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Retrofitting pool-and-weir fishways to improve passage performance of benthic fishes: Effect of boulder density and fishway discharge

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ABSTRACT

Retrofitting, or the addition of features to existing fishways to make them more suitable for upstream fish passage, is an issue of increasing interest in fishway science. Despite its potential for aiding fish passage, few studies are available on retrofitting of pool-and-weir fishways by adding boulders at the bottom of each pool of these facilities. The aim of this study was to assess the performance of a full-scale retrofitted pool-and-weir fishway model with boulders placed at the bottom of each pool, to enhance passage of a cyprinid species, the Iberian barbel (*Luciobarbus bocagei*), which was considered as a representative of medium-sized benthic potamodromous cyprinids in Iberia and Western Europe. Particular attention was given to testing the effects of boulder density and fishway discharge on passage success and fish transit time, both of which affect fish passage efficiency. Although no significant difference in passage success was detected between boulder spacings (mean proportion for high density: 35% success; mean proportion for low density: 40% success), increased flows (62.7 l/s) induced a higher mean proportion ($P < 0.05$) of successful negotiations (50%), relative to low flows (38.5 l/s, 25%). With regard to fish transit time, under higher flows, fish took significantly less time ($P < 0.05$) to ascend the fishway with the higher (5.3 ± 4.2 min) vs the lower boulder density (12.1 ± 6.5 min). This study showed that fish passage success was discharge-related and independent of boulder density. However, a high density boulder configuration combined with higher fishway discharge can be beneficial as it reduced fish transit time. Such information could be used to retrofit ill-functioning fishways in order to improve fish passage efficiency and negotiation of fishways for benthic potamodromous cyprinids.

1. Introduction

Pool-and-weir fishways are the most common type of fish passage devices worldwide (Hatry et al., 2013; Larinier, 2008; Pompeu et al., 2012). These facilities are predominantly installed at low head barriers built for small-scale hydropower and other water diversion structures and consist of a rectangular flume divided by cross-walls that create a series of consecutive pools arranged in a stepped pattern, with each one higher than the one immediately downstream (Katopodis et al., 2001). These pools divide the obstacle height into smaller steps to be negotiated by fish, which move from one pool to the next through openings in the cross-walls that are situated at the top (notches) and/or at the bottom (submerged orifices) (FAO/DVWK, 2002). Despite their worldwide popularity, the performance of these facilities, measured as the proportion of fish successful negotiations with minimum delay, is relatively low in many parts of the world, such as in southern European countries (Santos et al., 2012), because their design was biased by salmonid-based guidelines. Salmonids are typically strong swimmers with great leaping abilities, while the most abundant fish species in southern European countries are potamodromous and resident cyprinids that have weaker swimming abilities (Katopodis Ecohydraulics Ltd., 2013). Therefore, incorporating additional provisions for fish passage in pool-and-weir fishways could facilitate upstream movement of these species.

Retrofitting, or adding features to existing fishways to make them more suitable for upstream fish passage, is an issue of increasing interest in fishway science (Gough et al., 2012). The

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placement of boulders, a common component of natural fishways which are built to resemble a natural side channel with suitable substrate, water movements, morphology and gradient (Calles and Greenberg, 2005), can be useful in aiding fish passage of technical pool-and-weir fishways as long as the hydraulic capacity of the facility is not compromised (Stevenson and Baker, 2009). The placement of boulder substrate at the bottom of these facilities has been outlined as a possible action to improve fish passage, because it reduces flow velocities near the bottom and allows species of weaker swimming capabilities to take advantage of lower velocities created by the imbedded roughness elements during upstream migration (FAO/DVWK, 2002). Despite the potential for aiding fish passage, few studies (FAO/DVWK, 2002; Santos et al., 2013) are available on retrofitting technical fishways with the addition of boulders on the bottom of these facilities. Nonetheless, previous hydraulic studies lacking fish testing have demonstrated that boulder size and spacing (or density), as well as discharge, can be key parameters that determine flow behavior around an obstacle and may enhance suitable hydraulic conditions that promote upstream fish movement (Shamloo et al., 2001). Therefore, fishway modifications and new designs that incorporate hybrid components of natural and technical fishway types need to be tested with wild fish to assess and improve fish passage efficiency (Bunt et al., 2012). Given that current legislation, such as the European Water Framework Directive (European Commission, 2000), indicates the need for undisturbed migration of fish species as a key component of watershed restoration, such studies should ideally be performed for all species present in a river. Because such an approach would not be feasible due to cost and time constraints, fish species should be assembled into functional groups, based on basic body shape and ecological niche, a technique deemed suitable for multispecies approaches (Leonard and Orth, 1988).

