Negotiation of small weirs by potamodromous cyprinids: the effect of key hydraulic parameters

Passage de petits déversoirs par des cyprinidés potamodromes : effet des principaux paramètres hydrauliques

Susana D. Amaral [1;2]; Paulo Branco [1;2]; Christos Katopodis [3]; Maria T. Ferreira [1]; António N. Pinheiro [2]; José M. Santos [1]

[1] Forest Research Centre, Instituto Superior de Agronomia, University of Lisbon. Portugal
[2] Civil Engineering for Research and Innovation for Sustainability, Instituto Superior Técnico, University of Lisbon. Portugal
[3] Katopodis Ecohydraulics Ltd.. Canada

RÉSUMÉ

La présence de petits déversoirs, plus nombreux que les barrages, modifie les systèmes fluviaux et affecte négativement les communautés de poissons, principalement en perturbant leurs déplacements. Cependant, alors qu'il existe une vaste littérature sur les barrages, on en sait beaucoup moins sur les effets des petits déversoirs sur les mouvements des poissons. Cette étude vise à évaluer la performance de passage amont d'un cyprinidé potamodrome, le barbeau Ibérique (*Luciobarbus bocagei*), en présence de petits déversoirs, en prenant en compte l'interaction de variables hydrauliques clés : hauteur de chute (Δh), profondeur de bassin (D), crête de déversoir (W), et écoulement de l'eau (Q). Initialement, 16 configurations ont été testées en combinant hauteur de chute (Δh = 5, 10, 15, 25 cm) et profondeur de bassin (D = 10, 20, 30, 50 cm) à un débit constant de 50 L/s et une largeur de crête de 20 cm. Postérieurement, 2 autres largeurs de crête (W = 40, 80 cm) et 3 nouveaux écoulements (Q = 25, 75, 100 L/s) ont été implémentés sur la configuration ayant le plus grand succès de passage. L'environnement hydraulique en aval du déversoir a été caractérisé par un vélocimètre acoustique 3D à effet Doppler. Les résultats ont démontré que les variables étaient significativement corrélées au nombre de passages réussis. Ainsi, le passage amont apparaît comme un phénomène complexe, fortement dépendant de l'environnement hydraulique caractérisé par l'interaction de ces variables.

ABSTRACT

The presence of small weirs, far more numerous than dams, have altered the river systems and negatively affected fish communities, mainly by disturbing fish movements. However, contrarily to the vast literature on dams, much less is known about the effects of small weirs on fish movements. This study aims to evaluate the upstream passage performance of a potamodromous cyprinid, the Iberian barbel (*Luciobarbus bocagei*) when encountering small weirs, considering the interaction of key hydraulic variables: waterfall height (Δh), plunge pool depth (D), width of the weir crest (W), and flow discharge (Q). Initially, 16 configurations were tested considering the combination of waterfall height (Δh = 5, 10, 15, 25 cm) and plunge pool depth (D = 10, 20, 30, 50 cm) at a constant flow discharge of 50 L/s, and a crest width of 20 cm. Posteriorly, another 2 crest widths (W = 40, 80 cm) and 3 new discharges (Q = 25, 75, 100 L/s) were implemented on the configuration that had the highest passage success. Hydraulic environment downstream of the weir was characterized with a 3D Acoustic Doppler Velocimeter. Results demonstrated that variables were significantly correlated with the number of successful fish passages. Therefore, upstream passage appears to be a complex phenomenon, strongly dependent on the hydraulic environment that is formed by the interaction of these variables.

KEYWORDS

Ecohydraulic, potamodromous cyprinid species, river connectivity, small weirs, upstream migration

1 INTRODUTION

River fragmentation has been pointed out as one of the most serious threats to the sustainability of fish populations (Nilsson et al., 2005). Although far more numerous than dams, the impacts on the river system of small instream obstacles, like small weirs, have received much less attention (Ovidio and Philippart, 2002) as they are considered "small barriers" and "*a priori* permeable" to fish movements. However, the presence of these barriers changes the hydraulic environment, altering water depth and water velocity patterns, and creates vertical drops that may partially or totally block fish migratory routes (Baudoin et al. 2014). Potamodromous cyprinid species can be particularly affected by the presence of small weirs due to their need to perform seasonal reproductive migrations (Ovidio and Philippart, 2002). In addition, the limited swimming and jumping capacity of potamodromous cyprinids, when compared to salmonid species (Ovidio and Philippart 2002), augment the impacts of these barriers on fish upstream migratory movements.

This study aims to evaluate the upstream passage performance of a potamodromous cyprinid, the Iberian barbel (*Luciobarbus bocagei*) when encountering small weirs, considering the interaction of key hydraulic variables: plunge pool depth (D; water depth below the weir), waterfall height (Δh; distance from the plunge pool surface to the top of the weir crest), width of the weir crest (W), and flow discharge (Q). Iberian barbel was selected as the target-species, since it is considered representative of at least 8 species of medium-sized benthic potamodromous cyprinids in Iberia and Western Europe. It was hypothesized that upstream successful passage of barbel would increase with decreasing waterfall heights in association with increasing plunge pool depths, lower flow discharges and smaller crest widths.

2 MATERIAL AND METHODS

The experiments were performed in an indoor experimental channel installed at the National Laboratory for Civil Engineering (LNEC), in Lisbon. The channel consists of a rectangular steel frame (10.0 m long × 1.0 m wide × 1.2 m high) with glass-viewing panels on sidewalls (allowing observation of fish movements within the flume), connected to an upstream chamber and a downstream tank that enable the entry of water in the flume and its recirculation, respectively. The channel was adjusted with a 3% slope, that was considered representative of most Iberian rivers. An experimental broad-crested weir made of polyvinyl chloride (PVC) modules was used to study the effect of D, Δh, W and Q on the upstream successful passage of Iberian barbel. The experimental weir was installed in the flume at 2.75 m upstream of the acclimation area (area created by two mesh panels, 1 m apart on the downstream zone of the flume), spanning the entire channel width.

