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Spawning of Stocked Brown Trout *Salmo trutta* Linnaeus, 1758 (Actinopterygii: Salmonidae) in Tailwater Section, Downstream Ogosta Reservoir, Bulgaria

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Abstract: Ogosta River downstream Ogosta Reservoir (NW Bulgaria) experiences anthropogenic pressure due to hydrological and morphological alterations. The tailwater canal located downstream the dam is characterised by hypolimnetic cold-water release. For purposes of recreational angling, the tailwater canal was stocked with farmed brown trout *Salmo trutta* in 2018 and 2019. The aim of this study is to examine the environmental conditions in the tailwater section in view of their favourability for trout reproduction and maintaining self-sustainable population. Characterisation of basic water quality parameters, flow regime and food resources as well as monitoring of the spawning activity were implemented. Water flow during the two spawning seasons was set to minimum and remained stable. Optimal annual temperature (5–16 ^{o}C), sufficient oxygen content (6.86–13.57 mg.L^{-1}), low turbidity (0.73–20.6 NTU) and abundant food resources consisting mostly of *Gammarus* spp. (up to 7632 ind.m^{-2}) were considered as beneficial for the trout growth, maturation and successful spawning. Over 263 redds were counted for the two years, with density of 19 redds per km for 2020 and 68 redds per km for 2021. High rate of redd superimposition (c. 33% for 2020 and c. 41% for 2021) was registered. Increased water release during the post-spawning period (February – March) observed in 2021 could impair fry emergence and survival.

Key words: stocked brown trout, redd count, Ogosta tailwaters, fisheries

Introduction

Large dams alter the river continuity, morphology and flow regime. Their impact on fish populations could result in delayed, impeded or completely suspended migration and isolation of populations. Such constructions could prevent access to spawning, foraging or shelter habitats as well as induce changes in water or habitat quality and quantity. Tailwater sections, situated downstream the dam often receive cold, hypolimnetic water, released from the deeper layers of the reservoir through operating hydraulic facility. Though considered a modification, this change in the water temperature could be beneficial for cold-water species, e.g. trout; such sections are often considered highly productive for the trout fisheries (Pender & Kwack 2002, Meerbeek & Bettoli 2005, Dibble et al. 2015, Budy & Gaeta 2017). As part of sustainable management, tailwater fisheries often adopt the Catch-and-Release (C-R) regulations (Arlinghaus et al. 2007), in addition to continuous stocking for the purposes of fish growth maintenance (Pender & Kwack 2002). Enhanced flow regime (Moreira et al. 2019, Hayes et al. 2019) and habitat complexity (Pender & Kwack 2002, Barlaup et al. 2008) are essential for the high tailwater productivity. Providing favourable environmental conditions in order to establish self-maintenance population can lead to a reduction in economic costs. Fish monitoring is essential part of tailwater fishery management. Redd count is often used in fish monitoring as a rough but low cost estimation of the size of the trout population (Gallagher et al. 2007). The redd distribution is usually limited by local hydrology, morphology and geology, including riverbed features like, water depth, flow velocity, substrate availability, suitability, permeability, embeddedness, siltation rate, shelters, etc. Water release management determines water temperature and dissolved oxygen, which are crucial factors for trout growth (Elliott et al. 1995), reproduction (Solomon & Lightfoot 2008) and survival (Elliott 1994). Food resources are also important in the assessment of annual growth, considering macroinvertebrates as essential part of the trophic share consumed by brown trout *Salmo trutta* Linnaeus, 1758 (Johnson et al. 2007, Anderson et al. 2016, Flinders & Magoulick 2017).

There are 556 large dams in Bulgaria (Tasev et al. 2017); 54 of them are subject to complex operation and their priority purpose include water supply, irrigation and electricity production. Most of them have hypolimnetic release and could provide additional ecosystem services like cold-water fisheries. This study focuses on the tailwater section downstream Ogosta Dam and aim to identify if the area has the potential for management of self-sustaining brown trout fisheries. Redd count was applied as basic monitoring tool for trout recruitment. In addition, data about environmental factors connected to trout growth and spawning like water quality, food resources, species interactions, river morphology and flow regime were provided.

