EcoPeak – Impact analysis of different operational scenarios of a mini-hidropower scheme in the fish habitat and maintenance of the spawning grounds

Extend Abstract

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Introduction

The natural flow regime in rivers is affected by hydropower plant operation which causes variations of intensity, frequency and magnitude on the discharge downstream the hydropower plant, a phenomena that goes by the name of hydropeaking (Cushman 1985; Moog 1993). Fish populations are affected by hydropeaking, as this regime may cause stranding and drifting of the species, lead to the dewatering of the spawning grounds, and alterations of the habitat suitability and availability, compromising the population's dynamic (Young et al. 2011). The European Union Water Frame Directive (EU WFD) describes hydropeaking as one of the main events that cause stress in the aquatic systems, affecting the river aquatic biota. Structural and operational measures have been considered, to help mitigate hydropeaking. In these measures, it should be considered the environmental effect and the maintenance of the ecosystems and also the economic viability of the hydropower plant.

Despites the described impacts, hydroelectric energy has many advantages compared to other types of renewable energies production. Hydroelectric production is more efficient, has a faster response to peak periods of energy consumption, it is less pollutant and, in some cases, it can maintain the production during summer time (Balat 2006). The unstable consumption of electricity during the day demands an unstable production of energy by the hydropower plant which causes fluctuations in the discharge downstream. Turbined discharges are also dependent of the reservoir capacity and the most valuable economic tariff periods.

Therefore, the aquatic biota is constantly subjected to hydropeaking, downstream hydropower plants, as the result of fast changes in the discharge. This project intends to quantify hydropeaking indicators that are related to fish habitat suitability, discharge velocity and depth preferences, and dewatering of the spawning grounds, so hydroelectric energy production may be compatible with habitat and fish species preservation, analysing, for that matter, a hydropower plant in the north of Portugal.

To characterize the hydropeaking impact, some parameters have been calculated (Zolezzi et al. 2011; Sauterleute and Charmasson 2014; Carolli et al. 2015) indicators are related to the discharge parameters, as the wetted area (*A*), time (*t*), water depth (*h*), maximum and minim discharge (Q_{max} and Q_{min}, respectively), as Table 1 demonstrates.

Table 1 – Hydropeaking indicators related to the discharge parameters (adapted from Harby and Noack 2013)

Parameter	Hydropeaking indicator
Wetted area	Wetted area rate of change ($\Delta A/\Delta t$)
Water depth	Rate of change ($\Delta h/\Delta t$)
Q_{max} and Q_{min}	Flow ratio (Q_{max}/Q_{min})

Hydrologic and morphologic changes in the river ecosystem may be lethal to fish species (Chen et al. 2015). Therefore, one of the main questions related to hydropeaking is the quantification of the impacts that this regime has on the river ecosystem in order to find measures to mitigate those impacts. The construction and implementation of structural and operational measures to help mitigate hydropeaking have different ecological benefits that can be difficult to estimate and predict (Bruder et al. 2016). The applied measures should be adapted to river characteristics and the ecological aim to achieve. Structural measures include the diversion of the peak discharge to a natural retention basin such as a lake or a river (Bruder et al. 2016), or the modification/renovation of the morphology in the affected river by creating fish lateral refuges (e.g. Ribi et al. 2014; Costa 2018), among other structures. Decreasing the peak discharge or increasing the minimal discharge, decreasing the peak discharge frequency, and others, are some of the operational measures that can be applied to mitigate hydropeaking (e.g. Pragana et al. 2017; Boavida et al. 2019). There is a lack of monitoring programs to help predict the success of these mitigation measures, which they might fail do to their design, hydrologic conditions, fish behaviour, and other factors.

Managing river ecosystems include the capacity to predict and model habitat preferences for each specie and life stage (Haghi Vayghan et al. 2016). Water depth, discharge velocity, wetted area, bed cover and substrate, are some of the factors that fish individual seek in a habitat (e.g. Armstrong et al. 2003). Habitat availability and suitability can be quantified by numeric models (Dunbar et al. 2012).

