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Trophic State and Trophic Structure in Three Bulgarian Reservoirs

***Lyubomir Kenderov*[1], *Milena Pavlova*[2], *Teodora Trichkova*[2], *Violeta Tyufekchieva*[2], *Yanka Vidinova*[2], *Dimitar Kozuharov*[1], *Ivan Botev*[2], *Zdravko Hubenov*[3], *Yordan Uzunov*[2], *Stefan Stoichev*[2], *Mihaela Beshkova*[2], *Hristina Kalcheva*[2], *Roumen Kalchev*[2]**

[1] Faculty of Biology, Sofia University. 8 Dragan Tsankov Blvd., 1164 Sofia, Bulgaria; E-mail: lubomir.kenderov@gmail.com
[2] Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences. 2 Gagarin Str., 1113 Sofia, Bulgaria; E-mail: trichkova@zoology.bas.bg.
[3] National Museum of Natural History, Bulgarian Academy of Sciences. 1 Tsar Osvoboditel Blvd., 1000 Sofia, Bulgaria.

Abstract: The reservoirs Ogosta, Zhrebchevo and Koprinka were studied in the period 2009–2011. The Secchi Disk transparency and amount of chlorophyll-a were used for the assessment of the trophic state in the reservoirs. The structure and functioning of the trophic web and trophic integrity were analysed based on the composition of phytoplankton, benthic macroinvertebrate and fish communities. The trophic state of the three reservoirs was determined as mesotrophic. In the reservoirs, infested by *Dreissena* spp. (Ogosta and Zhrebchevo), the macrozoobenthic communities were represented mostly by filter feeders and deposit feeders. The fish fauna was predominated by benthivorous, followed by omnivorous species. In the non-infested reservoir Koprinka, the benthic community was composed mostly of deposit feeders, while the ichthyofauna was diverse in the trophic aspect. All reservoirs showed good trophic integrity.

Keywords: phytoplankton, benthic macroinvertebrates, fish, food web, ecosystem functioning, trophic integrity

Introduction

In Bulgaria, man-made lakes or reservoirs are of great economic importance, being used for drinking water supply, power generation, water abstraction for irrigation, aquaculture, etc. Generally, reservoirs are characterised by ecosystem instability due to changes in the general status from riverine to lacustrine conditions, high fluctuations in water level, eutrophication, fishery activities, and introduction of invasive alien species. Predicting and understanding these natural and anthropogenic disturbances on the reservoir ecosystem functional integrity requires information on the trophic structure (Seda *et al*. 2000, Saito *et al*. 2001, Johnson *et al*. 2002). The continuous deviation from natural succession might reduce the reservoir recovery capacity and induce alternative states that decrease or prevent the ecological and socioeconomic services provided by man-made lakes (Scheffer 1990). The possibilities for avoiding this and managing good practices in water use could be clarified by understanding the trophic state as a simple way to represent the biological conditions.

Our previous studies focused on the assessment of individual aquatic communities in the reservoirs – bacterioplankton and phytoplankton (Beshkova, Saiz 2006, Beshkova *et al*. 2007, 2008), zooplankton (Kozuharov *et al*. 2009, 2013), benthic macroinvertebrates (Kovachev, Uzunov 1981, Trichkova *et al*. 2013) and fish (Trichkova *et al*. 2001, Zivkov *et al*. 2003).

The main goal of the present study is to assess the trophic integrity of human-made aquatic ecosystems by examining the structure and functioning of food webs. Understanding these processes and revealing the mechanisms in operation is the key to effective water management. The objectives of the study are: to determine the trophic state of three Bulgarian reservoirs; to describe the trophic structure of benthic macroinvertebrate and fish communities with main trophic guilds in the reservoirs; to define the interrelations among species and the trophic groups; to define key species; to assess the trophic and functional integrity.

