mesocosms with bream or in the control.

Hydrochemical parameters. Changes in the concentration of dissolved mineral phosphorus during the experiment and its dynamics were similar in experimental mesocosms both with common carp and bream and enhanced by the end of the experiment (Table 1). Rather high concentrations of dissolved phosphorus were probably due to its resuspension from bottom sediments as a result of water mass mixing in the littoral of the lake. The concentration of nitrate nitrogen increased in all mesocosms by the middle of the experiment. In other periods its values did not exceed 0.1 mg/L (Table 1). The concentration of ammonium nitrogen changed in a similar pattern (Table 1).

An analysis of variance did not demonstrate a significant effect of common carp and bream on the nutrient concentration in respect to the control.

Phytoplankton. The structure of the phytoplankton community varied in the course of the experiment (Fig. 2).

In control mesocosms the relative abundance of diatoms, mainly of the genus *Cyclotella,* decreased, and the specific role of cryptophyte algae (*Rhodomonas pusilla*) increased slightly by the end of the experiment. The pattern was different in mesocosms with fish. The relative abundance of blue-green algae increased in mesocosms with bream in the middle of the experiment, whereas the relative abundance of dinoflagellates, mainly due to the genus *Glenodinium*, increased in mesocosms with common carp.

The total abundance of phytoplankton tended to decrease in all mesocosms (Fig. 3).

The statistical analysis demonstrated a weak correlation between the abundance of phytoplankton and the concentration of ammonium nitrogen ($r = 0.46$, $P = 0.1$) only for mesocosms with bream. There was no such correlation for other nutrients.

The biomass of algae varied in the following pattern. The phytoplankton biomass decreased in all mesocosms at the beginning of the experiment (Fig. 4).

But by the end of the experiment, the biomass of phytoplankton increased slightly in repect to the control. This may be due to the increased concentration of ammonium nitrogen, especially in mesocosms with bream, where the maximum increase in the phytoplankton biomas was recorded.

An analysis of variance of the effect of common carp and bream on the biomass of some phytoplankton groups (Bacillariophyta, Cyanophyta, and Chlorophyta) showed a significant variation in the biomass of diatom algae in respect to the control only in mesocosms with fish (common carp, $F = 8.45$, $P < 0.001$; bream, $F = 4.28$, $P < 0.001$).

Zooplankton. The total abundance of crustacean zooplankton (Cladocera + Copepoda (adults and

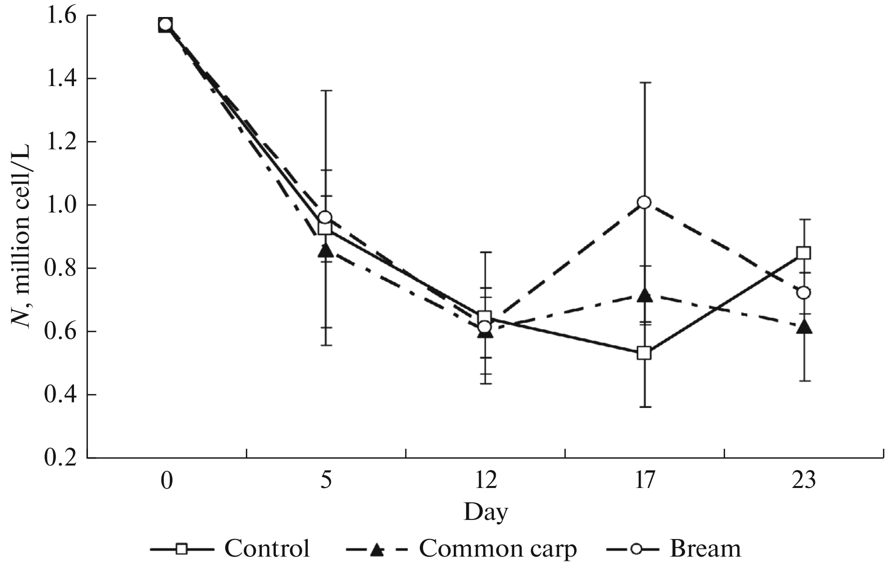

Fig. 3. Change in the abundance of phytoplankton in mesocosms during the experiment.