Materials and Methods

Ogosta Reservoir is one of the largest in Bulgaria, with full capacity of 506 million cubic meters. The reservoir is situated on Ogosta River at the foothill zone between the Balkan Range and the Danube Valley. The Dam was built for irrigation purposes but nowadays also produce hydropower energy. The river downstream the dam accumulates multiple anthropogenic pressure due to disrupted river continuity as well as hydrological and morphological alterations. The tailwater section includes weirs, sluices, modified riverbed, straightened watercourse, concreted riverbanks, detached floodplains and regulated river flow, including hydropeaking events because of hydropower plant (HPP) activity. The direct human pressure on the fish community also includes angling and poaching (personal communications with local anglers). However, the reservoir has hypolimnetic water release that could benefit cold-water fish. Hence, the local fishing community stocked the river section downstream the dam with farmed brown trout. About 10,000 fry from Toshkov Chark Reservoir were released in May 2018. About 3000 fry from Toshkov Chark Reservoir and 16,000 fry from Iskretz Farm were stocked in May 2019. Downstream the reservoir, 12 km long section was declared as C-R zone. The stocked fish grew fast and in October 2019 spawning behaviour as well as redd construction were observed. A population of rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) also occurred in the river section and interacted with the brown trout; it was believed that rainbow trout originated from a fish farm situated few kilometres downstream the studied river section. Before the dam construction in 1980-thies, the river section was a barbell zone dominated by barbell *Barbus petenyi* Heckel, 1852, chub *Squalius cephalus* (L., 1758) and nase *Chondrostoma nasus* (L., 1758) (unpublished data).

The redd survey was conducted within a 5-km-long river section downstream Ogosta Dam (Fig. 1). In order to assess the abiotic environmental factors of the spawning area, data about river structures, morphology, hydrology and passability were obtained. Physical and chemical water quality parameters (annual and longitudinal distribution of temperature, oxygen concentration, oxygen saturation, electroconductivity and turbidity) were measured. Sampling stations were selected at 0.3 rkm, 0.8 rkm, 2.1 rkm, 3.2 rkm, 4.1 rkm and 4.8 rkm downstream HPP (Fig.1). Additionally, physical and chemical parameters were measured downstream significant inflows: Wastewater Treatment Plant (WWTP) of the town of Montana at 8 rkm, the town of Boychinovtsi at 18 rkm and the main tributary Shougavitsa River at 13 rkm downstream the reservoir (Fig. 1). Physical and chemical parameters were measured during seven months between February 2020 and January 2021. Turbidity was measured before and after heavy rain in January 2021. Water flow regime was presented using data for daily and monthly water discharge from the website of Ministry of Environment and Waters (MOEW) of Republic of Bulgaria.

Macroinvertebrates (regarded as trophic resources) were quantitatively sampled every month from May to September 2020. The samples were taken from shallow bank sections close to potential spawning habitats, i.e. riffle sections with domi-

