Analysis of the effects of the operation of a hydropower plant on downstream habitat availability. COSH-Tool application

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Abstract:

Hydropower plant operations in response to variations in market energy demand and electricity production can generate rapid and frequent fluctuations of discharge in the river streams. The phenomenon, so-called hydropeaking, may result in a negative impact to fish populations. The present study aims to investigate the effects of hydropeaking in the Iberian barbel (*Luciobarbus bocagei*) habitat conditions. The River2D model was used to obtain the habitat suitability downstream of a hydropower plant. The influence of the ecological flow regime in the habitat conditions and in the rapid flow fluctuation due to hydropeaking was assessed. The COSH-Tool was applied in order to quantify and characterize those rapid fluctuations (with and without ecological flow), with the purpose of assessing impacts in the river ecosystem. Within this context, the applicability of an impact assessment method to a Mediterranean-type stream to assess hydropeaking impacts was discussed.

Keywords: hydropeaking, habitat modelling, Iberian barbel, hydrological time series, ecological flow, COSH-Tool.

1 Introduction

Storage power plants offer numerous advantages over other types of power plants, such as excellent efficiency, rapid response to grid demand, and carryover of electricity production from summer to winter. However, hydropower plants operating may alter the natural flow regime, mainly because of intermittent production in reaction to energy demand, and thereby cause severe daily and sub-daily fluctuations in discharge and water levels. This phenomenon is commonly referred to as hydropeaking (Moog, 1993; Charmasson and Zinke, 2011; Meile et al. 2011).

According to the European Water Framework Directive (EU, 2000) hydropeaking is one of the main stressors on aquatic ecosystems. In fact, because of the unpredictability and intensity of flow change, sub-daily hydropeaking events disturb the natural regime, a key factor in the ecological integrity and the natural abiotic structure of the ecosystems (Person *et al.*, 2013).

Hydropeaking is not clearly and consistently defined or quantified in literature, but could be described by rate, speed, frequency and periodicity of change in discharge and water level. Based on this, a set of parameters are defined, such as the flow ratio (i.e. the ratio between peak and base flow) and ramping rates. Parameters describing hydropeaking can be measured directly in the rivers or could be calculated through the use of hydrodynamic models. The COSH-Tool is a computer program that processes time series of discharge and water level and can calculate the extent of hydropeaking operations over longer time periods (Bakken *et al*., 2016).

The main goal of this research was to assess the impacts of hydropeaking in the habitat of the Iberian barbel life-stages, in a Mediterranean-type stream. The River2D model was used for both hydrodynamic and habitat modelling. This model integrates the Habitat Suitability Index (HIS) - that is, a habitat preference that describes the frequency of an individual of a specific species or life stage occupying a microhabitat compared with the relative frequency of that microhabitat in the environment. The index was represented through Habitat Suitability Curves (HSCs). The COSH-Tool was applied to a 10-year period in order to characterise the rapid fluctuations of flow and stage due to the hydropower plant operation. This software is particularly interesting when combined with systems to assess hydropeaking operations in rivers, considering the trade-offs between flexible hydropower production and environmental concerns, and to develop operational strategies and mitigation measures. Nevertheless, further studies are required to develop proper methods to assess hydropeaking impact in Mediterranean-type rivers.

2 Materials and methods

2.1 Study area

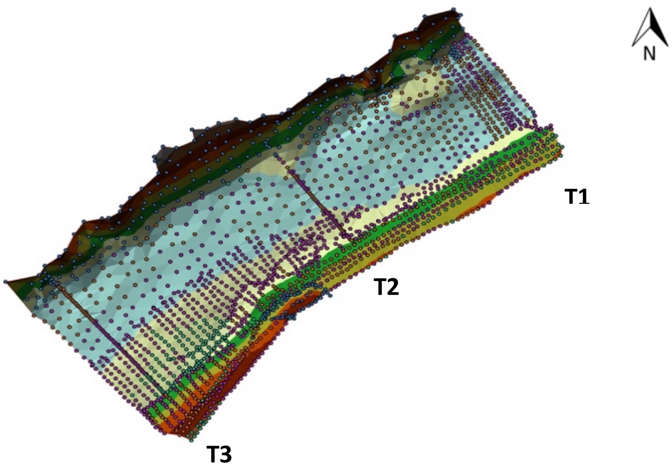
The study was conducted in the Ocreza River (80 km long), one of the largest tributaries of the Tagus River in Eastern central Portugal. The climate is typically Mediterranean, with more than 80% of rainfall occurring between October and April, and a dry season from June to August.