This study intends to define and analyse different operational scenarios of a mini-hydropower scheme (MHP), considering the impact of hydropeaking regime in fish habitat and maintenance of the spawning grounds, in the river reach where the MHP is located. To accomplish these goals, the Bragado mini-hydropower scheme, located in Avelames River, Tâmega basin was selected as a case-study. The river 2D modelling was achieved in HEC-RAS numeric model. To evaluate the habitat suitability and availability, ArcGIS was used.

Matherial and methods

- **Case study**

Bragado MHP is located in Avelames River, in Vila Pouca de Aguiar council, Vila Real district. This river is a tributary from Tâmega River, with a total catchment area of 78,8 km^2. The Bragado MHP has a total head of 159 m, maximum turbined discharge of 2,2 m^3/s and an installed capacity of 3,1 MW. The hydropower plant has a Francis turbine (1000 rpm) with an horizontal axis and the annual energy production is 9,0 GWh.

Downstream Bragado MHP a 150 m long reach was selected with a slope of 0,0332 m/m (Trincão 2018). The fish assemblage community of the Avelames River is dominated by the *Cyprinidae* family, namely Iberian nase (*Pseudochondrostoma duriense*), Iberian chub (*Squalius carolittertii*) and calandino (*Squalius alburnoides*). Iberian nase is a relatively abundant specie, that prefers areas with moderate velocity, feeds of vegetation and small invertebrates and debris, reproducing between March and June (Diretiva Habitats 2005). Iberian chub can be found both in mountains or plain rivers, feeding of arthropods and other small animals (Fishbase). Calandino chooses rivers with low water depth and width (Godinho et al. 1997), feeding of insects larvae and reproducing between March and July (Diretiva Habitats 2005).

▪ Data collection

Riverbed topography survey was performed between 8 and 10 of September 2017, collecting a total of 5045 points (x, y and z coordinates). Also, in 5 transversal sections, water depth was recorded. The collected data was used to calibrate the hydrodynamic model, by modifying the bed roughness and the finite element mesh, to adjust the difference between recorded values and the simulated ones.

Fish species were marked with the PITtag technique (Passive Integrated Transponder tag), that tracks and monitors fish location and displacement, through a portable antenna. Previously, fish were captured with electric fishing, following the European standards (CEN, 2003) and the national legislation (INAG, 2008). A total of 79 fish were marked (average length and average weight of 8,8 ± 1,9 cm and 8,5 ± 8,6 g, respectively). After that, fish locations were sampled by means of a portable antenna. Each time a fish is recorded, the velocity and depth were also measured. Sampling took place in two seasons, roughly corresponding to Spring (June 2018) and late Summer (October 2018). In each season, fish were sampled in 6 randomly days when Bragado MHP was not operating. From the 79 fish tagged we were able to record 36 fish. Average velocity for Spring and late Summer was 0,22 and 0,05 m/s, respectively, and average water depth was 36,2 and 32 cm, respectively.

Spawning grounds were identified in the river reach in a total of 14, on the 3 of October 2018. Their characteristics (dimension, location and depth) were collected.

▪ Hydrodynamic modelling

To perform the hydraulic simulations, the HEC-RAS model was used in two dimensions. The HEC-RAS model performs the simulation in unsteady flow, applying full Saint Venant equation (where turbulence and Coriolis force are considered) or Diffusion Wave equation. Simulation time is different in both equations, however, Saint Venant equation is more suitable for shallow water problems. The inputs are the boundary conditions (flow hydrograph in the upstream boundaries and normal depth in the downstream boundary) and Manning's roughness coefficient *n* (1).

$$n = \frac{1}{k_s} \tag{1}$$

where k_s is the effective roughness.