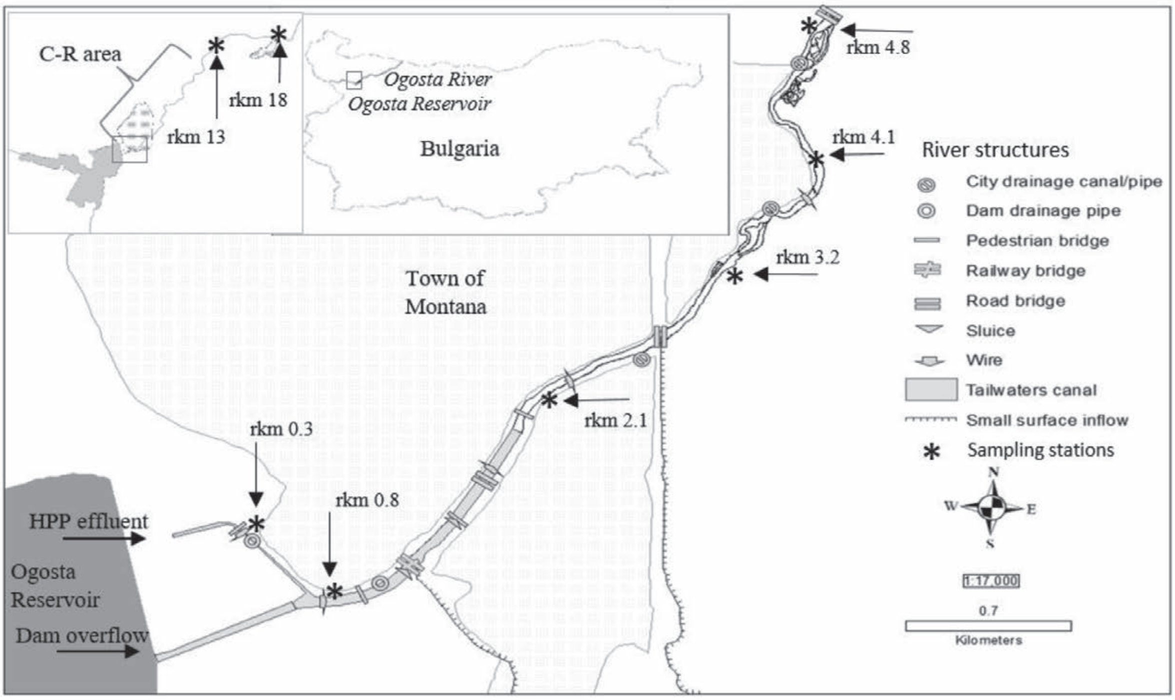

Fig. 1. Redd assessment area – 4 km long section between 0.8 and 4.8 rkm downstream Ogosta Reservoir. Arrows are indicating the distance (km) downstream the dam-wall. Sampling stations * at 0.3, 0.8, 2.1, 3.2, 4.1, 4.8, 13 and 18 rkm downstream the Reservoir. Macroinvertebrate samples were taken from 0.8, 2.1, 3.2, 4.1 and 4.8 rkm downstream the Dam.

nated gravel substrate (16–128 mm) at five sampling sites within 0.8 to 4.8 km downstream the reservoir (Fig.1). Samples were taken with kick net with frame 0.25 x 0.25 cm, 1 mm mesh size, for 30 seconds tearing the bottom surface, with replicate. Main taxonomic groups were identified and average abundance was calculated per square meter area.

Redd count was conducted in February 2020 and January 2021, in the end of the spawning season. The count was performed along a 5-km-long river section by one or two persons, by zig-zag wadding downstream. Bank and bridge observations if applicable were also applied. Identification of complete redd was considered if both distinctive structures, i.e. pit and tail, were distinct; otherwise, the redd was considered to be doubtful or false (Crisp & Carling 1989, Gallagher et al. 2007). Overall, five redds during February 2020 and 19 redds during January 2021 were sampled in order to verify the stage of development as well as the timing of fry emergence. Sampling was performed by excavation of a small part of the redd area (c. 0.023 m^2) up to 0.30 m depth from the area of the egg pocket.

Results

Modified river morphology was represented by straightened watercourse and concrete vertical banks along two kilometres downstream of the dam. The connection between the river and the floodplain was interrupted up to 4 km downstream. Eight bridges (four pedestrian, three for vehicles and one railway) cross the river within the town of Montana (Fig.1). Eight river obstacles, including six weirs and two sluices (most of them for bridge fortification) entirely cross the river. The high of the weirs and sluices ranged between 0.2 m and 0.8 m, gradually increasing in height upstream. Four of them situated downstream were considered as passable for most of the fish. Only the first weir (situated at the 0.3 rkm downstream of the HPP) reached over 1 m height; it was considered impassable due to its height, strong currents and lack of rest pool nearby. The two sluices were not in working condition, forming a river bottleneck, resulting in downstream riverbed scouring and upstream impoundment pools.