Initially, 16 configurations were tested considering the combination of plunge pool depth (D = 10, 20, 30, 50 cm) and waterfall height (Δh = 5, 10, 15, 25 cm) at a constant flow discharge of 50 L/s, and a crest width of 20 cm. Posteriorly, another 2 crest widths (W = 40, 80 cm) and 3 new discharges (Q = 25, 75, 100 L/s) were implemented on the configuration that had the highest passage success. All 25 combinations tested had 4 replicates, carried out with schools of 5 fish per replica. Fish movements were monitored by direct observation and recorded by a video camera (GoPro HERO3). Registered observations included: number of fish that approached the weir (Ap; fish that entered the approach area), number of passage attempts (At; fish that actively tried to negotiate the waterfall), and number of passage successes (N). To determine the potential negotiation of the weir for the combinations tested, the percentage of attraction efficiency (%AE = number of attempts/number of approaches × 100) and passage efficiency (%PE = successful passages/number of attempts × 100) were calculated. For the statistical analysis, to verify the influence on the number of successful passages of D, Δh, and D×Δh, as well as W, Q, and W×Q, a distance-based MANOVA (PerMANOVA) based on Euclidean distance was performed. As for the hydraulic environment, water velocity downstream of the weir was characterized with a 3D Acoustic Doppler Velocimeter, and over the crest of the weir was measured by a flow probe.

3 RESULTS AND DISCUSSION

On average, 657 movement approaches and 195 attempts to pass the weir were recorded indicating that Iberian barbel were stimulated to move upstream and negotiate the weir. All configurations tested were successfully negotiated by fish (Table 1 and 2). However, results from passage successes (N),

passage efficiency (%PE), and attraction efficiency (%AE), were very different among configurations. The combination D×Δh (Table 1) with the best results was D20Δh10, with 50 successful passages and high values of attraction efficiency (53%) and passage efficiency (17%). On the other hand, D10Δh25 was the configuration that presented the poorest results, with only one successful pass and low values of passage efficiency (1%) and percentage of success (20%). Configuration D50Δh05, which was expected to have the highest number of successes due to the high D and the lower Δh to overcome, ranked third with 25 successful passages. Analysing the passage performance of barbel on configuration D20Δh10 during increasing W and Q (Table 2), it was found that successful passages were not compromised by the increase of W, with more successes being recorded in the configurations with larger widths; however, the increase of Q influenced the passage performance of barbel, with a decrease in the number of successes on configurations with Q = 100 L/s.

Table 1 - Results from the 16 combinations of D×Δh initially tested, with W = 20 cm and Q = 50 L/s. N, passage successes; %PE, percentage of passage efficiency; %AE, percentage of attraction efficiency.

	D10 Δh5	D10 Δh10	D10 Δh15	D10 Δh25	D20 Δh5	D20 Δh10	D20 Δh15	D20 Δh25	D30 Δh5	D30 Δh10	D30 Δh15	D30 Δh25	D50 Δh5	D50 Δh10	D50 Δh15	D50 Δh25
N	10	11	18	1	9	50	24	19	17	28	9	3	25	8	18	4
%PE	15	8	20	1	5	17	10	11	5	9	4	3	13	6	11	2
%AE	8	19	12	25	27	53	26	23	48	46	39	15	27	22	17	24

Table 2 – Passage performance of barbel across increasing W (cm) and Q (L/s) on configuration D20Δh10.

	W20 Q25	W20 Q50	W20 Q100	W40 Q25	W40 Q50	W40 Q100	W80 Q25	W80 Q50	W80 Q100
N	14	50	1	52	26	25	44	48	13
%PE	5	17	8	12	12	23	15	27	22
%AE	19	53	46	36	37	66	32	40	41

Results of the PerMANOVA analysis on the number of successful upstream passages corroborated the previous findings, showing significant effects of Q ($F = 5.47$; $P = 0.008$), and both D ($F = 5.46$; $P = 0.004$) and Δh ($F = 4.68$; $P = 0.006$), and their interaction term D× Δh ($F = 3.02$; $P = 0.005$). As for the factor W, and the interaction W×Q, there was no evidence that influenced upstream passage of fish.

4 CONCLUSIONS

The results of this study enable us to conclude that shallow plunge pool depths, high waterfall heights, and high flow discharges may restrict the successful passage of Iberian barbel. Contrary to what was hypothesized, increased passage did not occur at higher plunge pool depths in association with a lower waterfall height, although combination D50Δh05 provided reasonable results. Moreover, the increase of the crest width did not compromise the successful negotiation of the weir. So, this study showed that successful passage of small instream obstacles seems to be a more complex phenomenon, where these key hydraulic variables (D, Δh, W, Q) interact to set the most favourable hydrodynamic conditions for fish to overcome the obstacle.

The outcomes of this work are expected to be useful to identify potential migration obstacles for potamodromous cyprinids, and to define design criteria for the requalification of small barriers, improving fish passage and consequently habitat connectivity.

LIST OF REFERENCES

Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science*, 308, 405-408.

Ovidio, M., Philippart, J.C. (2002). The impact of small physical obstacles on upstream movements of six species of fish - synthesis of a 5-year telemetry study in the River Meuse basin. *Hydrobiologia*, 483, 55-69.

Baudoin, J.M., Burgun, V., Chanseau, M., Larinier, M., Ovidio, M., Sremski, W., Steinbach, P., Voegtle, B. (2014). *Assessing the passage of obstacles by fish. Concepts, design and application*. Onema. France.