Material and Methods

Three reservoirs, one belonging to the Danube River basin (Ogosta) and two to the Aegean Sea basin (Zhrebchevo and Koprinka), were studied (Fig. 1, Table 1). The field surveys were conducted during the periods: August 2009, April-May 2010, September-October 2010, July 2011. A total of 12 sites were sampled as follows: Ogosta - 5 sites, Zhrebchevo - 4 sites and Koprinka - 3 sites (Fig. 1).

Standard hydrobiological sampling methods were applied (EN ISO 5667-1:2006/AC: 2007). The phytoplankton samples were collected by bathometer (Hydrobios PVS 436 302) at depths of 0, 5, 10, 15, 20, etc., meters depending on the site depth. The samples of benthic macroinvertebrates were collected by "Petersen" grab with 280.5 cm^2 working area (ISO 9391:1993). The littoral samples of benthic macroinvertebrates were collected by 500 μm mesh size hand net (ISO 10870:2012). The fish were caught by electrofishing and beach seining in the littoral area, and by gillnets of different mesh size in areas of greater depths. A total of 46 phytoplankton samples (20 in Ogosta, 15 in Zhrebchevo, and 11 in Koprinka), and 60 samples of benthic macronivertebrates (34 in Ogosta, 14 in Zhrebchevo, and 12 in Koprinka) were collected.

The macrozoobenthic trophic guilds were determined according to Cheshmedjiev, Varadinova (2013), and the fish trophic guilds according to Kottelat, Freyhoff (2007).

The trophic state of the reservoirs was assessed using the Trophic state index (TSI) (Carlson 1977). The latest modification of the index (Carlson 1983, Pavluk, Bij De Vaate 2008) was performed because of its simplicity. The estimated values of the three trophic state indices: one based on the Secchi disk transparency/ TSI(SD) (m), the second one based on the vital chlorophyll-a concentrations/ TSI(Chl-a) ($\mu g.dm^{-3}$), and the third one based on the Total phosphorus concentrations/ TSI(TP) ($mg.dm^{-3}$), were used for the calculation of the trophic state index after Pavluk, Bij De Vaate (2008) – the average Trophic state index (TSIa). The vital chlorophyll-a concentrations (($\mu g.dm^{-3}$) and the total phosphorus concentrations ($mg.dm^{-3}$) were measured according to the standards ISO 10260:1992 and EN ISO 6878:2004.

Results and Discussion

Trophic state of the reservoirs

The estimated mean values of the three single Trophic state indices used were almost the same as the average TSI index (Figs. 2 and 3) and indicated the "mesotrophic state" of the studied reservoirs. The need to clearly separate different zones (water bodies) of the reservoirs, which strongly depend on the morphometry, seasons, retention time and development of their shoreline, was reported by Beshkova *et al*. (2008). Here this separation can be easily tracked on the TSI(Chl-a) index chart for the Zhrebchevo Reservoir (Fig. 3a), where the trophic state ranged from oligotrophy to meso- and even to eutrophy from sampling site No. 1 (at the dam) to sampling site No. 4 (the ecotone zone where the Tundzha River enters). In the reservoirs Koprinka and Ogosta, the TSI(Chl-a) values ranged from mesotrophy to eutrophy in different seasons and sites (Fig. 3b, c). There were a few exceptions, where the trophic state showed oligotrophy, but this occurred at single sites and at greater depths (20-28 m).

When analysing the trophic state in the reservoirs and using the Trophic state indices, we must consider the fact that the Ogosta Reservoir was heavily infested by the invasive mussels of genus *Dreissena* - *Dreissena polymorpha* (Pallas, 1771) and *Dreissena bugensis* (Andrusov, 1897), and Zhrebchevo Reservoir by *D. polymorpha* (Trichkova *et al*. 2009). It is known that as filter feeders *Dreissena* spp. can reduce turbidity and improve water clarity through top-down control of phytoplankton and particulate material (Strayer *et al*. 1999, Idrisi *et al*. 2001, Vanderploeg *et al*. 2002). In many systems, *Dreissena* spp. invasion was followed by a reduction in phytoplankton biomass (decrease in chlorophyll-a) and a shift in community composition, but this appears dependent on physical factors and seasonality (Kelly *et al*. 2010). The most important factors that can moderate *Dreissena* spp. effect on phytoplankton and transparency were lake depth and water column mixing (Noonburg *et al*. 2003, Vanderploeg *et al*. 2002). This indicates the need for more detailed analysis of the trophic state in the infested reservoirs.