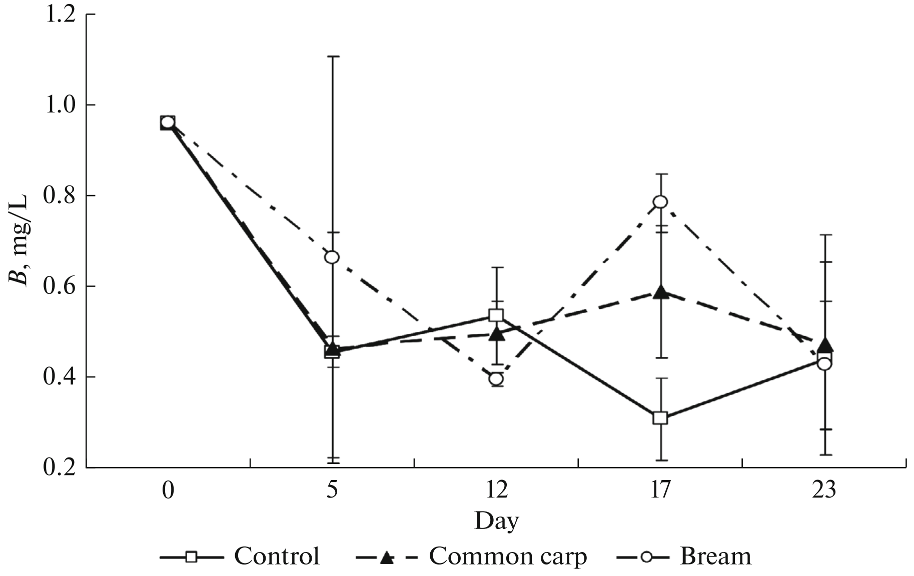

Fig. 4. Dynamics of changes in the phytoplankton biomass during the experiment.

copepodites)) increased in respect to the initial abundance in all mesocosms (Fig. 5).

This increase was more pronounced in mesocosms with carp than in those with bream.

There was a significant positive correlation between the total abundance of zooplankton and phytoplankton in mesocosms with common carp (r = 0.89, $P = 0.01$). This correlation is extremely weak in mesocosms with bream ($r = 0.58$, $P = 0.1$).

It is known that Cladocera, especially small-sized species, respond more quickly to changes in the trophic condition when compared to Copepoda. In this regard, the changes in the abundance of large (*Diaphanosoma brachyurum*) and small (*Bosmina longirostris*) species of cladocerans, which were the most abundant during the experiment, were analyzed.

The abundance of *D. brachyurum* in mesocosms both with bream and common carp varied in a similar pattern during the experiment (Fig. 6). Therefore, the decrease in the abundance of *D. brachyurum* was more expressed in mesocosms with carp when compared to bream.

The decrease in the abundance of one more abundant species, *B. longirostris*, was recorded in mesocosms both with common carp and bream; in the control its values varied insignificantly (Fig. 7).