The hydrological regime of the river was considered as regulated. During both investigated spawning periods, the reservoir water volume was low and significant release of water was not registered (Fig. 2a). Minimal ecological flow was maintained 2–4 m^3s^{-1}. Slight dynamics in water discharge due to HPP operation was registered in the fall of 2019 as well as in the summer of 2020 (Fig. 2a). Even though the water discharge was maintained relatively stable during the spawning period, runoffs due to heavy rains and snowmelts led to its occasional increase. In the beginning of 2021, the water volume of the reservoir

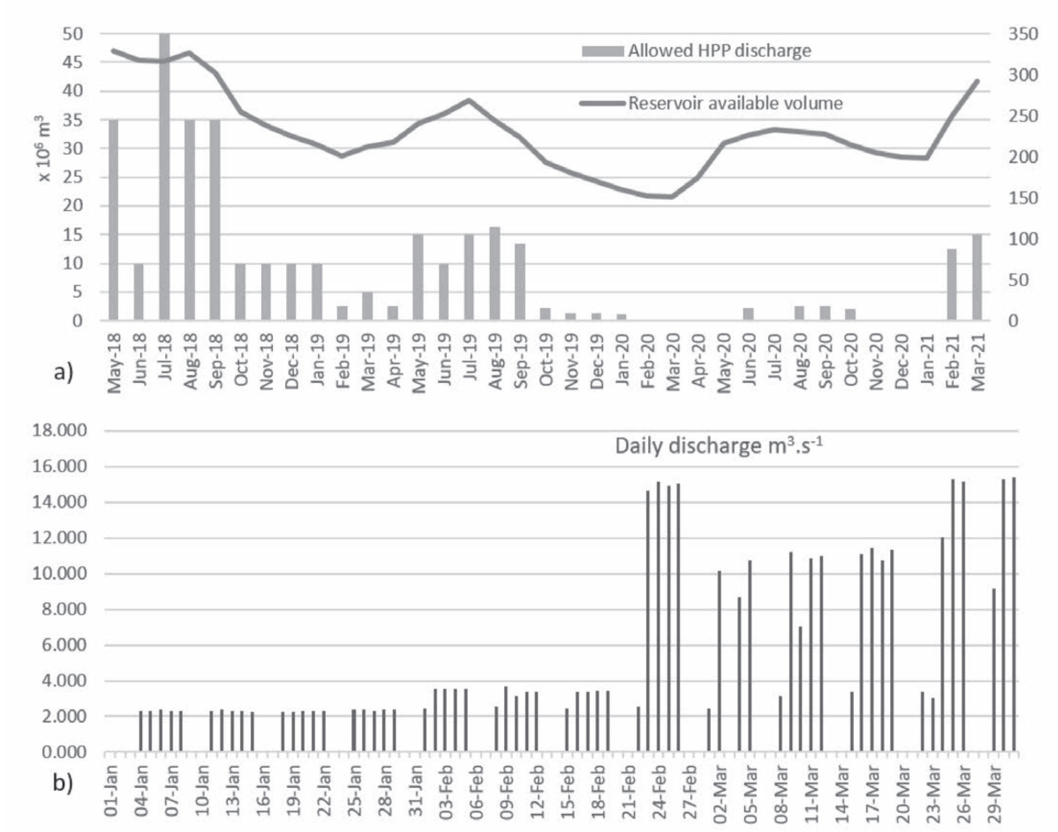

Fig. 2. a. The columns indicate the monthly discharge provided by hydropower plant HPP allowed by authorities. The line indicates the available volume of water in Ogosta Reservoir. Data include the period since the first stocking in May 2018 until the post-spawning period in March 2021. Minimal ecological flow not included. **b.** Average daily discharge during the post-spawning period. In January 2021, only minimal ecological flow was maintained. In February and March 2021, weekly hydropeaking dynamics were registered.

increased. As a result, water release increased, with monthly discharge from 2.32 x 10^6 m^3 (SD±0.04) in January to 5.12 x 10^6 m^3 (SD±4.83) in February and 6.2 x 10^6 m^3 (SD±4.22) in March 2021. The water release performed under HPP operation caused weekly hydropeaking dynamics with daily discharge ranging 2.43–15.16 m^3s^{-1} (Fig. 2b).