Before calibrating the model, a sensitivity analysis was made to the simulation time. Simulation time depends on the finite element mesh and average discharge velocity in the river reach, and also the Courant number (*C*). The simulation time is also an input to the simulation. A Courant number was considered for the Saint Venant (2) and Diffusion Wave (3) equations. After setting the Courant number, simulation time is calculated, considering the average discharge velocity (V), time interval (Δt) and average cell dimension (ΔX).

$$C = \begin{cases} \Delta T \leq \frac{\Delta X}{V} \; (with\; C = 1) \\ \frac{V \Delta T}{\Delta X} \leq 1 \; (with\; C_{max} = 3) \end{cases} \quad (2)$$

$$C = \begin{cases} \Delta T \leq \frac{2\Delta X}{V} \; (with\; C = 2) \\ \frac{V \Delta T}{\Delta X} \leq 2 \; (with\; C_{max} = 5) \end{cases} \quad (3)$$

By adjusting the roughness coefficient and the finite element mesh, the model was then calibrated using the rating curve by Trincão 2018 (simulating a set of discharges from 0,01 to 10 m^3/s, in a total of 21 simulations), and the water depth values recorded in the 5 transversal sections during field work. The calculated and simulated values were compared in terms of water surface elevation. The finite element mesh and roughness coefficient are modified until the model is calibrated, and also the Courant number and simulation time. At the end of the calibration process, the model was simulated for the selected discharges corresponding to the discharges during the field survey and a range of turbined discharges.

- **Habitat modelling**

Habitat assessment was performed with ArcGIS. The inputs to this modelling were the results obtained with the hydrodynamic model of HEC-RAS, in terms of water velocity, depth and wetted area. These results were intersected with fish and spawning grounds location. The intersection of the fish and spawning grounds location with the simulated data, describes the habitat characteristics and fish species preferences. For the data intersection a 1 m buffer around each fish was considered (Boavida et al. 2017). Considering the spawning grounds, the buffer used for the intersection had a value equal to the spawning ground section ratio.

Fish location was intersected with the values of water velocity, depth and wetted area for the discharge occurring during the field survey, with absent of the hydropower plant. Spawning grounds were intersected with the operational scenarios established.

- **Hydropower plant operational scenarios**

Hydropower plant operational scenarios were defined considering the knowledge about the hydropower operation scheme:

i. Hydropower plant operation for the maximum discharge of 2,2 m^3/s.
ii. Hydropower plant operation for the minimum discharge of 0,7 m^3/s.
iii. Hydropower plant operation for the discharge of 1 and 2 m^3/s.

All the previous scenarios were combined with the river natural regime. Additionally, the discharge during the days of fish sampling and the turbined discharge immediately before the fish sampling were also considered as an operation scenario. These scenarios were considered to understand how the hydropower plant operation may affect habitat suitability and availability, in terms of water velocity, depth and wetted area. The considered operational scenarios are shown in Table 2, where $Q_{turbined}$ is the turbined discharge and Q_{river} is the discharge from the river natural regime.

Table 2 – Operational scenarios considered for Bragado hydropower plant

Scenarios	$Q_{turbined}$ [m^3/s]	Q_{river} [m^3/s]
Sampling	0,9	0,35
		0,40
		0,60
	1,0	0,50
	1,8	0,60
	1,9	0,50
Operation	0,7	0,07
	1,0	0,07
	2,0	0,07
	2,2	0,07
		1,00
		2,00

Results

- **Habitat conditions**

The maximum turbined discharge (2,2 m^3/s) and the maximum discharge from the river natural regime (2,0 m^3/s) generated the highest velocities in the river reach, that in some locations were higher than 3 m/s, as it can be seen in Figure 1.

