12 Hydropeaking Impact Assessment for Iberian Cyprinids: Hydropeaking Tool Adaptation

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12.1 Introduction

Hydroelectric power plants operated in response to short-term, sub-daily changes of the electricity market, undergo rapid variations of turbine discharge, entailing quickly fluctuating water levels downstream (Moog 1993; Moreira et al. 2019). This operation regime, likely to rise in the near future in countries with increasing shares of variable renewable electricity generation (Ashraf et al. 2018), often causes numerous adverse impacts on river ecosystems, particularly fish assemblages (Moog 1993; Young et al. 2011; Schmutz et al. 2015).

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Although many rivers can naturally experience rapid flow changes, namely during floods, the hydrographs of peaking rivers are unique, leading to a harsh environment for freshwater organisms due to frequent and unpredictable disturbances, with no natural analogue (Poff et al. 1997; García et al. 2011). The hydrograph of peaking rivers can be characterized by parameters that change over space and time, such as magnitude, rate of change, frequency, duration, and timing (Harby and Noack 2013). Each of these parameters may be correlated with ecological consequences and therefore may be used to scale the impacts of hydropeaking.

The response of salmonid fishes to hydropeaking has been studied for some time (e.g. Valentin et al. 1996; Scruton et al. 2008; Puffer et al. 2015; Rocaspana et al. 2019). Salmonids can be affected by peaking, whereby the most common responses include stranding, drift, and dewatering of spawning grounds, which have been related to up- and down-ramping rates (Saltveit et al. 2001), peak flow magnitude (Auer et al. 2017), and baseflow duration (Casas-Mulet et al. 2016). In contrast, information is much scarcer regarding other fish taxa (e.g. Boavida et al. 2015, 2020), making it difficult to appraise peaking impacts of existing and new hydropower plants. Information gaps about hydropeaking impacts are particularly critical in the Iberian Peninsula, where threatened non-salmonid fish assemblages with high levels of endemicity coexist with existing and planned hydropower plants, including multi dam large hydropower schemes such as the one being constructed in the Tâmega river basin (Douro catchment). The Iberian freshwater fish fauna is characterized by native cyprinids that dominate river fish assemblages except for headwater streams and lowland rivers (Doadrio 2001; Reyjol et al. 2007). Given this scenario, it would be useful to have a tool in the Iberian Peninsula to quickly assess a priori hydropeaking impacts and to screen candidate hydropower plants for further investigations and for the implementation of appropriate mitigation measures.

Harby et al. (2016) developed a systematic approach in Norway to assess the additional impacts of hydropeaking on salmonid fish. The approach divides the impact from hydropeaking into two components: (direct) effects and vulnerability. The effect component characterises the possible impacts of peaking from how ecological relevant physical conditions changes, given the hydropower system and river morphology considering the regulated river as reference, whereas the vulnerability component characterise how vulnerable the system is to the additional impact from peaking.

Although the ecology of cyprinids is distinct from salmonid´s, this study adapts the tool for native Iberian cyprinids. The adaptation builds on the experience gathered so far on impacts of hydropeaking in Iberia (Boavida et al. 2015, 2020; Costa et al. 2019; Moreira et al. 2020; Oliveira et al. 2020) and on expert knowledge.

12.2 The Hydropeaking Tool for Salmonids

In the approach developed by Harby et al. (2016), physical conditions characterizing peaking flows consider the rate of flow change (water level change ratio), the dewatered area (change in water-covered area when flow is reduced from Qmax to Qmin), the magnitude of flow changes (Qmax/Qmin), and the frequency, timing and distribution of peaking operations.

For salmonid vulnerability, the following factors are taken into account in the approach: number of adult females, amount and distribution of spawning grounds, low flow periods, habitat degradation, low temperature impacts, pollution and other external factors. These effect and vulnerability factors are assessed for each HPP and are classified in semi-quantitative classes according to criteria developed from the literature, research in CEDREN (Centre for Environmental Design of Renewable Energy) or by expert opinion. The factors for peaking operations and vulnerability are finally combined to produce an overall assessment of hydropeaking impact at a particular site (from very high to small).