Annual water temperature along the 5-km section downstream of the reservoir ranged between 5 to 16.3 ^oC (Fig. 3). The released water temperature during the winter remained about 5 ^oC, slightly varying few kilometres downstream. About 13 rkm downstream HPP, the water temperature dropped at 3.4 ^oC due to the colder water of Shugavitsa River confluence. The highest temperature of the released water was 10.4 ^oC in August 2020 due to limited discharge caused by low water level in the reservoir. Due to the summer heat and low water discharge, the released water quickly warmed up to 15.4 ^oC at 0.8 rkm downstream HPP and then slightly increased up to 16.3 ^oC at 2.1 rkm.

As the oxygen content is highly dependent on temperature, it showed the opposite trend (Fig. 3). The highest dynamic in oxygen content and saturation was registered at 0.3 rkm downstream HPP (Fig. 1). The released water experienced nearly hypoxia in the summer, with 2.75 $mg.L^{-1}$ in September and 3.68 $mg.L^{-1}$ in August. At 0.8 rkm downstream HPP, at the beginning of the fishery, the water quickly saturated with oxygen and the values increased to 6.86 $mg.L^{-1}$ in August and 7.33 $mg.L^{-1}$ in September. Highest oxygen content of the released water was 11.64 $mg.L^{-1}$ registered in the coldest period (February 2020). During the winter months (December – February), oxygen content ranged from 8.93 $mg.L^{-1}$ up to 13.37 $mg.L^{-1}$, while saturation ranged from 76 % up to 110 %. Oxygen drop was registered at 8.3 rkm downstream the dam (after Montana WWTP) and at 18 rkm downstream the dam (after the town of Boychinovtsi).

Average electroconductivity of 227 $\mu S.cm^{-2}$ (SD±10.48) and pH 8.23 (SD±0.18) were relatively constant for the first 5 km, with small fluctuations usually after small inflows or drainage pipes or canals (Fig. 3). Significant increase in conductivity and decrease in pH were registered downstream Montana WWTP and the town of Boychinovtsi. The