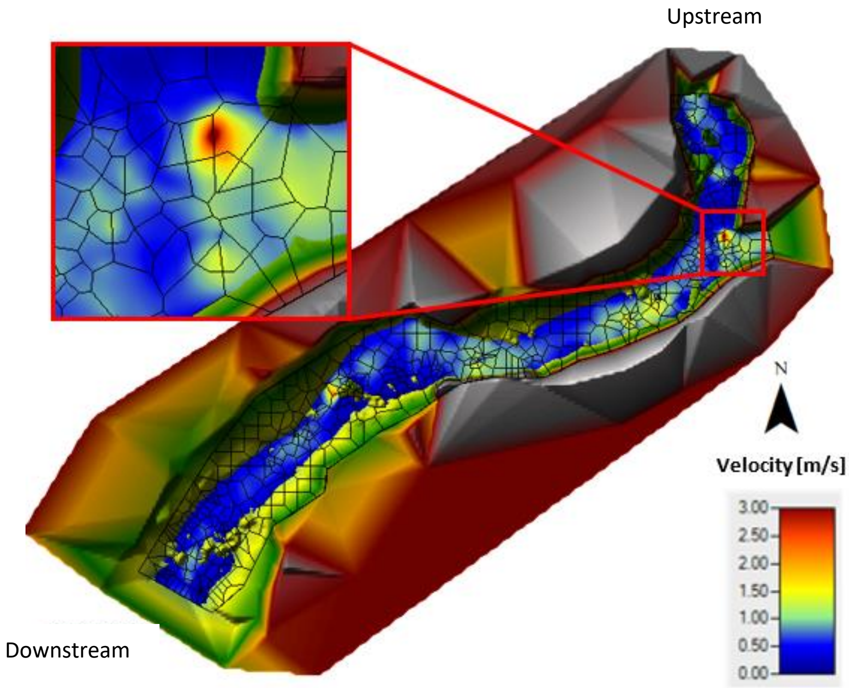


Figure 1 – Discharge velocity in the river reach considering the maximum turbined discharge (2,2 m^3/s) and the maximum discharge from the river natural regime (2,0 m^3/s).

During the fish sampling, each fish location was intersected with water velocity and depth simulated values for the discharge occurred during sampling. Upstream the water release from the hydropower plant, fish are located in areas with higher depth and lower velocity, with no difference between June and October (Spring and late Summer, respectively), unlike individuals located downstream. A decrease in the water velocity and depth can be observed between both seasons, which is consistent with the discharge decrease. The results for this analysis are illustrated in the graphics present in Figure 2.