12.3 Adapting the Tool for Iberian Cyprinids

The general framework of the tool developed for salmonids was kept for the Iberian cyprinids, with the combined use of effect and vulnerability factors to assess the overall hydropeaking impact.

As initial step, a set of effect and vulnerability hydropeaking related factors/indicators were developed for Iberian cyprinids based upon available, published and unpublished, information. Moreover, preliminary thresholds separating different impact and vulnerability classes were established for each indicator to account for different levels of impact of hydropeaking on the focus taxa (the cyprinids *Luciobarbus bocagei*, *Pseudochondrostoma duriense*, *Squalius* spp. and *Achondrostoma* spp.).

The proposed factors/indicators and thresholds were then evaluated by eight experts on Iberian cyprinids ecology and Mediterranean rivers functioning. A final set of effect and vulnerability parameters/indicators was developed for Iberian cyprinids by including the expert opinions in the initial proposal (Tables 12.1 and 12.2).

All the effect parameters proposed for the salmonids were retained for the Iberian cyprinids, except the magnitude of flow changes, as assessed by Qmax/Qmin. Due to the limitations in available information, only three classes were established for each indicator when compared with the salmonids tool. Other differences included the consideration of distinct critical periods as well as different thresholds to classify some indicators given the specificity of the Iberian climate. Given the more generalist autoecology of the common Iberian cyprinids, the thresholds proposed were generally less stringent than the ones proposed for the salmonids.

Table 12.1 Final effect factors, indicators and criteria for characterization of Iberian non-salmonid rivers affected by hydropeaking

Effect factors	Indicator	Criteria for characterization		
		Very large (value 3)	Moderate (value 2)	Small (value 1)
E1: Rate of change	Water level change ratio (cm/h)	>15	15–5	< 5
E2: Dewatered area	Change in water-covered area when flow is reduced from Q_{max} to Q_{min} (%)	>40	40–10	< 10
E3: Frequency	Annual frequency (proportion/number of days per year with peaking)	> 75% (>273 d)	25–75% (91–273 d)	< 25% (<91 d)
E4: Distribution		Irregular during Spring (spawning period)	Irregular	Regular throughout the year
E5: Timing	Flow reductions in critical periods	During the spawning	During the Winter	During the low flow period

As expected, more differences are noticeable between the salmonids and the cyprinids vulnerability factors. In contrast to salmonids, two taxa groups were initially established, considering the Iberian barbel (*Luciobarbus bocagei*), the largest native species present in many Iberian rivers (e.g. Godinho et al. 1997), in one group, and the remaining cyprinids in another.

Instead of using the number of females as an indicator of the population size, the use of capture-per-unit-of-effort (CPUE; number of specimens collected in Spring with single-pass electrofishing /100 m^2) was proposed as indicator of abundance for the species or group of species considered. Initial threshold criteria to separate vulnerability classes were obtained as percentiles of the CPUE for barbel and the other cyprinids occurring in several Portuguese central and northern river reaches, including both natural and impacted reaches (The authors, unpublished data).

As a measure of recruitment limitations, the proportion of juvenile native cyprinid specimens, based on total length, are used, instead of the amount and distribution of spawning grounds considered for salmonids. Although growth for a particular species varies among different rivers and reaches, the following general size thresholds (total length, in mm) are proposed to identify juvenile specimens: Luciobarbus bocagei (120 mm); *Pseudochondrostoma duriense* and *Squalius carolitertii* (80 *mm*); *Squalius*

Table 12.2 Final vulnerability factors, indicators and criteria for characterization

