Research Article

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Effects of Small Hydropower Plants on Fish Communities in Bulgarian Rivers: Case Studies

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Abstract: Surveys of the state of fish fauna upstream and downstream eight small hydropower plants (SHPPs) situated on middle and upper courses of rivers of East and West Aegean Sea basins in Bulgaria were carried out. Sampling of fish with electricity was performed complying with the Standard EN 14011. Assessment of the ecological state of the surveyed rivers was done using the Bulgarian Fish Based Index and the Trout River Index. In the middle courses of the rivers Arda and Vacha (meta-/hyporithron covering the Maritsa barbel zone), no specific negative impacts of the surveyed SHPPs on the fish fauna were found. In the epi-/metarithron zones of some tributaries of the Struma river (Trout and Maritsa barbel habitats), more pronounced barrier effect were found downstream than upstream. In other cases, local factors and human activities probably have more pronounced effect on the state of the fish community upstream and downstream the SHPPs than the expected barrier effect.

Key words: fish fauna, Small Hydropower Plant, impact, barrier effect, local pressures

Introduction

The impact of small hydropower plants (SHPPs) on the river ecosystems are widely discussed because they are widespread and increasing in numbers (Lucas & Marmulla 2000, Lucas & Baras 2001, Steinmetz & Sundqvist 2014). Indeed, in the last decades in Bulgaria, trends of increase of the investments focused on the SHPPs have occurred. According the Bulgarian legislation, „small" hydropower plants are considered those with an installed effect of up to 10 MW. Two types of SHPPs are constructed in Bulgaria: run-of-the-river hydroelectrics and diverted hydropower plants. The main reported negative effects on the fish communities in rivers (Steinmetz & Sundqvist 2014, Vasilev et al. 2017) result from the hydro-morphological pressure: barrier effect (river fragmentation and breaking the migration corridors), change of hydrological and morphological features (depths, current velocities, sediment's granulometry, etc.) and water abstraction (in diverted SHPPs). Significant deterioration of the main physical and chemical parameters of the water (such as temperature, dissolved oxygen, pH and conductivity) seems to be not a typical effect of the SHPPs because of the relatively small volumes or areas of the water reservoirs where the potential deterioration occurs as well as the short retention time.

Although the general effects of SHPPs on the fish fauna are well known, their specific features may change depending on the constructive peculiarities of SHPPs, river specificities and some further pressures. Regardless the fact that the SHPPs in Bulgaria have become too widespread, their specific impact on the river fish communities is still not described in detail.

The aim of the present study was to check and describe the specific effects of SHPPs on the fish communities in model affected sections of mountain and semi-mountain Bulgarian rivers.

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Materials and Methods

The surveys cover eight SHPPs, three of them situated on the middle courses of rivers Arda and Vacha (belonging to the river type R5 according the national river typology) within the Eastern Aegean Sea basin and five situated on the upper courses (river types R1, R3 and R15) of rivers Petrovska, Pirinska Bistritsa, Slavova, Tremoshtnitsa and Vlahinska within the Western Aegean Sea basin (Fig. 1). According the classification of WFD, both East and West Aegean Sea basins belong to the Ecoregion 7 (West Balkans).

Two of the surveyed SHPPs are run-of-the-river hydroelectrics and the other six are diverted SHPPs. Irrespective the type, almost all they (except the Petrovo SHPP) have dams and water reservoirs of different volume as basic components.

Multihabitat fish sampling with electricity by wadding using backpack electrofishing devices was performed in the summer of 2016 upstream the water reservoirs formed by the dams (water abstraction facilities) and downstream the water discharge of each SHPP in compliance with the Standard EN 14011. Assessment of the ecological status of the surveyed rivers was performed according the Ordinance H-4/2012 (2013-2014) using the Bulgarian Fish Based Index (BFBI) (Table 1) as described in Mihov (2010) and Belkinova et al. (2013) and the Trout River Index (TRI) (Table 2) as described in Pehlivanov et al. (2012).