The selected study reach was approximately 100 m long and 20 m wide located immediately downstream Pracana dam. Drainage area is 1410 km^2 and the mean annual flow is 16.7 m^3/s (Boavida *et al.*, 2015). At the toe of the dam there is a 41 MW powerhouse, equipped with 3 Francis turbines, producing c. 63.8 GWh/year. Maximum total turbine flow is 88 m^3/s. Currently, the ecological flow is not implemented.

In what concerns to geomorphology, the study site is an open valley where the riverbed is dominated by schistones and alluvial deposits. Downstream the dam, the riverbed is morphological uniform with low habitat heterogeneity. It presents unstable linear banks with occasional vegetation or woody debris providing sheltering areas. The substrate composition was visually assessed using a Wentworth scale, according to Boavida *et al*. (2013) [(1) organic cover; (2) silt, 1–2 mm; (3) sand, 2–5 mm; (4) gravel, 5–25 mm; (5) pebble, 25–50 mm; (6) cobble, 50–150 mm; (7) boulder, >150 mm; and (8) bedrock]. Mostly pebbles, cobbles and boulders were found in the study reach.

2.2 Hydraulic and biological data

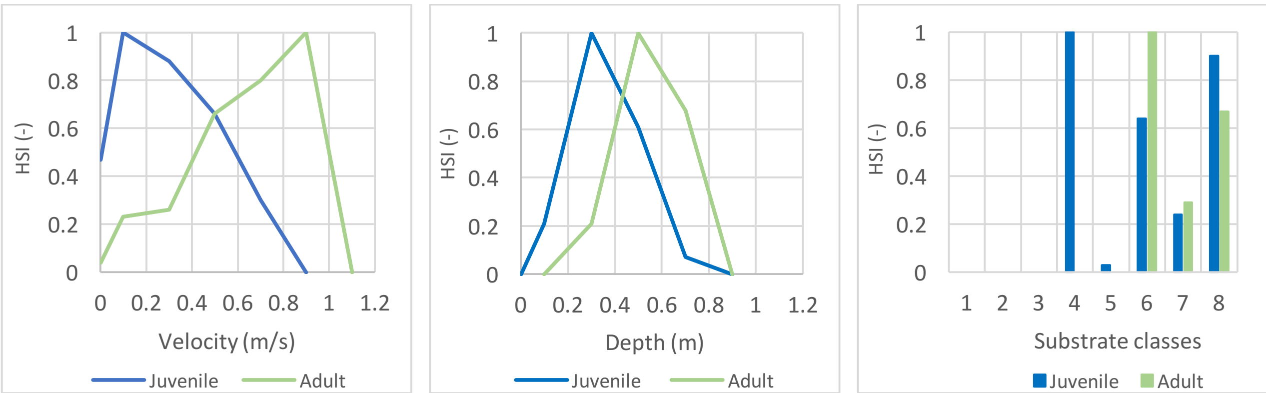
All the field work was done by UTAD team, supervised by Professor Rui Cortes, during the 22 May and 27 June 2009. The riverbed topography was surveyed with a combination of a total station and a Global Positioning System (GPS). Altogether, 2001 points were surveyed (x, y and z coordinates). Boulders and large objects emerging from the water were defined. Hydraulic data, namely velocity and depth, were collected at two different times and at a series of points along 3 cross-sections, where significant changes in depth, water velocity and slope were observed (Figure 1). These data were used to calculate discharge and to calibrate the model by varying the bed roughness. Moreover, they allowed the definition of a discharge rating curve hereinafter referred to as “original rating curve”.