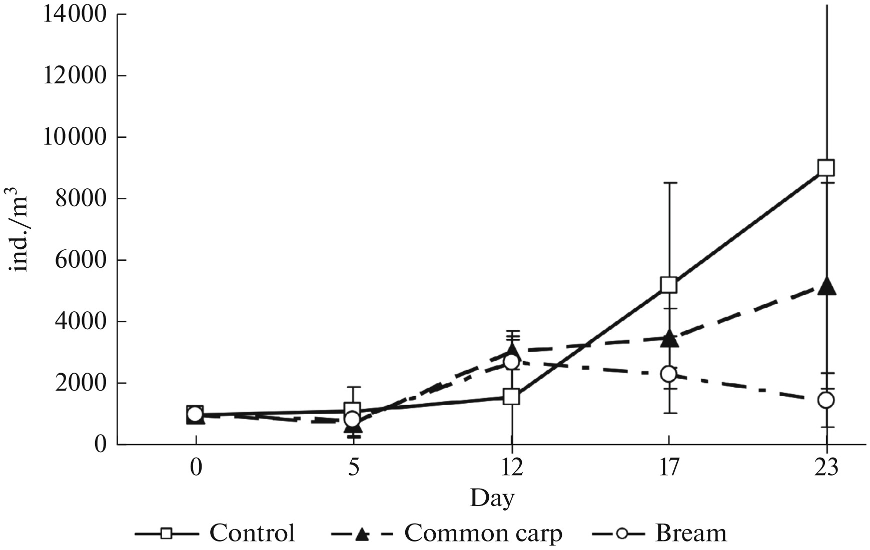

Fig. 5. Dynamics of the total abundance of zooplankton in experimental mesocosms.

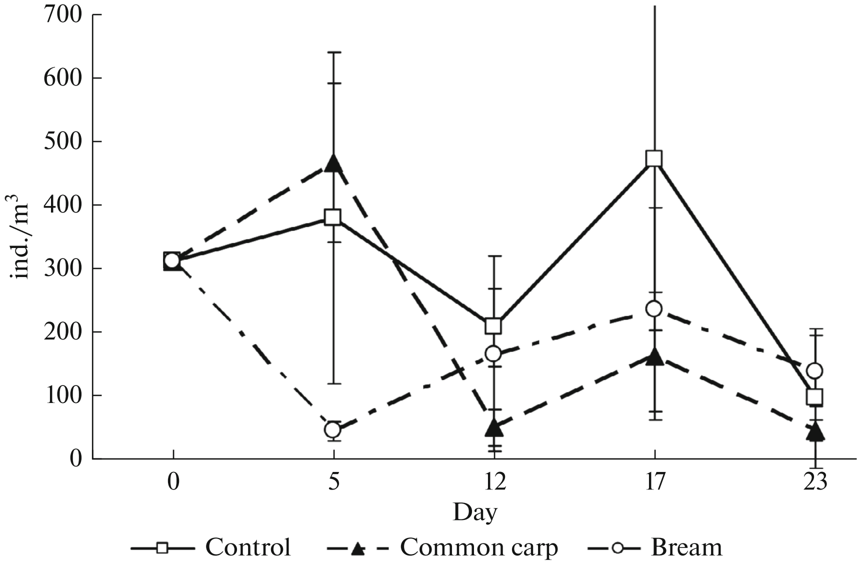

Fig. 6. Dynamics of the abundance of *D. brachyurum* in experimental mesocosms.

The statistical analysis demonstrated significant differences in the values of abundance of *D. rachyurum* and *B. longirostris* in respect to control (Table 2).

Macrozoobenthos. The biomass of macrozoobenthos in the control mesocosms varied insignificantly, and it gradually decreased in mesocosms with bream (Fig. 8). The greatest changes were observed in the mesocosms with common carp, where the biomass of macrozoobenthos decreased 5 times by the middle of the experiment, whereas in the mesocosms with bream it decreased 2 times.

An analysis of variance demonstrated a significant effect of common carp ($F = 4.68$, $P = 0.005$) and bream ($F = 3.60$, $P = 0.016$) on the biomass of macrozoobenthos.

Common carp had the maximum effect on larvae of mayflies, the biomass of which decreased to the minimum values from the middle of the experiment (Fig. 9).

The biomass of chironomid larvae was considerably higher in mesocosms with bream when compared to those with common carp (Fig. 9). The mean weight of specimens in mesocosms was calculated to explain differences in values of chironomid biomass in mesocosms with bream and common carp. The mean weight of chironomid larvae was 6.53 ± 0.54 in control mesocosms and 4.82 ± 0.86 in mesocosms with bream. The mean weight of chironomid larvae in mesocosms with common carp was much lower, 2.32 ± 0.82.