Trophic structure of benthic macroinvertebrates

Various trophic groups: collector gatherers, deposit feeders, filter feeders, predators, scrapers and shredders were represented in the benthic macroinvertebrate communities in the three studied reservoirs (Table 2). They belonged to 13 taxonomic groups. High level of similarity between the trophic and taxonomic groups in the three reservoirs was observed. It was found that the differences in the trophic groups of benthic communities were much larger in relation to different seasons than to different reservoirs in the same season.

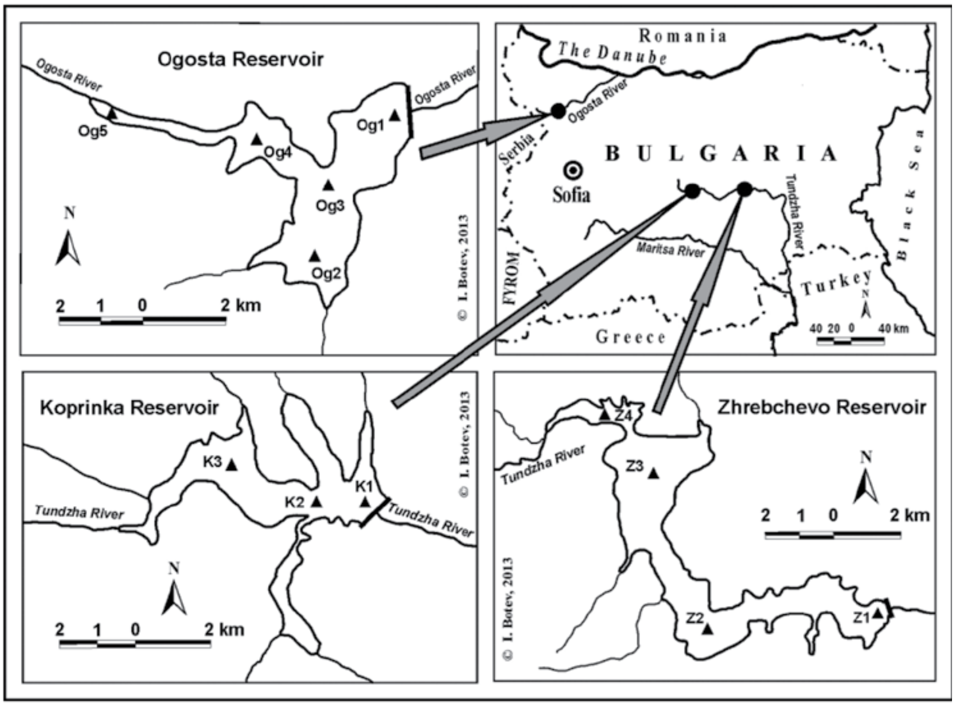

Fig. 1. Location of studied reservoirs: Ogosta, Koprinka and Zhrebchevo; and sampling sites (black triangles). Site numbering starts with No. 1 from the dam

Table 1. Characteristics of the studied reservoirs

Reservoir	River catchment	Altitude, m a.s.l.	Max surface area, ha	Max storage volume, m^3x10^6	Max depth, m	Usage
Ogosta	Ogosta River, Danube River basin	202.5	2360	506	56	Irrigation, power generation, recreation, recreational fishing
Zhrebchevo	Tundzha River, Aegean Sea basin	274	2580	400	52	Irrigation, power generation, aquaculture, recreation, recreational fishing
Koprinka	Tundzha River, Aegean Sea basin	397	840	140	32 (sampling depth)	Power generation, aquaculture, recreation, recreational fishing