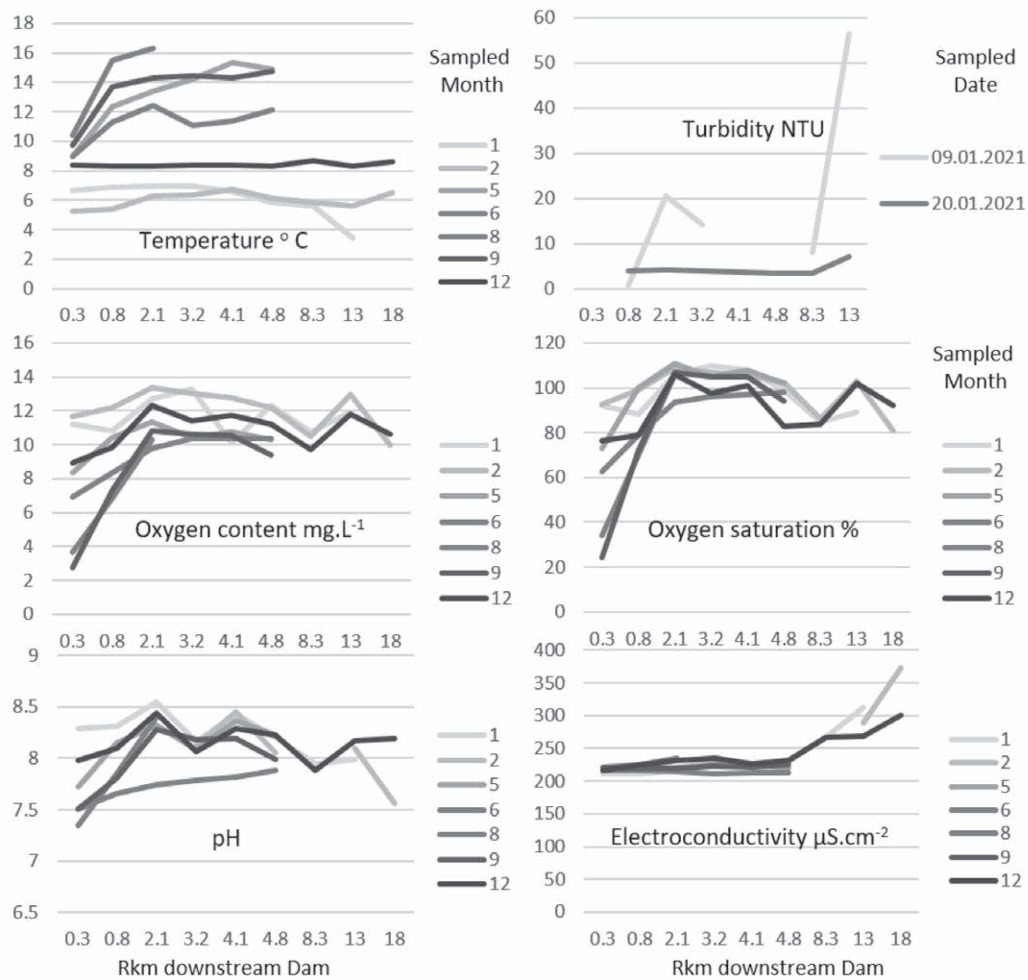

Fig. 3. Monthly values of temperature, oxygen, pH, electroconductivity and turbidity for the investigated section downstream Ogosta Dam. Turbidity was measured during stable conditions on 20 January 2021 and after heavy rains on 9 January 2021.

inflow of Shougavitsa River (13 rkm downstream the reservoir) resulted in normalising pH and electroconductivity.

Turbidity in the main stream of the 5-km section was relatively low – 6.79 NTU (SD±6.84). Small surface inflow at 1.2 km downstream the reservoir, after heavy rains temporary increased the turbidity of the main canal up to 20.6 NTU (Fig. 3). More significant increase of turbidity of 56 NTU was registered downstream of the survey area, due to major tributary Shougavitsa River. The turbidity at the released water downstream HPP remained low at 3.8 NTU even after heavy rains.

About twenty main taxonomic groups of macroinvertebrates were identified but only eleven of them contributed to 96 % of the total abundance (Table 1). Within the tailwater canal section at 0.8 rkm, main contribution was due gammarid amphipods, with average of 3018 ind.m^{-2} or about 37.7 % of the total abundance of macroinvertebrates. During the redd survey, trout feeding on gammarids were often observed. Only few kilometres downstream, the share of more tolerant to organic loading taxa like Chironomidae, Ephemeroptera, Oligochaeta, Hirudinea and Isopoda (*Asellus aquaticus*) increased significantly.

First spawning activity was observed in October 2019 by local anglers. Fish maturation was assessed as 1+ years for males and females, considering fry stock in May 2018. The size of the observed spawning fish often exceeded 30–40 cm total length. The peak in redd construction was in the middle of December 2019. The spawning behaviour and redd construction was rare but still observed in February 2020 when the redd count was initiated. Over 109 redd structures were counted. About 58 complete redds were identified (Fig. 4). We considered 17 redds as doubtful and over 34 as false; these were not presented here. Downstream 3.8 rkm, only false redds were encountered for both spawning seasons. Complete redds were calculated as 19 redds per river kilometre.

Table 1. Average abundance of macroinvertebrates per sampling station represented as ind.m^{-2} and 96 % contribution during the period May to September 2020.

Taxonomic group	rkm 0.8	rkm 2.1	rkm 3.2	rkm 4.1	rkm 4.8	Total Average	Contribution %	Cumulative contribution %
Amphipoda	7632	3951	325	3	3	3018	37.7	37.7
Chironomidae	1056	590	1710	861	1749	1166	14.6	52.2
Oligochaeta	242	275	1339	2291	1262	970	12.1	64.3
Ephemeroptera	398	642	1276	1269	673	836	10.4	74.8
Simuliidae	3	188	348	104	1227	345	4.3	79.1
Isopoda	73	34	91	427	808	288	3.6	82.7
Turbellaria	222	62	181	381	494	267	3.3	86.0
Gastropoda	446	449	27	2	12	245	3.1	89.1
Nematoda	41	27	178	627	173	190	2.4	91.4
Hirudinea	144	82	130	275	379	187	2.3	93.8
Trichoptera	3	47	656	88	203	179	2.2	96.0