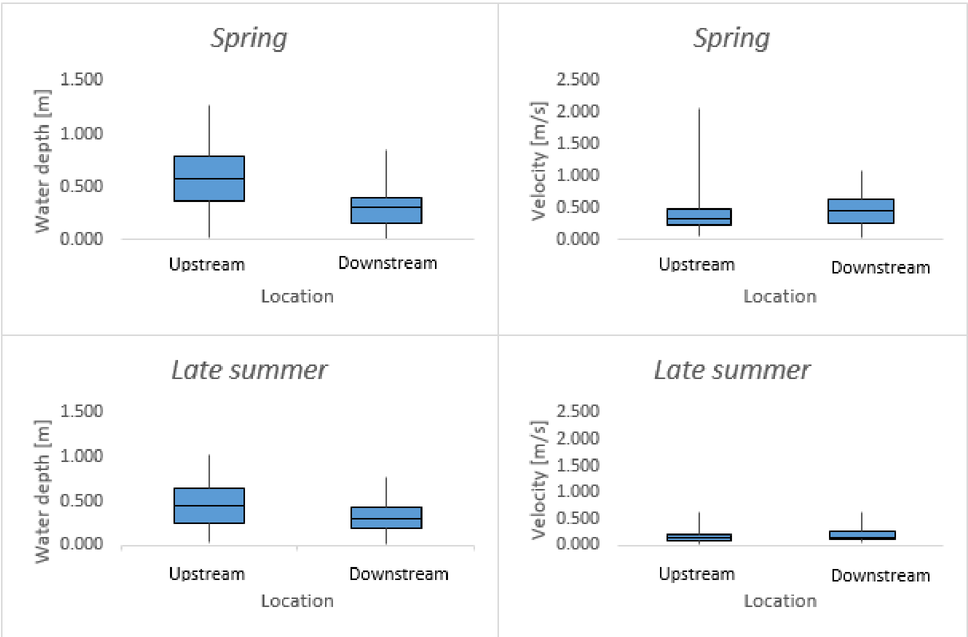
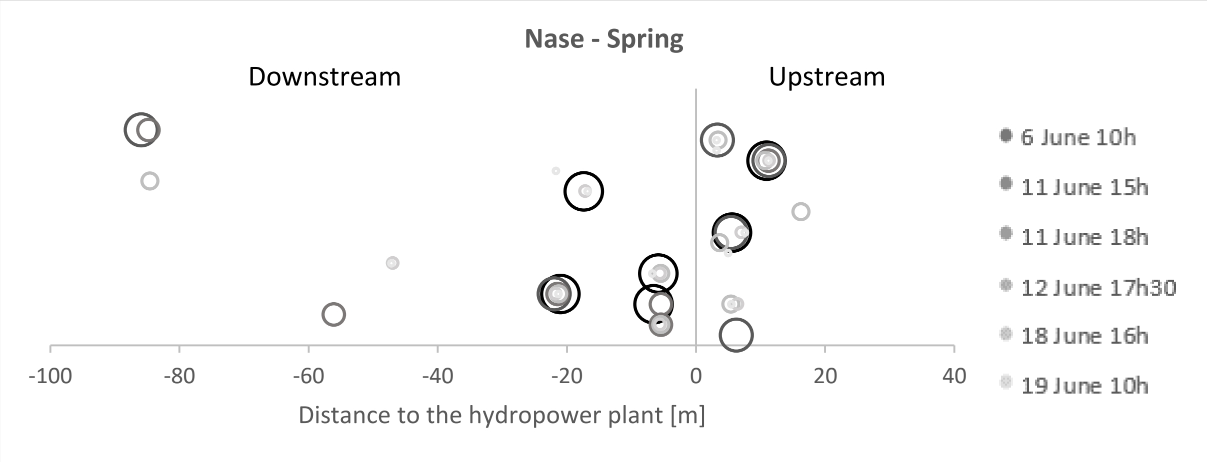
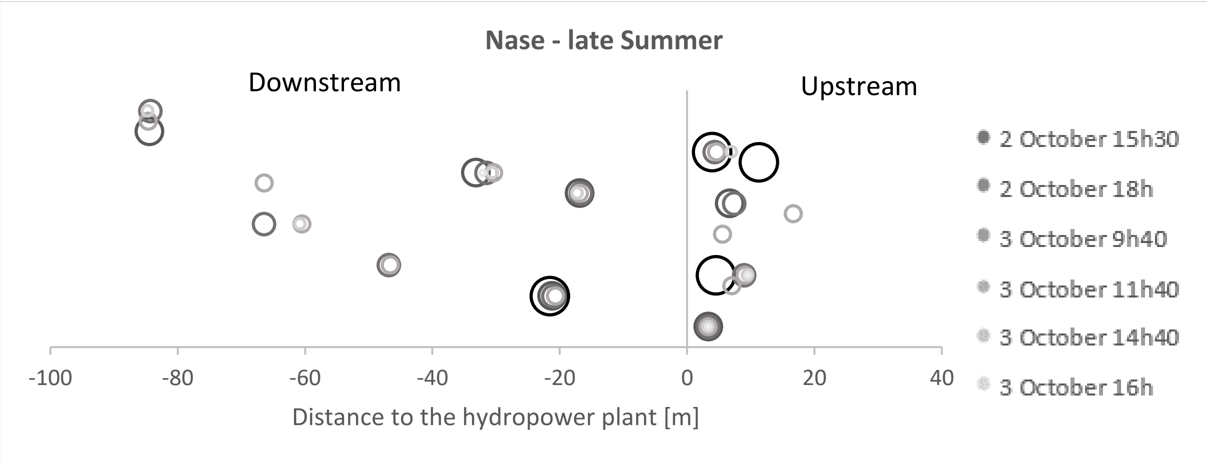