The data make it possible to explain differences in the total biomass of chironomid larvae in mesocosms

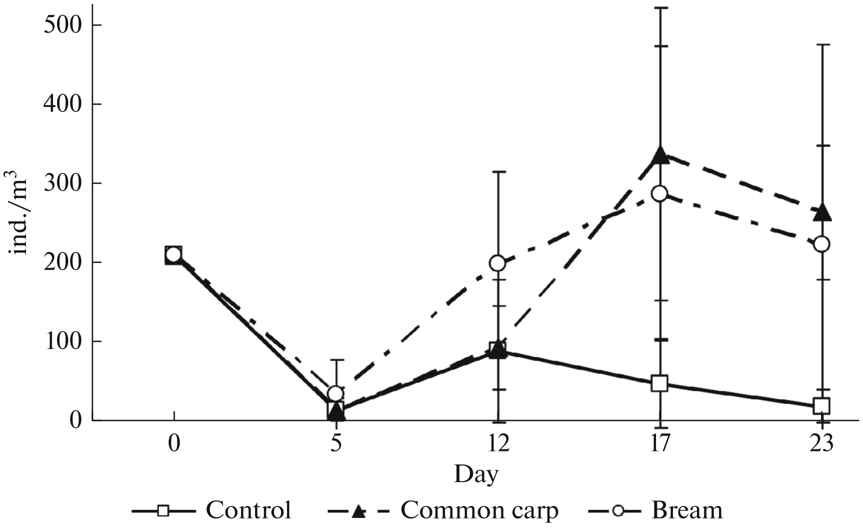

Fig. 7. Dynamics of the abundance of *B. longirostris* in experimental mesocosms.

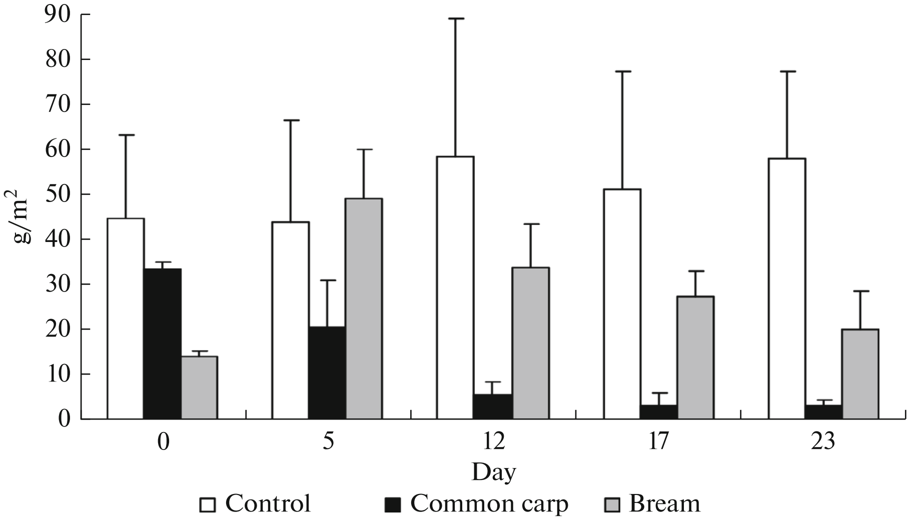

Fig. 8. Change in the biomass of macrozoobenthos (g/m^2) in experimental mesocosms during the experiment.

with fish, which are caused by the different size selectivity of brean and common carp when feeding on chironomids.