Results

Arda River – SHPP Srednogortsi

As the SHPP Srednogortsi is a run-of-the-river hydropower plant (Table 3) with turbines situated immediately below the dam, no river section with

Table 1. Assessment of the ecological state according to the Bulgarian Fish Based Index (BFBI)

Ecological state	BFBI score	EQR*
High(H)	> 86	> 0.86
Good (G)	60–85	0.60–0.85
Moderate (M)	30–59	0.30–0.59
Poor (P)	16–29	0.16–0.29
Bad (B)	< 15	< 0.15

*Ecological Quality Ratio

Table 2. Assessment of the ecological state according to the Trout River Index (TRI)

Ecological state	TRI score	EQR
High (H)	32–40	1
Good (G)	23–31	0.86
Moderate (M)	14–22	0.65
Poor (P)	5–13	0.43
Bad (B)	< 5	0.22

Fig. 1. Location of the studied SHPPs. The names of the target SHPPs are indicated: 1. Sampling site upstream the water abstraction facilities. 2. Sampling site downstream the water discharge.

Table 3. Ecological state of the river stretches adjacent to the target SHPPs

River	River typology	SHPP name	SHPP type	Fish pass construction	Studied site	Geographical coordinates		BFBI	TRI	EQR	Ecological state
						E	N				
Arda	R5	Sredno-gortsi	run-of-the-river	Iron spiral stair design	Upstream the dam lake			62		0.62	Good
					Downstream SHPP outflow			85		0.85	Good
Arda	R5	Byal izvor	diverted SHPP	Concrete pool & weir	Upstream the dam lake			62		0.62	Good
					Downstream SHPP outflow			72		0.72	Good
Vacha	R5	Kadievo	run-of-the-river	Concrete pool & weir	Upstream the reservoir			57		0.57	Moderate
					Downstream SHPP outflow			52		0.52	Moderate
Petrovska	R15	Petrovo	diverted SHPP	Concrete pool & weir	Upstream the water catchment facilities	023.55009	41.41604	N.A.	N.A.	-	N.A.
					Downstream SHPP outflow	023.50462	41.43596	N.A.	N.A.	-	Bad (e.j.*)
Pirinska Bistritsa	R3	Pirinska Bistritsa	diverted SHPP	Concrete pool & weir	Upstream the water catchment facilities	023.51109	41.62360	N.A.	31	0.86	Good
		Pirin	diverted SHPP	Concrete pool & weir	Downstream SHPP outflow	023.56528	41.55183	N.A.	28	0.86	Good
Slavova	R1	Slavova	diverted SHPP	Concrete pool & weir	Upstream the water reservoir	023.29345	42.01277	N.A.	25	0.86	Good (e.j.)
					Downstream SHPP outflow	023.27013	42.03078	N.A.	21	0.65	Moderate (e.j.)
Tremoshtnitsa	R1	Arnaut dere	diverted SHPP	Concrete, combined: pools with large slope and canal	Upstream the water reservoir	023.36338	41.68100	N.A.	21	0.65	Moderate (e.j.)
					Downstream SHPP outflow	023.37032	41.65874	N.A.	15	0.22	Bad (e.j.)
Vlahinska	R3	Vlahi	diverted SHPP	Concrete pool & weir	Upstream the water catchment facilities	023.22165	41.73924	N.A.	28	0.86	Good
					Downstream SHPP outflow	023.19942	41.73861	0.68	N.A.	0.86	Good

*e.j. = Expert judgment.