A total of 40 taxa of benthic macroinvertebrates, belonging to 11 taxonomic groups, were recorded in the Ogosta Reservoir (Table 2). Of these, deposit feeders were best represented (by 15 taxa, mostly Oligochaeta and Diptera), followed by scrapers (9 taxa, mostly Gastropoda and Diptera), predators (7 taxa) and filter feeders (5 taxa mainly Bivalvia). Our previous study showed that the highest quantitative parameters were attributed to three groups: the invasive mussels *D. polymorpha* and *D. bugensis*, the oligochets *Tubifex tubifex* (Müller, 1774), *Limnodrilus hoffmeisteri* Claparede, 1862, and the chironomid larvae of *Chironomus gr. riparius* Meigen, 1804, and *Chironomus gr. plumosus* (Linnaeus, 1758) (Trichkova *et al*. 2013). Therefore, the dominant trophic groups in terms of quantitative parameters were deposit feeders and filter feeders. The littoral zone supported a greater variety of habitats (stones, sand, vegetation, mud), and therefore more trophic groups, such as: predators *Erpobdella octoculata* (Linnaeus, 1758), scrapers: *Asellus aquaticus* (Linnaeus, 1758), *Radix auricularia* (Linnaeus, 1758), *Physella acuta* (Draparnaud, 1805), and filter feeders: *Anodonta anatina* (Linnaeus, 1758).

The Zhrebchevo Reservoir was characterised by the highest number of benthic macroinvertebrate

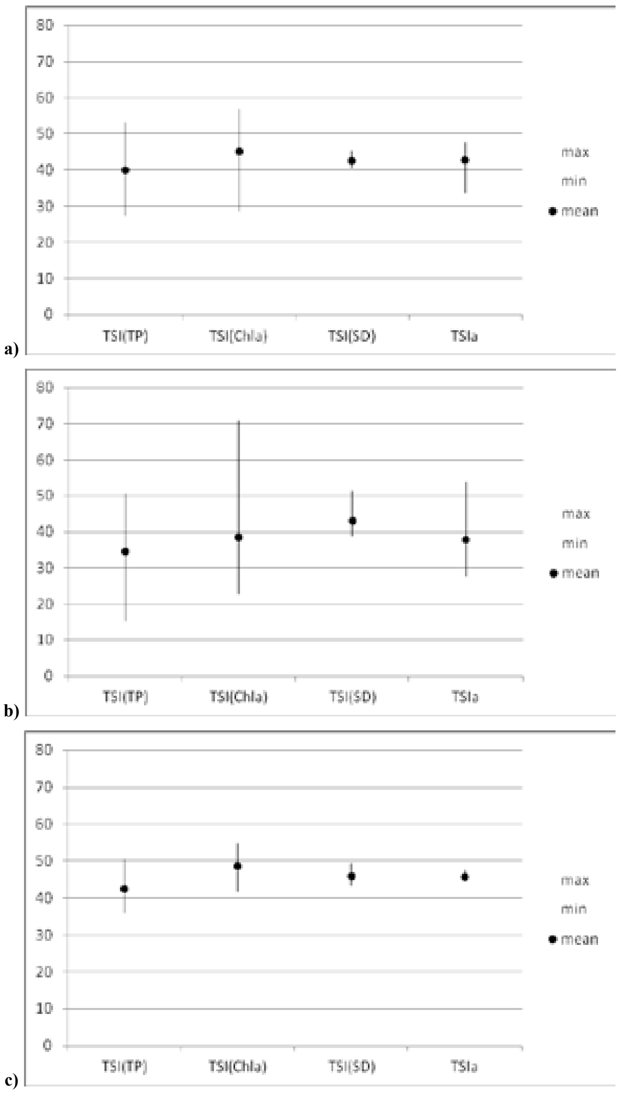

Fig. 2. Values of the four Trophic state indices (TSI), calculated for the three reservoirs: a) Ogosta Reservoir; b) Zhrebchevo Reservoir; c) Koprinka Reservoir. TSI(TP) – Trophic state index based on the total phosphorus concentrations (mg.dm^{-3}); TSI(Chl-a) – Trophic state index based on the vital chlorophyll-a concentrations (µg.dm^{-3}); TSI(SD) – Trophic state index based on the Secchi disk transparency (m); TSIa – average Trophic state index