DISCUSSION

The major effects of the introduction of common carp on ecosystems of waterbodies are associated with a reduction in macrophyte development, an increase in water turbidity, and the release of nutrients from bottom sediments that cause cascading trophic interactions between phytoplankton and zooplankton (Weber et al., 2010). According to the data of Breukelaar et al. (1994), bream had a greater effect on sediment resuspension in experimental ponds when compared to common carp. In the authors' opinion, this paradoxical effect is associated with the larger range of bream preys when compared to common carp. No significant differences were recorded in concentrations of nutrients in mesocoms with fish compared to the control, despite particular changes in the concentration of nutrients in our experiments.

Changes in the structure of the phytoplankton community occurred in mesocosms with common carp when compared to the control. Diatoms dominated in control mesocosms at the beginning of the experiment, whereas the role of cryptophytes increased by the end of the experiment. Similar results were obtained by Matsuzaki et al. (2007); *Cryptomonas* spp. dominated in control mesocosms by the end of the experiment.

By the middle of the experiment, the relative abundance of blue-green algae increased in bream enclosures, whereas the abundance of dynoflagellates, mainly due to the genus *Glenodinium*, increased in

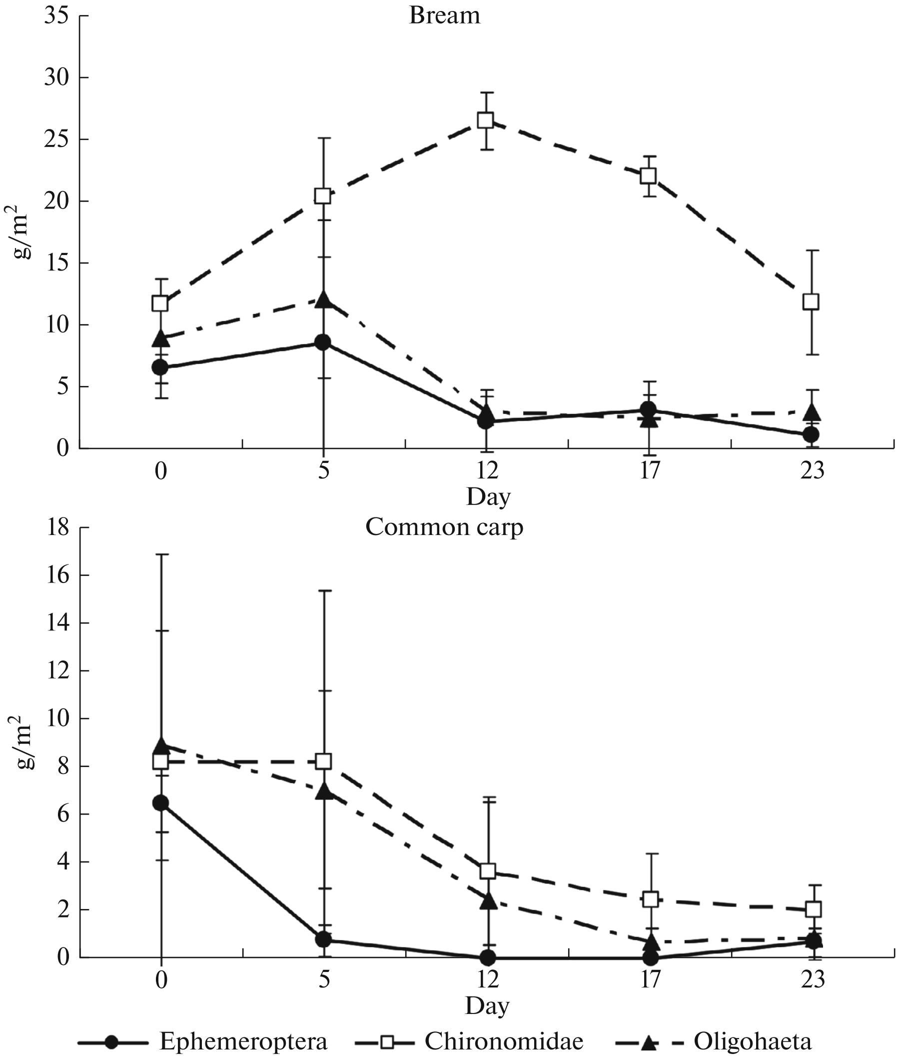

Fig. 9. Change in the biomass of larvae of mayflies, chironomids, and oligochaetes (g/m^2) in mesocosms.