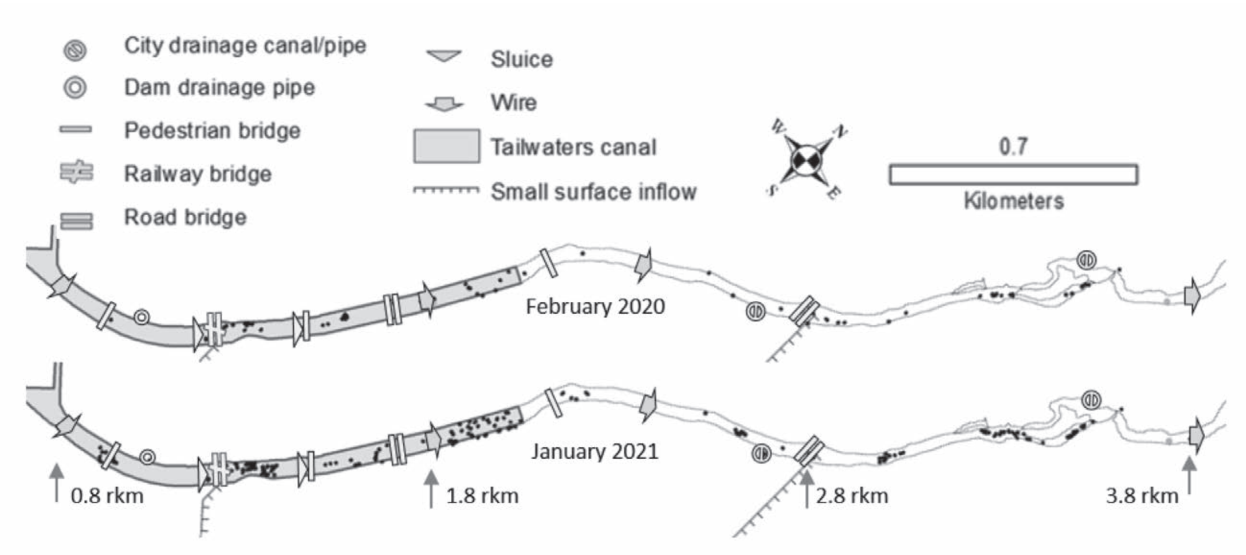

Fig. 4. Redd distribution (small black spots) between 0.8 and 3.8 rkm downstream Ogosta Reservoir surveyed after spawning seasons in 2020 and 2021. Downstream 3.8 rkm only false redd were observed and were not included in the map.

The spawning behaviour of the next spawning season started from October 2020, immediately after the end of the angling season. This time the observed peak in redd construction was in November 2020, i.e., earlier than the previous spawning season. Some spawning fish exceeded 50 cm total length. In January 2021, when the redd survey was conducted observation on spawning behaviour was rare. Overall, 205 redds were considered as complete for the same 3-km section 0.8–3.8 rkm. The average density was calculated to 68 redds per river kilometre.

Redd clustering was registered in riffle structures downstream sluices and wires. Most of redds were situated within the tailwater canal between 1.2–1.4 rkm and 1.8–2.0 rkm (Fig. 4). Additional redd aggregation was observed in a riffle with gravel deposit in front of an island and along its main branch between 3.3 and 3.5 km downstream the reservoir. The lowest redd density was registered in pool sections in front of weirs and sluices, characterised with increased siltation and dense submerged vegetation as well as in run sections with highest slope, highest current and boulder occurrence. In large number of cases, redds overlapped each other to different extend. In the winter of 2020, redd superimposition was observed for 19 redds (c. 33% of the total cases) compared to 86 redds (c. 41%) for the winter of 2021 (Fig. 4). Scouring over older redds were also observed.

About 23 out of 25 samples used for complete redd verification contained fish material at different stages of development. Trout eggs were found in seven of the sampled redds, while alevines were found in thirteen of the sampled redds and fry were found in three redds. The earliest emerged fry was accidentally observed at 6th March 2020. Overall, fry emergence was expected between February and April.

According to the information obtained by recreational angling, the catches of the brown trout (*S. trutta*) and rainbow trout (*O. mykiss*) during the summer of 2020 were equally represented. During the winter spawning season, rainbow trout (*O. mykiss*) showed well-pronounced features of maturation like bright coloration and kype extension in males. Redd constructions were also observed, next to brown trout redds. Eggs, sampled from a redd constructed by a pair of rainbow trout, were rotten.