Cross-section	Discharge (m^3/s)	Survey date
T1	0.28	27/6/2009
	0.67	27/6/2009
T2	0.18	22/5/2009
	0.17	27/6/2009
	0.69	27/6/2009
T3	0.06	22/5/2009
	0.33	27/6/2009
	0.72	27/6/2009

Figure 1 - Location of the cross-sections and measured discharges.

The target species of this study was the Iberian barbel (*Luciobarbus bocagei*). Habitat suitability curves for depth, water velocity and substrate during spring were used (Figure 2). These curves were developed by Boavida *et al*. (2013) for two life-stages, according to differences in length: juveniles (≤10 cm) and adults (>10 cm).



a) b) c)

Figure 2 – HSI for juvenile and adult barbel: a) velocity; b) depth; c) substrate [substrate classes: (1) organic cover, (2) silt, (3) sand, (4) gravel, (5) pebble, (6) cobble, (7) boulder and (8) bedrock].

2.3 Hydrodynamic modelling

Two-dimensional hydraulic simulations were carried out using the River2D model. This finite element model calculates depth and two velocity components at nodes of a triangular irregular mesh (Steffler and Blackburn, 2002). As input data, the model requires channel bed topography, effective roughness height (k_s), boundary conditions (discharge at inflow section and water surface elevation at outflow section), and initial flow condition.

The model was calibrated for a discharge of 0.7 m^3/s by adjusting the finite element mesh and the bed channel roughness until good agreement between simulated and surveyed hydraulic conditions was achieved. The roughness parameter describes the mean substrate diameter and was calculated using equation 1. The strong irregularity and obstructions in the riverbed (*e.g.* large boulders) significantly influence the *n* roughness coefficient value at low water levels. Therefore, two different roughness values were applied according to the magnitude of the discharge. For low discharges, defined as less than 5 m^3/s, the calculated k_s was 1.77 m; for discharges ranging from 5 to 90 m^3/s a k_s of 0.5 m was considered. These two roughness values were obtained according to previous studies by Wu and Mao (2007) and Lencastre (1991), respectively.

$$k_s = \frac{12R}{e^m};\ m = \frac{R^{1/6}}{2{,}5\ n\sqrt{g}};\ R = \frac{A}{P} \cong H \tag{1}$$

The discharge rating curve was defined by two different segments. The first one (until 5 m^3/s) corresponds to the original rating curve. The second was determined using HEC-RAS. Subsequently, 19 simulations were carried out in River2D, for a range of discharge between 0,50 and 90 m^3/s, all performed in steady flow.

2.4 Habitat modelling

Habitat simulations were performed with the fish habitat module of River2D. The habitat calculation method integrates habitat suitability curves containing known biological preference data for depth, velocity and substrate or cover to calculate the Weighted Usable Area (WUA) – i.e. the habitat availability for each fish species and life-stage as a function of discharge. The individual indices for Velocity Suitability Index (VSI), Depth Suitability Index (DSI) and Channel Suitability Index (CISI) (i.e. substrate or cover) for each life-stage were combined according to equation 2 in order to obtain the Combined Suitability Index (CSI) (Steffler and Blackburn, 2002).

$$CSI = VSI \times DSI \times CISI \tag{2}$$

The total WUA in square meters, for the given study reach and for each specie life-stage, is then computed by multiplying each model node area by the respective CSI (equation 3).

$$WUA = \sum_{n=1}^{i} CSI_i \times A_i = f(Q) \tag{3}$$

The habitat modelling results for the discharge range (0.5–90 m^3/s) allowed the definition of the habitat availability as a function of discharge (i.e. WUA versus discharge) and the habitat suitability maps, for both life-stages.

2.5 Hydrological time series analysis

In order to characterize and quantify the impact of flow fluctuations as a consequence of hydropeaking, the hydrological time series analysis was analyzed. Additionally the fish habitat was assessed by calculating the habitat availability as a function of discharge during the studied period.