Vulnerability factor	Indicator	Criteria for characterization		
		High (value 3)	Moderate (value 2)	Low (value 1)
V1a: Population size of native barbel (*Luciobarbus bocagei*)	Abundance: Capture-per-unit-of-effort (CPUE—number of specimens collected in Spring with single-pass electrofishing/100 m^2)	≤1.5[1]	1.6–6.0[2]	>6.0
V1b: Population size of straight mouth nase (P*seudochondrostoma* spp.)	Abundance: Capture-per-unit-of-effort (CPUE—number of specimens collected in Spring with single-pass electrofishing /100 m2)	≤2.0[3]	2.1–6.2[4]	>6.2
V1c: Effective population size of sensitive small native cyprinids (*Squalius alburnoides*, *Squalius carolitertii* and other *Squalius* spp.)	Abundance: Capture-per-unit-of-effort (number of specimens collected in Spring with single-pass electrofishing/100 m2)	≤1.5[5]	1.6–8.3[6]	>8.3
V2: Degree of limitations in recruitment	Proportion of juvenile native cyprinid specimens in Spring samples (based on specimens' length)	<30%	30–50%	50%-70%
V3: Habitat heterogeneity	River Habitat Survey (RHS, in Portugal) or the Spanish protocol for hydromorphological (HYMO) characterization of rivers (in Spain)	RHS or HYMO indicator compatible with bad ecological status	RHS or HYMO indicator compatible with moderate or mediocre status	RHS or HYMO indicator compatible with high or good status
V4: Habitat degradation	Change in magnitude and frequency of natural flood events	No floods	Some floods compared to the natural situation	Most of the natural floods still occur

[1] 30% percentile of the CPUE for nase occurring in 256 central and northern river reaches.
[2] 30% percentile of the CPUE for nase occurring in 256 central and northern river reaches.
[3] 30% percentile of the CPUE for nase occurring in 256 central and northern river reaches.
[4] 60% percentile of the CPUE for nase occurring in 256 central and northern river reaches.
[5] 30% percentile of the CPUE of small sized Iberian cyprinids (including *Squalius alburnoides* and *Squalius caroliterti*) occurring in 272 central and northern river reaches.
[6] 60% percentile of the CPUE of small sized Iberian cyprinids (including *Squalius alburnoides* and *Squalius carolitertii*) occurring in 272 central and northern river reaches.

alburnoides and *Achondrostoma* spp. (45 mm). The proposed values are a compromise between the maturity lengths for males and females. Habitat degradation was also included and assessed similarly as for salmonids, as the change in magnitude and frequency of natural flood events.

Low flow periods as bottleneck for salmonid fish stock size were not considered due to the tolerance of most Iberian cyprinids to low flow periods (e.g. Pires et al. 1999, 2010). The influence of reduced water temperature was also not included as a vulnerability factor. As for factors other than hydropeaking influencing the vulnerability of fish, a measure of habitat heterogeneity was included for Iberian cyprinids, since fish populations should be more vulnerable at homogeneous river reaches. Finally, the proportion of impacted river length compared to the total length was used for cyprinids as for the salmonids. This implies that we assume fish had access to the whole river length before hydropower development.

The joint assessment of the effect and vulnerability parameters was defined by adapting the combined assessment made for salmonids in Norway (Harby et al. 2016).

All the effect and vulnerability parameters were considered equally important and the values assigned to each one (from High, value 3, to Low, value 1) were added. The total scores for the effect and vulnerability parameters were then divided in three classes. For the parameter V1a, V1b and V1c a single value correspondent to the average of the species/species group naturally occurring in the river reach should be considered. In the end, an overall assessment of hydropeaking impact is made, by combining the effects of hydropeaking with the vulnerability of the river system (Fig. 12.1).

12.4 Discussion

Despite the different hydrographs between Nordic and Iberian rivers, most of the effect factors included in the initial tool were kept for Iberian rivers. This likely reflects the similar nature of hydropeaking irreflective of river type, in what it relates to inflow variations over space and time. From all the effect factors included for salmonids, the magnitude