Fig. 2. Water abstraction facilities of the Petrovo SHPP

reduced runoff occurs. There is no data about the effectiveness of the fish pass at the dam but its spiral design seems to be not suitable for the cyprinid fish species typical for this river section. The surveyed river section being a semi-mountain river of the type R5 belongs to the metarithron ecological zone, with a type-specific fish community dominated by the Maritsa barbel *Barbus cyclolepis* and including also *Squalius orpheus*, *Gobio bulgaricus*, *Chondrostoma vardarense*, *Rhodeus amarus* and *Cobitis strumicae*. Almost the same species composition of the fish community was found in both surveyed river sections downstream the SHPP and upstream the water reservoir. The sensitive potamodromous species *C. vardarense* was presented both down- and upstream the barrier. Atypical for this river zone, bleak *Alburnus alburnus* was recorded downstream the SHPP but not upstream the water reservoir where theoretically more favourable conditions for this species existed. In contrast, the Bitterling *Rhodeus amarus* occurred only in the river section upstream the dam lake what suggested that the ecological conditions in the dam lake provide prerequisites for development of population of unionid bivalves. The values of BFBI in the river sections up- and downstream the SHPP are within the limits of the **Good** ecological state (Table 3). This means that both species composition and quantitative parameters of the fish community are close to the referent for the river type and ecozone. The lower index value established upstream the dam lake is considered a response to the predominance of the sandy-stony habitat along the surveyed transect where the hydromorphological conditions determine lower abundance of some type-specific species. Such habitat is missing within the surveyed river stretch downstream the SHPP where higher abundance of the main species occurred. These results do not indicate a pronounced barrier effect on the river fish community caused by the SHPP Srednogortsi but they suggest that the changed hydro-morphological features favour some eurytopic species in the river section.

Arda River – SHPP Byal Izvor

As the SHPP Byal Izvor is a diverted SHPP (Table 3), water abstraction through a bypass tube occurs. This results into a reduced water flow in the river section between the water reservoir and the SHPP. According to employees of HPP, local fish successfully use the existing fish pass at the dam but there are no data from any research observations on this issue. The surveyed river section is a semi-mountain river of the type R5 belonging to the metarithron ecological zone, with a typical community consisting mainly of *B. cyclolepis* and including also *S. orpheus*, *G. bulgaricus*, *C. vardarense*, *Vimba melanops* and *C. strumicae*. The same species composition of the fish community was found in both surveyed river sections bellow the SHPP and above the water reservoir, with the type-specific potamodromous species *C. vardarense* and *Vimba melanops* being presented both down- and upstream the barrier. The values of BFBI both up- and downstream the SHPP are within the limits of the **Good** ecological status (Table 3). The higher index value found downstream the SHPP probably could be an effect of the higher oxygen content in the water mixed by the SHPP turbines. Type-specific potamodromous species, such as *Chondrostoma vardarense* and *Vimba melanops*, are presented both down- and upstream the barrier. Thus, the results obtained do not indicate some barrier effect of the SHPP Byal Izvor on the fish community in the target section of the Arda River.

Vacha River (Maritsa River basin) – Kadievo SHPP

No data were available about the effectiveness of the fish passage at the dam of the run-of-the-river SHPP Kadievo (Table 3). The surveyed river section is a semi-mountain river of the type R5 belonging to the hyporithron ecological zone. Maritsa barbel *B. cyclolepis* predominates in the samples but with a few accompanying type-specific species represented such as *Rhodeus amarus*, *Proterorhinus semilunaris* and *C. strumicae*. Altered fish communities that include alien, translocated and atypical species were recorded both down- and upstream the barrier, obviously as a result of some intentional or non-intentional stocking. Thus, upstream the barrier high abundances of the atypical species for this river ecozone Brown trout *Salmo trutta fario* and Eurasian minnow *Phoxinus phoxinus* as well as of the translocated *Barbatula barbatula* were found. Downstream

Fig. 3. Water outfall of the Slavova SHPP (no outflow occurs)

the barrier, three alien species (*Lepomis gibbosus, Pseudorasbora parva* and *Carassius gibelio*) were recorded and the above mentioned *B. barbatula* and *P. phoxinus* occurred. The number of fish species downstream was higher than upstream the barrier but this is only due to the presence of several alien and translocated species that are absent upstream. Thus, the barrier effect of the SHPP facilities obviously affects mainly the alien lowland fish species. Atypical low water temperatures measured at both surveyed sites and the evidence of strong fluctuations of the water level and the current velocity indicate a hydropeaking effect of the water discharge from the big reservoirs Vacha and Krichim situated upstream. The values of BFBI both upstream and downstream this SHPP are within the limits of the Moderate ecological state (Table 3). This means that the species composition and quantitative parameters of the fish community significantly deviate from the reference values. The main driver is probably the introduction of alien and translocated species and hydropeaking by the discharge of the upstream big reservoirs. The established features of the ichthyofauna do not provide evidence of some specific impact of the particular barrier on the local fish community but rather suggest a high antropogenous pressure differing from the typical impact of SHPPs.