The COSH-Tool software (Sauterleute and Charmasson, 2014) was applied to the time series of flow Q [m^3/s] and stage H [m] of the Gauging Station of Pracana (16K/01A). Daily flow data, including turbined and released flows, for a period of 10 years (2001-2011) was analyzed.

The COSH-Tool analysis is based on establishing a threshold for the rate of change of the signal $X(t)$ (equation 4), enabling the identification of individual peaking events (rapid increases or decreases in flow or stage) and an analysis of their main characteristics. The rate of change (i.e. first derivative of the signal $X(t)$) is positive for an increase and negative for a decrease.

$$\dot{X}\,(t) = \frac{dX(t)}{dt} = \frac{f(n+1) - f(n-1)}{t(n+1) - t(n-1)} \tag{4}$$

For both increases and decreases, thresholds for the rate of change are defined as part of an iterative process. The magnitude of the thresholds is determined by multiplying the absolute maximum values of the rate of change occurring in the time series by the factors c_{inc} and c_{dec}, respectively: $\dot{X}_{th,inc} = c_{inc} \max\{\dot{X}\}$ and $\dot{X}_{th,dec} = c_{dec} \min\{\dot{X}\}$. After selecting the starting values for c_{inc} and c_{dec}, the rate of change of the signal is compared to the corresponding threshold at each data point of the time series. If the rate of change is positive, it will then be compared to the threshold for rapid increases ($\dot{X} > \dot{X}_{th,inc}$). If it is negative, it will be compared to the threshold for rapid decreases ($\dot{X} < \dot{X}_{th,dec}$). For both cases, if the absolute value of the rate of change is larger than the threshold, the data point will be defined as part of a peaking event. The software recognizes multiple peaks, meaning that certain peaking events have several succeeding phases of increases (or decreases).

The threshold values that were set for this study are given in Table 1. The outputs are a set of parameters describing the rapid fluctuations, statistics and graphs. The parameters are divided into three categories (Table 2). The first category describes the magnitude or amplitude of the variations. The second category takes into account the scale of time, i.e. how rapid and when the changes in flow and stage occur. The third category defines the frequency and describes how often or regularly they appear.

Table 1 – Threshold values set for the analysis of the discharge and stage time series for the Ocreza river.

Moving average window size *n* (-)	$\mathbf{c_{inc}}$ **(-)**	$\mathbf{c_{dec}}$ **(-)**	***p*** **(-)**	***T*** **(minutes)**	***d*** **(minutes)**
3	0.06	0.06	0.2	120	120

Table 2 – List of selected parameters including units and symbols, used to characterise stream hydropeaking (Baumann e Klaus, 2003, *in* Sauterleute e Charmasson, 2014).

Category	**Parameter**	**Symbol**	**Unit**
Magnitude	Flow	Q	m^3/s
	Stage	H	m
	Flow maximum/minimum of a rapid increase	$Q_{max,inc}, Q_{min,inc}$	m^3/s
	Flow maximum/minimum of a rapid decrease	$Q_{max,dec}, Q_{min,dec}$	m^3/s
	Stage maximum/minimum of a rapid increase	$H_{max,inc}, H_{min,inc}$	m
	Stage maximum/minimum of a rapid decrease	$H_{max,dec}, H_{min,dec}$	m
	Flow ratio of a rapid increase/decrease	F_{inc}, F_{dec}	-
Time	Mean rate of flow increase/ decrease	$R_{Qm,inc}, R_{Qm,dec}$	$m^3/s/h$
	Mean rate of stage increase/ decrease	$R_{Hm,inc}, R_{Hm,dec}$	cm/h
	Maximum rate of flow increase/decrease	$R_{Qmax,inc}, R_{Qmax,dec}$	$m^3/s/h$
	Maximum rate of stage increase/decrease	$R_{Hmax,inc}, R_{Hmax,dec}$	cm/h
	Time of the start of a rapid increase/decrease	$t_{s,inc}, t_{s,dec}$	hh:mm
	Time of the end of a rapid increase/decrease	$t_{e,inc}, t_{e,dec}$	hh:mm
	Duration between a rapid increase and decrease	T_{high}	h
	Duration between a rapid decrease and increase	T_{low}	h
Frequency	Counts of rapid increases/ decreases per year	$N_{a,inc}, N_{a,dec}$	n
	Proportion of days with a given number of rapid increases/decreases per day	$D_{n,inc}, D_{n,dec}$	-
	Proportion of rapid increases/decreases during daylight/twilight/darkness	N_{dl}, N_{tl}, N_{nl}	-