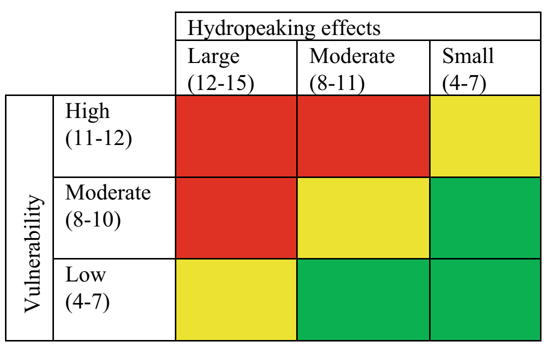

Fig. 12.1 Assessment matrix combining hydropeaking effects and vulnerability for total impact assessment. The colours denote the impact classes (large, moderate and small impacts are denoted, respectively, by red, yellow and green)

of flow changes was not kept for the Iberian rivers. The computation of this factor, as assessed by Qmax/Qmin, would invariably return larger values than for Norwegian HPPs since flow is near zero during the low flow period in many rivers in Mediterranean climate regions. The natural flow regime of Mediterranean-type streams is characterized by large differences between minimum and maximum discharge that are related with predictable, seasonal events of flooding and drying over an annual cycle (Gasith and Resh 1999; Bonada and Resh 2013).

Overall, the final set of effect factors was similar after the expert inputs, but some class thresholds were changed, namely for the dewatered area and the hydropeaking frequency. The distribution of hydropeaking events was also changed, with the highest impact linked to events occurring irregularly during Spring instead of irregular events occurring during all year. Spring was selected as a particularly vulnerable period as all Iberian cyprinids spawn largely during this season (e.g. Rodriguez-Ruiz and Granado-Lorencio 1992). In addition, regular hydropeaking events were considered less impacting, as fish individuals appear to memorize spatial and temporal environmental changes and to adopt a "least constraining" habitat (Halleraker et al. 2003; Costa et al. 2018; Jesus et al. 2019). Hydropeaking timing was also changed after the expert's input, with the highest impact related not only to the spawning period but also the sequent period of larvae development. In contrast to salmonids, density-related mortality during larvae period is unlikely for cyprinids, with year-class strength being related to stochastic environmental factors (Mills and Mann 1985). Consequently, hydropeaking could be particularly distressful for larvae in years where environmental conditions result in weak cohorts. The impact was considered reduced when occurring during the winter, and moderate if happening during the summer low flow period.

Contrasting with the effect factors, vulnerability factors for the cyprinids showed more differences with the ones proposed for the salmonids. These differences reflected the distinct auto-ecology of the two ray-finned fish families. First, we selected two taxonomical groups (Iberian barbel and smaller cyprinids), but based on expert's opinions, the breath of the smaller cyprinids justified the separation in two groups, one including the nase, and the other including the remaining cyprinids, but without *Achondrostoma* spp., due to their tolerance to hydropeaking and other anthropogenic impacts (Oliveira et al. 2012). The straight-mouth nases are usually the second largest cyprinid in fish assemblages, performing potamodromous spawning migrations such as the ones described for the barbel (Rodriguez-Ruiz and Granado-Lorencio 1992).

Since the number of females used for salmonids are more appropriate for an anadromous species such as the Atlantic salmon (*Salmo salar*) than for cyprinids, we opted to use CPUE as an indicator of population size of cyprinids. The abundance thresholds developed in this study were supported on available data on CPUE of native cyprinids in river reaches, but the indicator can be adapted to other databases on fish abundance, and can be also derived for specific river types. In the tool for salmonids, the rate of change (E1) is multiplied with the dewatered area (E2) factors. This is because the rate of change is not considered important if it does not lead to a significant reduction in dewatered area when water levels sink, and vice versa. This is due to the risk of stranding, which is considered a major challenge for salmonids. In our system, the effect factors are just an addition of all factors, because other impacts like disturbing movements, changing habitats, access to feeding, spawning, are also equally important. Besides, dewatered areas in Mediterranean-streams are typically large due to peak magnitude.

The hydropeaking tool developed for salmonids in Norway was successfully adapted to Iberian cyprinids and Mediterranean rivers. Nevertheless, it should be emphasized that both effect and vulnerability factors and the criteria for their characterization might be improved in the future if new studies on Iberian hydropeaking rivers come out with new insights.

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