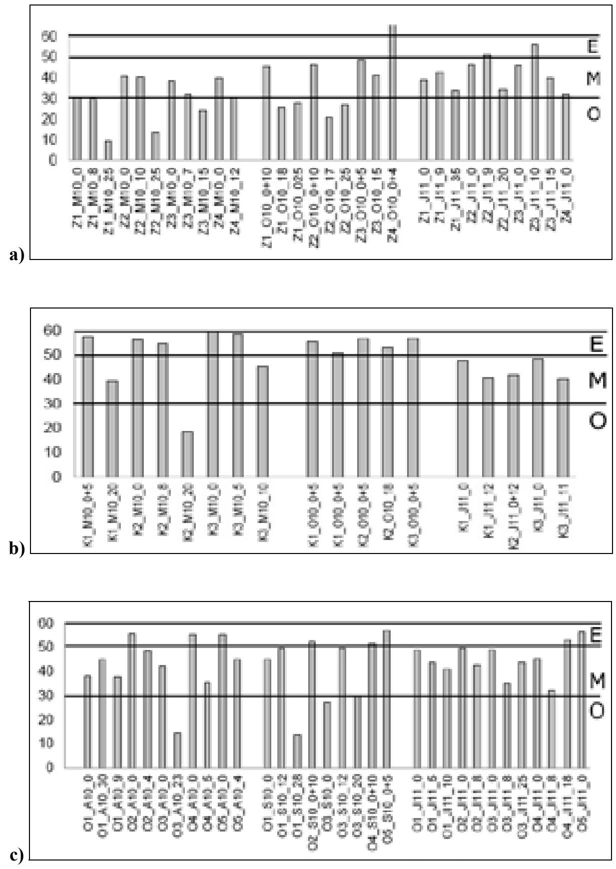

Fig. 3. Trophic state index (TSI) values in the three reservoirs in three seasons based on the vital chlorophyll-a concentrations/ TSI(Chl-a). Legend: Site code - the first letter with number indicates the reservoir and sampling site, the symbols after the first underscore indicate the month and year of sampling, and the number after the second underscore indicates the sampling depth (m). Reservoirs: Z - Zhrebchevo (a), K - Koprinka (b), O - Ogosta (c); Dates of sampling: M10 - May 2010, O10 - October 2010, J11 - June 2011, A10 - August 2010, S10 - September 2010, Jl11 - July 2011; Trophic state: E - eutrophy, M - mesotrophy, O - oligotrophy

taxa (46 taxa), belonging to 11 taxonomic groups (Table 2). It had a similar trophic structure of benthic community to Ogosta Reservoir (Table 2). Here the best represented were the deposit feeders (20 taxa, mostly Oligochaeta: Tubificidae), followed by scrapers (12 taxa, mostly Oligochaeta: Naididae and Gastropoda), predators (8 taxa mainly Odonata) and filter feeders (3 taxa of Bivalvia). Our preliminary results (Tyufekchieva *et al*. 2010) and the present study showed that the dominant trophic groups in terms of quantitative parameters were the filter feeders and scrapers - *D. polymorpha*, the water snails *Viviparus* sp. and *Radix balthica* (Linnaeus, 1758), as well as the chironomid *Cricotopus gr. sylvestris* (Fabricius, 1794). They were followed by the deposit feeder oligochets *T. tubifex*, *Limnodrillus spp.*, and the deposit feeder chironomids *Ch. gr. riparius* and *Cryptochironomus gr. defectus* (Kieffer, 1913). The trophic structure was quite different compared to the earlier studies of Kovachev, Uzunov (1981), when the filter feeders were not reported to have a significant role in the trophic relationships in the reservoir. Rather, the authors found that the benthic community was formed exclusively of deposit feeders from the families Chironomidae (Diptera) and Tubificidae (*Limnodrillus spp., T. tubifex*) (Annelida: Oligochaeta).