Discussion

Stocked farmed trout usually grow faster and bigger than wild populations. However, native trout population was not reported for this river section. Increasing redd density was a sign of a growing trout population and considered as evidence for favourable environmental conditions. Annual and seasonal water temperature was within the optimum range for all developmental stages of brown trout (Elliott et al. 1995, Solomon & Lightfoot 2008). Water oxygen content during the spawning period was also considered as sufficient for successful egg development. The hypolimnetic water release provided protection against siltation and redd clogging. Contrarily, highly turbid and silted sections were observed downstream after heavy rains or snowmelt. Abundant food resources, in particular gammarid crustacean, as one of the most utilised food resources in trout tailwater fisheries (Flinders & Magoulic 2017), were considered as contributor to the fast growth, early maturation and large size of the fish.

However, decreased water quality, as evidenced by domination of more tolerant macroinvertebrate taxa, was registered only few kilometres downstream the reservoir. It could be associated with low water quality directly from the reservoir or due to numerous drainages and sewage canals through the town of Montana discharged into the river.

Most of redds were situated in the complex riffle sections, upstream and along islands, or downstream fortification weirs and sluices within the tailwater canal. Redd density was within the range previously reported (Wood & Budy 2009, Gortázar et al. 2012, Blain et al. 2018). The degree of redd superimposition for 2020 was comparable with reports from natural populations (Gortázar et al. 2007, 2012) but increased in 2021. The study was conducted after the peak of the spawning period, hereafter the total number of redds could be underestimated in both spawning seasons. Nevertheless, the relatively low and stable water discharge favoured the redd longevity, respectively the redd count.

The dry years 2019 and 2020 were associated with water crisis in Bulgaria and imposed restrictions on water resources, including hydroelectricity. This resulted in maintaining minimal but constant water discharge downstream Ogosta Reservoir, especially in the winter periods. Stable water discharge during the spawning periods was considered as important for successful spawning and egg development (Meerbeek & Bettoli 2005). Timing of fry appearance highly depend on thermal conditions determined by flow regime and should be considered in water flow management (Moreira et al. 2019, Hayes et al. 2019). During the post-spawning period of February-March 2021, the increased water discharge resulted in hydropeaking events, which could directly impair the redd structure, egg development and survival as well as fry emergence (Hayes et al. 2019). More detailed and prolonged studies on hydropeaking and thermal modification could improve the assessment of the impact of the water flow regulation on trout recruitment.

In our study, the natural reproduction of the rainbow trout (*O. mykiss*) in the region remained unconfirmed. Natural reproduction of this species was reported widely across Europe (Stankovic et al. 2015). The observed features of maturation, spawning behaviour, redd construction and egg deposition evidenced for natural reproduction of the rainbow trout in the Ogosta tailwater. However, the recorded mortality of eggs of this species suggests that its population in the region could be maintained by fish escapes from the nearest fish farm.

The intensive spawning of an introduced species such as brown trout raises the question of whether this species poses a threat outside the introduced range, i.e. for native trout populations (Simonović et al. 2015, Kanjuh et al. 2021) or what is the cumulative effect of interactions with the rainbow trout on the local fauna. Ogosta Dam is practically impassable barrier for upstream fish migration. Nevertheless, some mountain tributaries such as Shougavitsa and Botunya joining downstream the stocked section could be concerned. However, it remains unknown to what extent the native trout populations have already been affected by the continuous, unregulated stocking during the last century throughout the country. On the other hand, it is still unknown to what extend the water flow management of the reservoir as well as the upcoming climate changes could limit or benefit downstream trout dispersion and survival.

Conclusions

Although the study was carried out only two seasons, the increasing trout density reflected by the redd survey indicates a growing trout population. Reduced but constant water discharge determined optimal and stable environmental conditions for trout recruitment, especially during the spawning periods. However, it remains unclear how the water flow management would influence the trout population during periods with increased dynamics in climate. This study could provide a baseline for monitoring future reproductive efforts of both brown and rainbow trout in tailwaters and (or) C-R areas, thus supporting research-based management of recreational fisheries.

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