The first step to obtain a processed time series is the preparation of the data set to be analyzed. Outliers and errors in values are deleted if necessary. Correction for time shift and leap years are realized and interpolated values are computed for all missing data. After the identification of peaking events and the calculation of the parameters, the last step involves the classification of peaking events into three categories according to the daylight conditions: i) Daylight peaking events: daylight throughout the entire peak duration; ii) Darkness peaking events: darkness throughout the entire peak duration; iii) Twilight peaking events: twilight during at least parts of the peak duration. Events involving overlapping conditions (such as daylight-twilight, twilight-darkness, etc.) are classified as twilight peaks.

Besides the analysis to the discharge and stage data above-mentioned, hereinafter referred to as "Original Analysis", a second analysis was performed, which is then called "Eco Analysis". The same thresholds (Table 1) were applied in order to obtain a reliable comparison. The aim was to assess the influence of an ecological flow regime in the rapid fluctuations of flow and stage, due to the hydropower plant operation, and hence in the habitat availability. This regime was proposed by Cortes *et al.* (2009) (Table 3). For each month, every value of the original discharge time series that was lower than the correspondent ecological flow was replaced by the latter.

Table 3 – Ecological flow regime for the Pracana dam (Cortes *et al*., 2009).

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Ecological flow (m^3/s)	5,30	4,50	2,80	1,62	1,22	0,40	0,07	0,01	0,03	0,73	2,00	4,40

2.6 Impacts from hydropeaking assessment method

Statistical outputs from COSH-Tool are especially relevant as a basis for environmental impact assessment. In this context, the applicability of a method proposed by Harby *et al.* (2016) was tested. The method considers the evaluation of parameters: direct effects from hydropeaking; and vulnerability. The first one characterizes the possible ecological impacts of peaking from how physical conditions such as flow, water level and water covered area changes, given the hydropower system and river morphology. The second characterizes how vulnerable the system is to further influence from peaking.

3 Results and discussion

The WUA versus discharge curves are shown in Figure 3. Both life-stages exhibit the same tendency: the WUA increases with the discharge up to a maximum value which is followed by a decreasing trend. According to the habitat simulation results, both adults and juveniles profit from similar areas of suitable habitat (i.e. maximum habitat of 550 m^2 and 563 m^2 for adults and juveniles respectively). As expected, this maximum is found to occur at a lower discharge for juveniles (1.4 m^3/s) than for the adults (7 m^3/s).

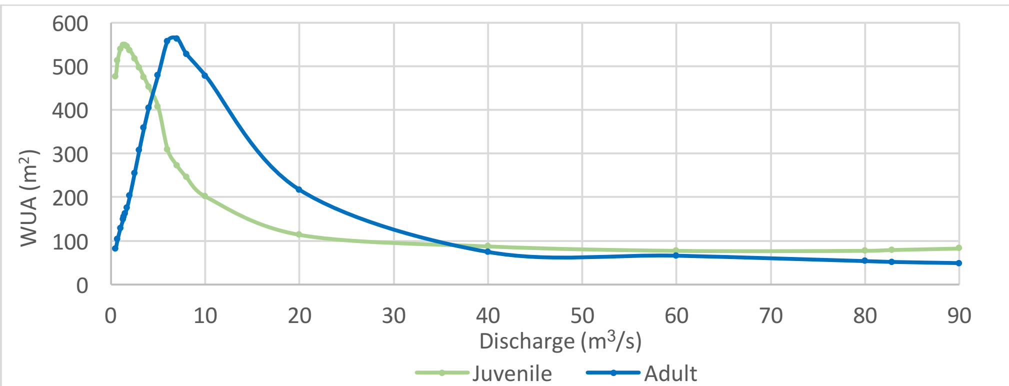


Figure 3 – Variation in the WUA for the juvenile and adult barbel at different discharges.