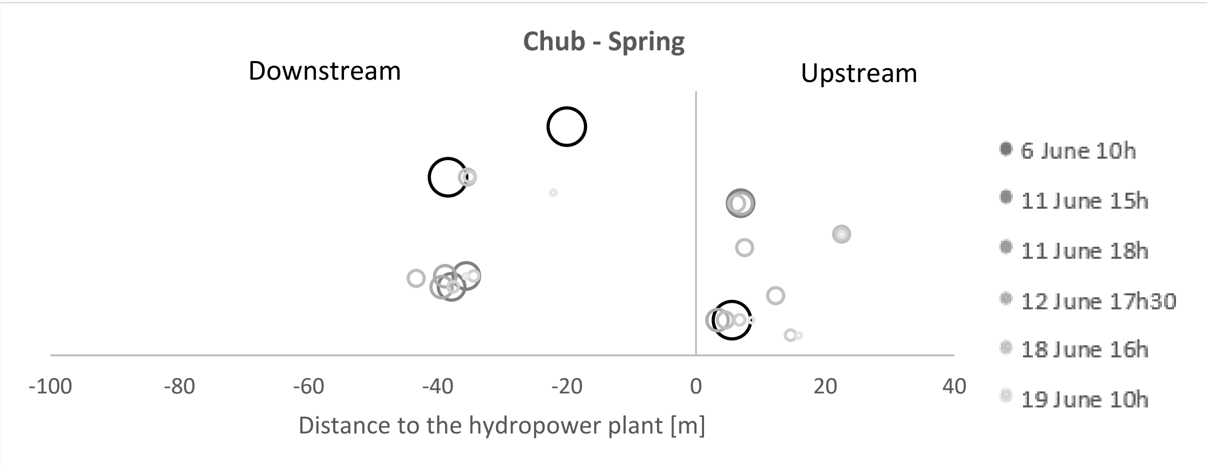
Figure 2 – Water depth and discharge velocity conditions for fishes upstream and downstream the water release from the hydropower plant, during Spring and late Summer season

- **Fish location and displacement**

Immediately upstream the water release, where water depth is higher and discharge velocity is lower, Iberian nase can be found in a large number. The chub was not observed in the disturbed area immediately downstream the water release. Also, during late Summer season, this specie was hardly found in the upstream area, probably due to habitat conditions, namely low water velocity that occurs in this area during the season. Figure 3 refers to the location and displacement of fish individuals, nase and chub respectively, considering the location of the water release plant (zero), during both seasons.







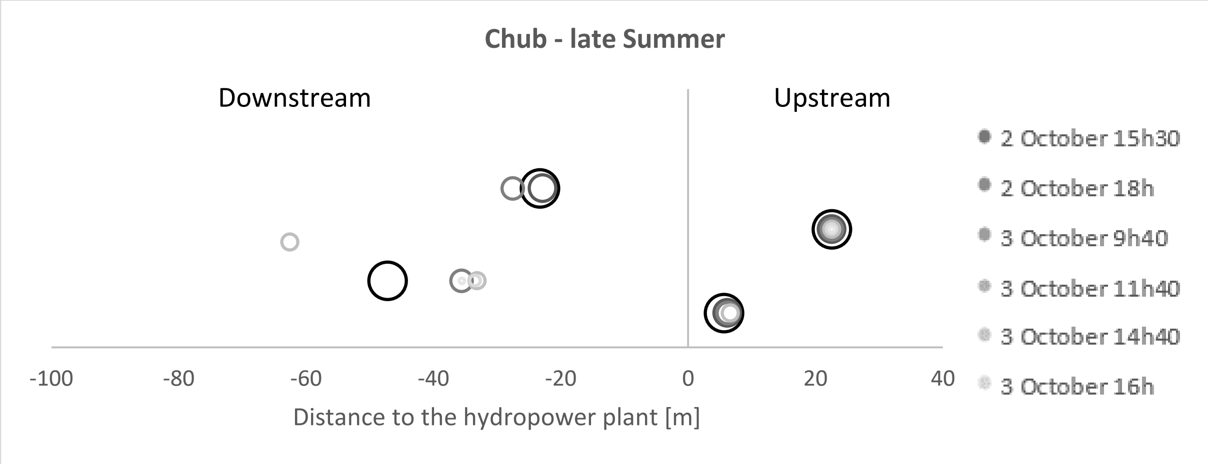


Figure 3 - Location and displacement of fish individuals, nase and chub respectively, considering the location of the water release plant (zero), during both seasons (Spring and late Summer)

Considering the operational scenarios for the hydropower plant, spawning grounds with 100 % of wetted area increase in number when discharge increases also, and spawning grounds with less than 50 % of wetted area decrease in number when discharge increases (Figure 4). Less than 10 % of the spawning grounds have less than 10 % of wetted area, independently of the operational scenario considered (e.g. discharge value).