Petrovska River (Struma River basin) – SHPP Petrovo

Petrovska River is mountain river of the specific type R15 (Spring river sections), for which the Biological Quality Element (BQE) Fish is not considered relevant. The site upstream the water catchment facilities, which belongs to the epirithron ecological river zone, is settled as adjacent to the karsts spring of the river, where fish fauna is totally absent due to natural factors. No dam lake was built and water abstraction for hydropower performs directly through bypass tube (Fig. 2). The river section of about 5 km length between the water abstraction facilities and the SHPP is characterized with very low runoff as a result of the water abstraction for the SHPP. The water abstraction facilities are equipped with concrete fish pass, which is suitable for brown trout but the long river section with highly reduced flow obviously does not allow fish to reach the pass moving upstream. The river section downstream, which belongs to the metarithron ecological zone, is the zone of Maritsa barbel *B. cyclolepis*. However, the fish community was represented only by single juveniles of *B. cyclolepis*. The extremely low fish abundance and species richness are considered rather a response to other pressures (some migration barriers downstream and water pollution by the settlements) than to the impact of SHPP. As the BQE Fish is not relevant for ecological classification of this river type, the ecological state of this river section assessed through expert judgment is **Bad** because of the extremely low fish species richness and abundance.

Pirinska Bistritsa River (Struma River basin) – SHPP Pirin

The two surveyed sections of the Pirinska Bistritsa River (upstream the water catchment facilities of the SHPP Pirinska Bistritsa and downstream the SHPP Pirin) are typical trout streams of type R3 (Mountain rivers) belonging to the epirithron ecological zone. The ichthyofauna is presented only by Brown trout *Salmo trutta fario* what is normal for this river type. The better state of the trout population found in the river section upstream the water catchment probably is an effect of the higher habitat diversity, better protection against illegal fishing in the Pirin National Park, absence of pollution and partially – trout stocking. Two diverted SHPPs (HPP Pirinska Bistritsa and SHPP Pirin) are situated along the river section between the two sampling sites affecting the river runoff by water abstraction. There are no data about the effectiveness of the fish passes at the dams of the two SHPPs. The ecological state of Pirinska Bistritsa River both up- and downstream the barrier was assessed by TRI as **Good** (Table 3) despite the cascade of two SHPPs with their dams and water abstraction facilities situated between the sampling sites. No specific barrier effect or other above mentioned impacts of the SHPPs were identified. The main drivers for the fish community composition in the two surveyed sections of the Pirinska Bistritsa River seem to be some other factors, such as the

seasonal variations of the runoff, microhabitat variety, settlements, land use on the river terraces and forest protection.

Slavova River (Struma River basin) – SHPP Slavova

The surveyed section of Slavova River also belongs to the epirithron ecological zone, being a typical trout stream of type R1 (Alpine rivers). Fish based indices are relevant under conditions for ecological classification of this river type because of the naturally low fish abundance. Therefore, the TRI is considered useful only for preliminary orientation. The diverted SHPP Slavova is with a small water reservoir. The dam is equipped with a concrete fish pass suitable for brown trout passing. In the river section between the water catchment facilities and the SHPP, highly reduced runoff occurs as a result of the water abstraction (Fig. 3). Upstream the water reservoir of the SHPP Slavova, close to borders of the Pirin National Park, both abundance and size structure of the trout population was found to be close to the referent conditions; therefore, the ecological status of the river was determined as **Good** by expert judgment based on TRI (Table 3), regardless the migration barrier of SHPP Slavova. Downstream the SHPP, the water quantity was highly reduced since there was no outflow from the SHPP (Fig. 3). Thus, the **Moderate** status of the river Slavova downstream the SHPP is due to the reduced water discharge, which allows the presence only of few juvenile trouts in this section. According to our results, the potential barrier effect was not identified as a factor affecting the trout population upstream the barrier, where the effect of some forestry activities and other factors prevail. The negative effect of the Slavova SHPP is much more pronounced downstream the barrier because of the reduced water discharge.