carp enclosures. Significant differences in the biomass of different phytoplankton groups in mesocosms with carp and bream compared to the control were found only for diatoms. Roozen et al. (2007) reported that the increase in the phytoplankton biomas may be caused both by excretion by fish and the resuspension of nutrients and phytobenthos from bottom sediments, the latter mechanism being more important than excretion.

A significant correlation between the abundance of zooplankton and phytoplankton was found in mesocoms with carp, whereas the correlation was weak in mesocosms with bream.

Common carp had a more dramatic impact on large zooplankton when compared with bream. According to the data of Lougheed et al., (1998), this is a result not only of the direct impact of the species on zooplankton, but of enhanced water turbidity due to the burrowing activity of carp, which leads to a decrease in the abundance of zooplankton, especially of large species. The shift in zooplankton size structure from large to small species after the introduction of the common carp was reported by Richardson et al. (1990), Schrage and Downing (2004), and Nieoczym and Kloskowski (2014). In our experiments such a shift was observed in mesocosms both with bream and common carp.

At a particular density, common carp becomes a strong competitor with benthivorous fish species. In mesocosms with carp, the biomass of the main groups of macrozoobenthos (larvae, mayflies, chironomids, and oligochaetes) reduced at a higher rate when compared with mesocosms with bream. Common carp had the maximum effect on the biomass of mayfly larvae, which reduced to zero by the middle of the experiment. Changes in the abundance of mayfly larvae were caused due to the elimination of macrophytes by common carp, which are refugees for a number of macrozoobenthos species (Miller and Crowl, 2006; Williams and Moss, 2003).

As was reported by Miller and Crowl (2006) and Matsuzaki et al. (2008), the burrowing activity of common carp had a strong effect on larvae of chironomids when compared with oligochaetes. According to our data, the impact of common carp on larvae of chironomids and oligochaetes was practically similar.

CONCLUSIONS

Common carp and bream affected the abundance and structure of the phyto- and zooplankton community in a similar pattern. A significant difference in the biomass of various phytoplankton groups in mesocosms with common carp and bream compared to the control were found for diatoms.

The abundance of two species of cladocerans, *D. brachyurum* and *B. longirostris,* in mesocosms both with bream and common carp varied in a similar pattern in the experiment; the abundance of *D. brachyurum* reduced and that of *B. longirostris* increased.

The main differences between common carp and bream were in their impact on the macrozoobenthos community. Thus, by the middle of the experiment, the biomass of macrozoobenthos in mesocosms with common carp reduced almost five times, whereas in mesocosms with bream the biomass decreased two times. Differences were found in food selectivity by common carp and bream. Common carp had the maximum effect on mayfly larvae, whereas the consumption of chironomid and oligochaete larvae was practically similar.

Bream mainly affected larvae of mayflies and oligochaetes and, to a lesser extent, chironomid larvae.

ACKNOWLEDGMENTS

We are grateful to Tatiana Rybkina for conducting the hydrochemical analysis.

REFERENCES

Breukelaar, A.W., Lammens, E., Klein Breteler, J., and Tatrap, I., Effects of benthivorous bream (*Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll *a, Freshwater Biol.*, 1994, vol. 32, pp. 113–121.

Koehn, J.D., Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways, *Freshwater Biol.*, 2004, vol. 49, no. 7, p. 882.

Lougheed, V.L., Crosbie, B., and Chow-Fraser, P., Predictions on the effect of common carp (*Cyprinus carpio*) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland, *Can. J. Fish. Aquat. Sci.*, 1998, vol. 55, pp. 1189–1197.