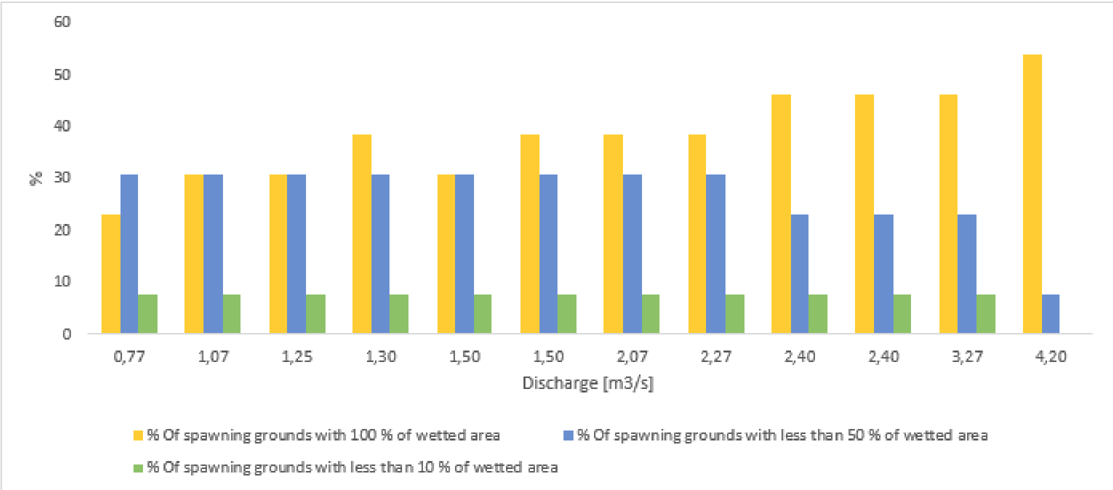


Figure 4 – Relation between spawning grounds percentage and wetted area percentage, related with each operational scenario considered for the hydropower plant.

Discussion and Conclusions

This study was focused on the hydropeaking effect, considering Bragado MHP case-study, by simulating different operational scenarios of the hydropower plant, in order to analyse habitat conditions for 3 fish species and the maintenance of the spawning grounds. The 2D hydraulic modelling was conducted with the numeric model of HEC-RAS, and for the habitat modelling ArcGIS was used. For each operational scenario, water velocity, depth and wetted area were obtained.

There is a significant difference ($p < 0,05$) in terms of velocity and water depth, between seasons (Spring and late Summer), which was expected due to the difference in discharge. As the reservoir capacity is low, increasing the discharge at the river is not possible. Nevertheless, during late summer, as there is no operation in the hydropower plant, the effect of hydropeaking does not occur. Fish spawn during spring, migrating upstream, time in which hydropeaking has a higher impact. During spring time, the reduction of the peak discharge or its frequency should be considered. In winter the best solution would be the construction of fish shelters to avoid fish displacement downstream.

Analysing the time and places where fish species is more abundance, can help locating the river sections where bed morphology may need to be rehabilitated, in order to maintain the fish habitat and use.

The wetted area depends on the hydropower plant operation and the river morphology. Higher values of discharge lead to a higher wetted area. In all the considered scenarios, less than 50 % of the spawning grounds have 100 % of their section area filled with water. This percentage increases when discharge increases though never higher than 60 %. Only a small percentage (less than 10 %) has a wetted area inferior to 10 % of the spawning ground area. These spawning grounds are usually located close to the river banks, in areas where water depth is very low, and that are immediately affected once the turbines shut down and discharge decreases. Factors such as the spawning grounds location, dimension, and the operational scenarios of the hydropower plant, influence the maintenance of the spawning grounds. Stablishing a minimum discharge that allows the spawning grounds to be constantly flooded may be the most favourable solution for their maintenance and preservation.

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