The results of the habitat availability maps show that considering a lower discharge (1.4 m^3/s) the suitable habitat for juveniles is more uniformly distributed along the river channel than the adults, where the suitable habitat is located predominantly at the inner part of the riverbed. For higher discharges (e.g. 80 m^3/s), and for both life-stages the available habitat is concentrated next to the riverbanks, where lower velocities and water depth were found. It is important to note that in those conditions almost the entire reach has no suitable habitat conditions for barbel.

After performing the Original Analysis in COSH-Tool, results indicate that 21% of the days in the time series are affected by rapid fluctuations. Standard statistical parameters, as medians, percentiles, and maximum of all rapid increases and decreases occurring during the entire period under analysis are given in Tables 4 and 5 respectively.

Table 4 –Values of the flow ratio (Q_{max}/Q_{min}), mean and maximum rates of change in flow, and mean and maximum rates of change in stage for rapid increases.

Parameter	Flow ratio	Mean rate of flow increase	Maximum rate of flow increase	Mean rate of stage increase	Maximum rate of stage increase
Unit	**-**	**$m^3/s/h$**	**$m^3/s/h$**	**cm/h**	**cm/h**
Minimum	2.4	5.4	5.4	8.1	8.1
Mean	3969.0	21.4	23.2	29.3	32.8
Median	6068.7	22.3	24.6	30.7	36.8
90th percentile	7474.0	24.9	25.9	37.4	39.1
Maximum	8168.7	26.4	27.2	39.8	45.5

Table 5 –Values of the flow ratio (Q_{max}/Q_{min}), mean and maximum rates of change in flow, and mean and maximum rates of change in stage for rapid decreases.

Parameter	Flow ratio	Mean rate of flow decrease	Maximum rate of flow decrease	Mean rate of stage decrease	Maximum rate of stage decrease
Unit	**-**	**$m^3/s/h$**	**$m^3/s/h$**	**cm/h**	**cm/h**
Minimum	1.3	1.7	1.7	2.8	2.8
Mean	4753.5	17.4	20.1	26.6	31.5
Median	6254.7	18.8	23.7	28.3	36.3
90th percentile	7655.9	24.9	25.8	37.7	39.1
Maximum	8211.3	27.1	27.4	40.7	41.0

The number of increases and number of decreases per year varies between the years. The maximum number (80 peaks) is observed in 2003 and in 2011. The minimum number of increases occurred in 2001 and in 2007 for decreases. On average, the Ocreza River is affected by hydropeaking on 19% of the days during a year. In most of the affected days one increase or decrease occurred, while a small portion of days had two increases or decreases (c. 0.9% of the days during a year). Three peaks per day are very rare and are only observed for rapid decreases.

The monthly distribution of peak events shows, as expected, that most of them are concentrated during the cold and rainy season (between November and April). The month with the lowest number of occurrences, either increases or decreases, is June.

In terms of the distribution of rapid increases and decreases according to the time of day, results show that about 50% of the rapid increases occur between 7 and 10 am, while rapid decreases occur mainly between 9 and 12 pm (53%). Additionally, a concentration of rapid increases between 5 and 7 pm are found to occur. This tendency matches the patterns of activities and demand of electric energy; however, it does not represent the seasonal variations, since these results are average values, for all the peak events of the time series.

When considering light conditions, the majority of the rapid increases occur during daylight (55%), the minority during darkness (4%), and the rest are associated to twilight. Most of the rapid decreases occur during darkness (67%), a few during twilight (13%) and daylight (20%). Moreover, the results exhibit a seasonal pattern. In the winter months, a large proportion of rapid increases occur during twilight (and a few during darkness) whereas in the period between May and October the rapid increases are mainly recorded during daylight and some during twilight. In the period from October to March, rapid decreases appear predominantly during darkness and equal parts during daylight and twilight. In the summer months, a higher proportion of rapid decreases occur in daylight and twilight. It should be emphasized that these results depend on the seasonal variation of the average number of sunlight hours.