Tremoshtnitsa River (Struma River basin) – SHPP Arnaut Dere

The surveyed section of Tremoshtnitsa River belongs to the epirithron ecological zone and is also a trout stream of type R1 (Alpine rivers). Therefore, the fish based indices are relevant under conditions. The dam of the diverted SHPP Arnaut Dere is about 8 m height, being the highest one among the studied sites. The dam is equipped with a concrete fish pass but, even for the Brown trout, it is difficult to pass through it upstream because of the very steep lower part (Fig. 4). In the river section between the water catchment facilities and the SHPP, a reduced water flow occurs as a result of the water abstraction. Along the surveyed river section, only an unstable sandy bottom substrate was recorded. Downstream the SHPP, a strong anthropogenic pressure occurs, i. e. building constructions and river bed modifications. The population density of Brown trout was extremely low both down- and upstream the SHPP complex. This could be explained by the great height of the dam of water catchment, the inefficient construction of the fish pass, the low water runoff and the sandy bottom substrate without enough shelters. The ecological status of both up- and downstream

Fig. 4. Dam and dawn section of the fish pass of the Arnaut Dere SHPP

Fig. 5. Open lock and empty water reservoir of water catchment facilities of the SHPP Vlahi

sites was assessed by expert judgment based on TRI as **Moderate** but downstream the index value was close to **Bad** state (Table 3). According the obtained results, the Arnaut Dere SHPP is a significant migration barrier for the Brown trout. The local ichthyofauna is impacted by the cumulative effect of several negative natural (sediment features, low water runoff) and anthropogenic factors (high dam, water abstraction).

Vlahinska River (Struma River basin) – SHPP Vlahi

The diverted SHPP Vlahi has a very small reservoir of the water catchment facilities. According the information of the regional office of the Executive Agency of Fisheries, the fish pass of the dam is used effectively by migrating Brown trout. During the survey, the SHPP did not function because of the extreme seasonal low water and the water flowed freely through the dam (Fig. 5). Upstream the water abstraction facilities, Vlahinska River belongs to epirithron eco-zone being a typical trout stream, while downstream the SHPP Vlahi, it is metarithron eco-zone, transitional between the Brown trout and the Maritsa barbel streams. Actually, only *S. trutta fario* was presented in the upper surveyed site, while both *B. cyclolepis* and *S. trutta fario* occurred downstream. Therefore, for ecological classification of the site upstream the water abstraction facilities, we used TRI, and for those downstream – BFBI. The ecological state both upstream and downstream was determined as **Good** (Table 3)**.** The results do not allow identifying specific barrier effect of the SHPP Vlahi on the ichthyofauna in the Vlahinska River. Indeed, the established good state suggests the absence of significant impact of the SHPP on the fish community on long-term scale. The differences in the composition and abundance of fish communities in the two target river sections are within the natural limits, concerning the fish distribution along the river continuum taking in account the natural hydromorphological features and the presence of natural migration barriers.

Discussion

In the middle courses of rivers Arda and Vacha belonging to meta-/hyporithron eco-zones and covering the Maritsa barbel zone (river type R5), no evidence was found for specific negative impacts of the surveyed diverted or run-of-the river SHPPs, as assessed by BQE Fish according the Ordinance H-4/2012. In the epi-/metarithron zones of some tributaries of the Struma river (river types R1, R3 and R15) covering the habitats of the Brown trout and the Maritsa barbel, more pronounced barrier effect of the diverted SHPPs was established in downstream than in upstream direction. In some cases, the impact of other factors and human pressures on the fish communities next to the SHPPs, is more pronounced than the presumptive barrier effect and can cover it what make difficult the identification of different impacts. Barrier effect should be prospected on both sides of SHPPs, not only upstream.

Extended surveys of the impact of SHPPs on the fish communities in rivers of the Danube and Black sea basins are advisable with a view to collect more representative data for further analyses.

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