High abundance and biomass of *Dreissena* species in the infested reservoirs and their important role

Table 2. Trophic and taxonomic groups of benthic macroinvertebrates and fish in the studied reservoirs

Trophic group	Taxonomic group	Number of taxa per reservoir		
		Ogosta Reservoir	Zhrebchevo Reservoir	Koprinka Reservoir
Benthic macroinvertebrates				
Collector-gatherers	Diptera	3	2	3
Deposit feeders	Oligochaeta	8	13	1
	Ephemeroptera	2	1	7
	Diptera	5	5	4
	Mysida		1	
Filter feeders	Bivalvia	4	3	2
	Diptera	1		1
Predators	Oligochaeta	2		
	Hirudinea	1	2	1
	Hydracarina		1	1
	Odonata	1	4	1
	Heteroptera	2	1	
	Trichoptera	1		
Scrapers	Oligochaeta		5	
	Gastropoda	4	4	3
	Isopoda	1		1
	Diptera	3	2	2
	Turbellaria	1		
	Ephemeroptera		1	
Shredders	Trichoptera	1	1	1
Fish				
Omnivores	Cyprinidae	3	1	3
	Siluridae	1		
	Centrarchidae	1	1	1
	Percidae	1	1	1
Planktonivores	Cyprinidae	2	1	1
Zoobenthivores	Cyprinidae	6	4	5
	Cobitidae	1	1	1
	Gobiidae	1	1	
Predators	Percidae		1	1
	Esocidae		1	1

in the distribution of other benthic macroinvertebrate taxa was reported in our previous studies (Trichkova *et al*. 2008, 2013). The present results also indicate the important role of *Dreissena* species in the trophic relationships among benthic macroinvertebrates in the infested reservoirs Ogosta and Zhrebchevo. The colonization of water bodies by *Dreissena* spp. alters the habitats in several ways, the most pronounced of which is the energy "shunt" (from pelagic to bottom communities) (Mills *et al*. 2003). Many authors reported that *Dreissena* may facilitate other macrozoobenthic species by increasing habitat complexity, and by organic enrichment of the sediments, providing a new food source, leading to the development of a biodeposition-based food web (Stewart, Haynes 1994, Mitchell *et al*. 1996). On the other hand, they had a profound negative effect on native mollusks due to food competition and interference fouling of their shells (Burlakova *et al*. 2000, Kelly *et al*. 2010). Our results also showed poor abundance of other filter feeders and increased importance of deposit feeders (oligochets, chironomids).

The Koprinka Reservoir had the lowest number of taxa recorded (28) belonging to 10 taxonomic groups (Table 2). The best represented trophic group was that of deposit feeders (12 taxa, mostly Ephemeroptera), followed by the scrapers (6 taxa). Contrary to the other two reservoirs, the Koprinka Reservoir was not infested by *Dreissena* mussels. Other mollusks were also poorly represented, mainly in the littoral area, *e.g. A. anatina*. According to our preliminary study (Tyufekchieva *et al*. 2010) and the present results, the most important trophic significance was attributed to deposit feeders from families Tubificidae (*T. tubifex, L. hoffmeisteri*) and Chironomidae (*Ch. gr. riparius*) and one collector-gatherer chironomid species - *Tanytarsus gr. gregarius* Kieffer, 1909 (Table 2). The results were similar to those, published by

Dimitrov, Lyudskanova (1967). The authors found out that the main benthic components were represented by deposit feeders from families Chironomidae and Tubificidae. In the period 1964-1966 they recorded 14 chironomid species (mostly *Polypedilum convictum* Walker, 1856, *Procladius sp*. and *Ch. plumosus*), and of the oligochets - mostly *L. hoffmeisteri* and *L. claparedianus* Ratzel, 1869. The authors assumed that the composition and quantity of bottom species were determined by predatory press provided by fishes (mostly *Cyprinus carpio* Linnaeus, 1758 and *Squalius orpheus* Kottelat & Economidis, 2006). Although we found a different species composition, the trophic structure of the benthic macroinvertebrate community was not changed - the majority of species were deposit feeders.