Results demonstrate that the Eco Analysis, compared to the Original Analysis, provides a reduction in terms of: days with rapid fluctuations; number of increases/decreases per year; mean and maximum rates of change in flow and stage; and flow ratio. On the other hand, it originates higher values on some parameters such as mean and median flow and stage, and T_{high} and T_{low}. Concerning the distribution of peaking events according to the time of day and daylight conditions, the same patterns are observed in both analyses, with no significant changes. The differences between the two analyses, regarding the statistical parameters, are given in Table 6.

The ecological flow regime clearly improves de habitat conditions for barbel. It not only increases the percentage of time during the analyzed period that provides a WUA greater than 80% of the optimum conditions, as it reduces the periods with less than 50% of the optimum conditions. The benefits are larger for juveniles (Figure 4).

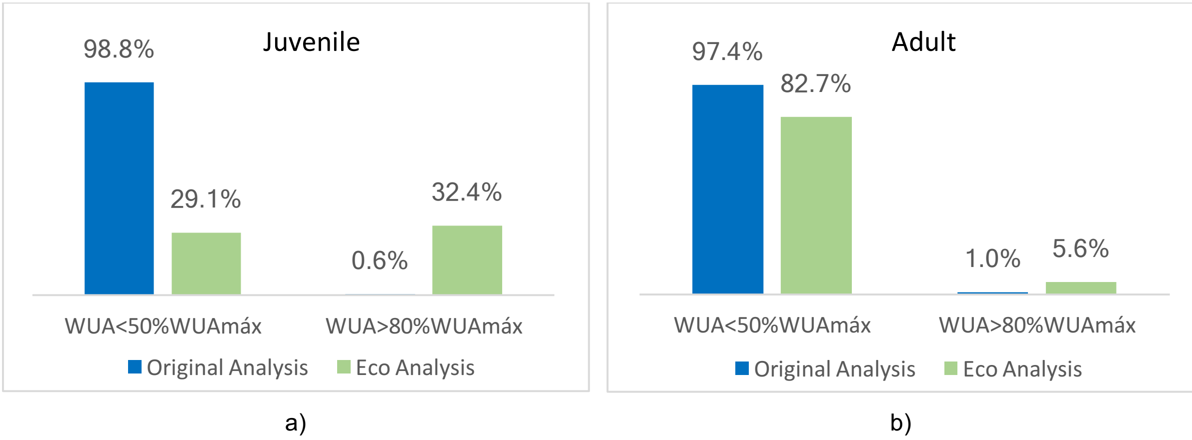


Figure 4 – Proportion (%) of time during the analyzed period with a WUA higher than 80%WUA of the maximum WUA and with a WUA less than 50% of the maximum WUA, for the Original Analysis and the Eco Analysis a) juvenile barbel; b) adult barbel.

Table 6 – Relative change (%) of parameters used to characterize the hydropeaking computed for Eco Analysis compared to the Original Analysis.

Parameter	Q	Flow ratio of flow increase	Flow ratio of flow decrease	Q at start of increase	Q at end of decrease	Mean rate of discharge increase	Mean rate of discharge decrease	Max rate of discharge increase	Max rate of discharge decrease
Minimum	0.0	0.0	-3.0	0.0	0.0	-0.9	0.0	-0.9	0.0
10th percentile	200	-25.3	-78.9	7200	600	-1.8	-3.7	1.5	-7.7
Mean	10.1	-93.5	-93.0	131.0	179.9	-2.8	-2.8	-3.3	-3.7
Median	1610 0	-99.7	-99.7	43900	27900	-2.7	-3.3	-4.3	-4.0
90th percentile	0.0	-99.1	-95.1	35.3	154.9	-2.8	-2.9	-3.1	-2.9
Maximum	0.0	-7.9	-8.9	0.0	4.2	-2.0	-2.0	-2.8	-2.9
SD	-1.9	-67.3	-60.1	4.6	5.8	-4.2	-2.3	-3.0	-2.9