Lougheed, V.L., Theÿsmeÿer, T., Smith, T., and Chow-Fraser, P., Carp exclusion, food-web interactions, and the restoration of Cootes Paradise Marsh, *J. Great Lakes Res.*, 2004, vol. 30, pp. 44–57.

Matsuzaki, Sh.S., Usio, N., Takamura, N. and Washitani, I., Effects of common carp on nutrient dynamics and littoral community composition: roles of excretion and bioturbation, *Fundam. Appl. Limnol.*, 2007, vol. 168, no. 1, pp. 27–38.

Matsuzaki, S.S., Usio, N., Takamura, N., and Washitani, I., Contrasting impacts of invasive engineers on freshwater ecosystems: an experiment and meta-analysis, *Oecologia*, 2008, vol. 158, no. 4, pp. 673–686.

Miller, S.A. and Crowl, T.A., Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake, *Freshwater Biol.*, 2006, vol. 51, pp. 85–94.

Nieoczym, M. and Kloskowski, J., The role of body size in the impact of common carp *Cyprinus carpio* on water quality, zooplankton, and macrobenthos in ponds, *Int. Rev. Hydrobiol.*, 2014, vol. 99, pp. 212–221.

Richardson, W.B., Wickham, S.A. and Threlkeld, S.T., Food web response to the experimental manipulation of a benthivore (*Cyprinus carpio*), zooplanktivore (*Menidia beryllina*) and benthic insects, *Arch. Hydrobiol.*, 1990, vol. 119, pp. 143–165.

Roozen, F.C.J., Lurling, M., Vlek, H., et al., Resuspension of algal cells by benthivorous fish boosts phytoplankton biomass and alters community structure in shallow lakes, *Freshwater Biol.*, 2007, vol. 52, pp. 977–987.

Schrage, L.J. and Downing, J.A., Pathways of increased water clarity after fish removal from Ventura Marsh; a shallow, eutrophic wetland, *Hydrobiologia*, 2004, vol. 511, no. 1, pp. 215–231.

Shevtsova, T.M., Nekhaeva, T.I., and Lyakh, A.N., *Ekologiya promyslovykh ryb Belarussii* (Ecology of Commercial Fishes in Belorussia), Minsk: Nauka i Tekhnika, 1986.

Sun, J. and Lui, D., Geometric models for calculation cell biovolume and surface area for phytoplankton, *J. Plankton Res.*, 2003, vol. 25, no. 11, pp. 1331-1346.

Tapia, M. and Zambrano, L., From aquaculture goals to real social and ecological impacts: Carp introduction in rural Central Mexico, *Ambio*, 2003, vol. 32, pp. 252–257.

Vilizzi, L., Tarkan, A.S., and Copp, G.H., Experimental evidence from causal criteria analysis for the effects of common carp *Cyprinus carpio* on freshwater ecosystems: a global perspective, *Rev. Fish. Sci. Aquacult.*, 2015, vol. 23, pp. 253–290.

Weber, M.J. and Brown, M.L., Effects of common carp on aquatic ecosystems 80 years after “Carp as a dominant”: ecological insights for fisheries management, *Rev. Fish. Sci.*, 2009, vol. 17, no. 4, pp. 524–537.

Weber, M.J., Brown, M.L., and Willis, D.W., Spatial variability of common carp populations in relation to lake morphology and physicochemical parameters in the upper Midwest United States, *Ecol. Freshwater Fish.*, 2010, vol. 19, pp. 555–565.

Williams, A.E. and Moss, B., Effects of different fish species and biomass on plankton interactions in a shallow lake, *Hydrobiologia*, 2003, vol. 491, pp. 331–346.

Zambrano, L., Scheffer, M., and Martinez-Ramos, M., Catastrophic response of lakes to benthivorous fish introduction, *Oikos*, 2001, vol. 94, pp. 344–350.

Translated by N. Ruban