Trophic structure of fish communities

The ichthyofauna in the studied reservoirs was relatively rich. A total of 22 species from 7 families was recorded; most of the species belonging to family Cyprinidae (14). The identified species represented the main feeding guilds: omnivorous (with 4 families), planktivorous (one family), zoobenthivorous (3 families) and predators (two families) (Table 2).

In Ogosta Reservoir, 16 fish species were found. Most of them were benthivorous (8 species) and omnivorous (6), only 2 species were planktivorous (Table 2). In our study, the species *Perca fluviatilis* Linnaeus, 1758 was considered as omnivorous, but different feeding patterns during different life stages were also taken into account. Our previous results on the food composition of *P. fluviatilis* in Drenovets Reservoir, showed that juveniles (0+) were entirely planktivorous, individuals at age from 1+ to 3 - omnivorous, and those over 3 years – mostly predators (Trichkova *et al*. 2005). In the gillnet catches in the Ogosta Reservoir, the most numerous were the benthivorous species: *Abramis brama* (Linnaeus, 1758), *Rutilus rutilus* (Linnaeus, 1758), the omnivorous: *Carassius gibelio* (Bloch, 1782), *C. carpio, Squalius cephalus* (Linnaeus, 1758), and the planktivorous *Alburnus alburnus* (Linnaeus, 1758). In the littoral catches, the best represented were the benthivorous *Pseudorasbora parva* (Temminck & Schlegel, 1846), *Neogobius fluviatilis* (Pallas, 1811), and the omnivorous *C. gibelio*, *Lepomis gibbosus* (Linnaeus, 1758) and *P. fluviatilis*.

In Zhrebchevo Reservoir, a total of 12 species was recorded. The most diverse group (similar to Ogosta Reservoir) was that of the benthivores, represented by 6 species. The other groups were represented as follows: omnivores (3 species), predators (2), and planktivores (1) (Table 2). The most numerous species in the gillnet catches were benthivorous *R. rutilus, Vimba melanops* (Heckel, 1837), and omnivorous *C. gibelio, P. fluviatilis*. The best represented species in the littoral area were the omnivorous *P. fluviatilis* and *L. gibbosus*. A previous study in Zhrebchevo Reservoir showed that the commercial catches in 1992-1996 were dominated by the omnivorous *C. gibelio* (60%), followed by benthivorous *V. melanops* (15%), omnivorous *S. orpheus* (8%) and predator *Sander lucioperca* (Linnaeus, 1758) (5-6%) (Grupcheva, Nedeva 1999). Compared to these results, an increase in the percentage of *R. rutilus* and *P. fluviatilis* in our catches was observed. Two predator species were present in the catches in both study periods: *Esox lucius* Linnaeus, 1758 and *S. lucioperca*.

In Koprinka Reservoir, a total of 14 fish species was recorded. They were divided into the following trophic guilds: benthivorous (6 species), omnivorous (5), planktivorous (1), predators (2) (Table 2). In the gillnet catches, the following trophic groups were found: *Rutilus rutilus* and *Vimba melanops* (benthivorous), *C. gibelio* and *P. fluviatilis* (omnivorous), and *S. lucioperca* (predator). The dominant species in the littoral catches in the study period was *R. rutilus*. In a previous study, a different species composition of commercial catches was reported - the highest percentage was for the omnivorous *C. carpio* (about 70%), followed by: the planktivorous *A. alburnus*, benthivorous *Chondrostoma vardarense* Karaman, 1928, omnivorous *S. orpheus* and the predator *S. lucioperca* (Dimitrov, Lyudskanova 1967). Despite the differences in species composition, the trophic structure of this reservoir was well balanced in both study periods.