Parameter	H	Mean rate of stage increase	Mean rate of stage decrease	Stage at start of increase	Stage at end of decrease	Max rate of stage increase	Max rate of stage decrease	Time after increase	Time after decrease
Minimum	0.0	-17.1	0.0	0.0	0.0	-17.1	0.0	0.0	0.0
10th percentile	0.1	-0.4	-29.0	0.2	0.2	1.4	-36.8	0.0	0.0
Mean	0.3	-13.0	-19.3	0.4	0.4	-15.6	-22.0	15.2	32.6
Median	0.5	-14.5	-20.9	0.5	0.5	-22.6	-23.6	11.1	0.0
90th percentile	0.0	-18.8	-21.4	0.5	0.6	-17.4	-19.5	86.2	14.7
Maximum	0.0	-5.6	-7.2	0.0	0.4	-15.4	-6.0	0.0	4.7
SD	-13.9	-35.9	-9.5	46.3	29.1	-37.9	-10.8	7.9	41.8

Percent of days in time series with rapid fluctuations (inc or dec)		Increases per year	Decreases per year	Increases during daylight	Increases during twilight	Increases during darkness	Decreases during daylight	Decreases during twilight	Decreases during darkness
-9.9	Minimum	-91.0	-41.0	4.8	-10.5	37.0	1.8	7.8	-2.1
	Mean	-22.0	-11.0						
	Median	-24.0	-13.0						
	Maximum	-10.0	-5.0						

One of the main advantages of COSH-Tool is that the outputs can serve as a relevant basis for the assessment of hydropeaking impacts. Nevertheless, some limitations were observed when trying to use it together with the method proposed by Harby *et al*. (2016) at Ocreza River. Since it was developed in Norway, both the software and the method incorporate certain characteristics that do not remain adequate if the region to be analyzed presents hydrological regimes quite different from that country. Namely, when this distinction is translated by a reduced water availability of the watercourses, compared to the water resources present in the Nordic countries.

The data preparation subroutine present in COSH-Tool proceeds to the interpolation of missing dates and outliers. However, zero values are also linearly interpolated until the next positive value, which can significantly modify the series. In regions with a small twilight, the distinction of this phase of the day when the software classifies peak events in relation to daylight conditions may result in a misinterpretation of the results concerning this parameter. Moreover, the impact assessment system developed by Harby *et al*. (2016) was based on the characteristics of Norway's regulated salmon rivers. Hence, when trying to apply it to the case study, for most of the factors, the need of an adjustment of the classification limits to the target species (cyprinids) and to the Mediterranean-type stream stands out. For instance, factors such as flow rate present a magnitude that is not well suited to the proposed characterization criteria, since the minimum flow in the Ocreza river is often highly inferior (nearly zero) to the minimum flow in Norway. On the other hand, the characterization of the vulnerability requires a significant change since it is quite dependent on the species characteristics (i.e. salmonids).

4 Conclusions

According to the habitat simulations carried out with the River2D model, the discharge that maximizes habitat availability for juvenile barbel is 1.4 m^3/s, and for adults, the WUA is maximum for 7 m^3/s. Furthermore, the adult life-stage is privileged in this study once they will profit from higher areas of suitable habitat for a wider range of discharges.

As expected, establishing an ecological flow regime is beneficial for the habitat suitability conditions and for the riverine ecosystem. In fact, it reduces the number of peak events, the flow ratio, and the rates of change in flow and stage. As a consequence, improvements are observed in the habitat conditions for both life-stages, with higher benefits for juveniles.

In general, the COSH-Tool is effective in the statistical characterization of peak events and its use within the scope of environmental impact studies should be explored. However, there are some limitations in its application to Mediterranean rivers, thus, the results have to be cautiously interpreted. Moreover, the impacts assessment system developed by Harby *et al*. (2016) it is not applicable to Mediterranean-type streams. In this context, the criteria for characterizing hydropeaking impacts require an adaptation according to the type of hydrological conditions and species that prevail in those regions.

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