Our results showed that in the reservoirs infested by *Dreissena* spp. Ogosta and Zhrebchevo, the benthivorous fish species dominated in the catches in terms of species richness and percentage in the catches (*e.g. A. brama, R. rutilus, V. melanops*). The non-infested Koprinka Reservoir was characterised with almost equal numbers of benthivorous and omnivorous species, as well as a more balanced trophic structure, which determined a higher trophic integrity related to fish compared to the other two reservoirs. It is reported in literature that the energy "shunt" from the pelagic to the benthic habitats is a central factor in determining the effects of *Dreissena* spp. on fish (Kelly *et al*. 2010). Open water fish species and their larval stages suffered from suppression of phytoplankton and zooplankton, while littoral fish species benefited from increased benthic productivity (Strayer *et al*. 2004, Johannsson *et al*. 2000).

Trophic webs and trophic net

Two types of trophic webs can be described in the studied reservoirs - grazing and detritus ones. The two food webs were connected in one general trophic net, which is the basis for functioning of the ecosystems:

Type 1 food web: Grazing. The grazing food web, including links between many grazing food chains, was spatially located within the depths of the reservoirs. Based on the chlorophyll-a data (TSI index), the leading community was assumed to be the phytoplankton (primary producer). The macrophytes did not have the same importance as the phytoplankton in the reservoirs, because of the negative influence of high fluctuations in the water level. The next level was occupied by the first order consumers - the filter feeders (the rotifers and lower crustaceans) in the zooplankton, and *Dreissena* mussels in the benthic community. The second order consumers were the carnivorous planktonic organisms (some copepods, rotifers and cladocerans), and some fishes, such as *A. alburnus* and juvenile *P. fluviatilis*, that feed on zooplankton. The third order consumers were represented by fish predators. *E. lucius, P. fluviatilis* and *S. lucioperca* were considered top predators. In this case they played the role of key species for the ecosystems.

Type 2 food web: Detritus. Detritus food web was supported in the littoral zones of the reservoirs. There, the detritus had an important role as the main trophic resource for the second order consumers in the macrozoobenthic communities and for some detritivorous fishes, such as *C. gibelio* and *C. carpio*.

Similar patterns of spatial distribution of food webs were specific for natural stagnant waters, for example in the Srebarna Lake, where one food web was described in the central open water body and a second one in the lateral pools (Pavlova *et al*. 2012).

Dreissena mussels in the infested reservoirs Ogosta and Zhrebchevo had an important role in the food webs as first order consumers. Furthermore, the accumulation of organic material by the mussels was assumed to be the source of another type – *Dreissena* biodeposition-based food web (Stewart, Haynes 1994, Mitchell *et al*. 1996). However, further studies are needed to prove the importance of the biodeposited material as a food source and its contribution to increased abundance of macroinvertebrates in the presence of *Dreissena* spp. in the infested reservoirs Ogosta and Zhrebchevo.

Conclusions

High levels of trophic integrity of different planktonic and benthic communities in the studied human-made aquatic ecosystems were found. The maintenance of this trophic integrity was directly related to the quality of the inflow surface water and only subtle variations in the water level of the reservoirs. Trophic relations in the reservoirs Ogosta and Zhrebchevo were largely determined by the invasive *Dreissena* spp., which was considered a keystone species. Furthermore, the primary producers (phytoplankton) and final consumers (predatory fish) were determined as the most important components in the trophic networks. Thus, the most effective approach for biomanipulation in the reservoirs could be the top-down manipulation of the food webs, using the top predators. Additionally, preventive and control measures for invasive *Dreissena* species need to be applied. The integral functioning of the trophic net should be ensured by management practices, which should be beneficial for reaching the maximum ecological potential of the reservoirs.

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