The aim of this study was to assess the performance of an indoor full-scale retrofitted pool-and-weir fishway with boulders at its floor, to enhance passage of a potamodromous cyprinid species, the Iberian barbel (*Luciobarbus bocagei*), which occurs in a wide range of lotic and lentic habitats (Lobón-Cerviá and Fernández-Delgado, 1984). This species can be considered as a representative of at least 15 species of medium-sized benthic potamodromous cyprinids in Iberia and Western Europe (encompassing species from the genera *Barbus*,*Luciobarbus*, *Pseudochondrostoma,* and *Parachondrostoma*), because it shares similar ecological guilds of physical habitat (benthic), reproduction strategy (lithophilic) and migratory behavior (potamodromous) (Doadrio et al., 2011; Kottelat and Freyhof, 2007). Particular attention was given to testing the effects of boulder density and fishway discharge on passage success and fish transit time. Specifically, the following questions were addressed: (a) was passage success dependent on boulder density, fishway discharge or both? and (b) did successful fish take the same amount of time (i.e., transit time) to ascend the fishway independent of boulder density? As a comparison with a scenario of non-altered pools (no boulders, smooth bottom) is needed to show the effect of adding boulders to improve fish passage performance, results will be later compared with the ones from a previous study conducted on the same facility and with the same species, though employing a distinct experimental design (Silva et al., 2011).

2. Material and methods

2.1. Experimental facility

The study was conducted in an experimental pool-and-weir fishway installed at the National Laboratory for Civil Engineering (LNEC), in Lisbon, Portugal. The facility consisted of a full-scale model, built on a steel frame with lateral acrylic transparent glass panels on both side-walls. It was composed of six pools, each 1.9 m long × 1 m wide × 1.2 m high, with the tilted portion of the flume having a total length of 10 m (Fig. 1). The pools were divided by compact polypropylene cross-walls, each one incorporating a submerged square orifice of adjustable area. The orifices were arranged in an offset pattern to maximize passage performance (Silva et al., 2012), while the surface notches remained closed, as a previous study revealed benthic species avoidance of these openings (Santos et al., 2012). The fishway also included an upstream chamber with a slot gate to control the discharge entering the flume, and a downstream tank (4.0 m × 3.0 m × 4.0 m), separated from the flume by two mesh panels, to allow acclimation of fish prior to the start of the experiments. The downstream tank is directly connected with the most downstream basin of the fishway, so they have the same water stage. The stage in any basin is, thus, controlled by the water stage at the tank, being equal 0.16 m (Δh, the head drop between consecutive pools) × number of cross-walls upstream of the tank. Large cloth screens, erected at a distance of 3 m from the flume, and along both channel walls prevented lateral illumination and fish disturbance. The 10 m

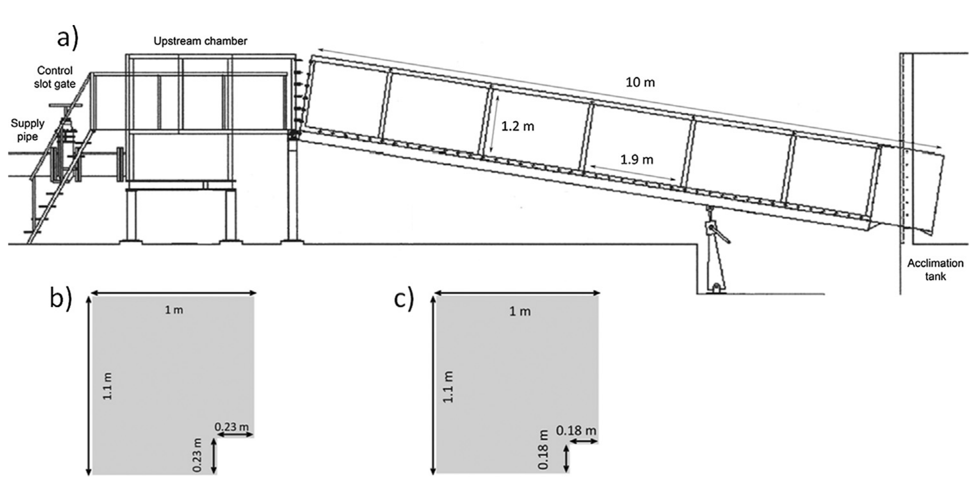

Fig. 1. (a) Side view diagram of the experimental full-scale pool-and-weir fishway showing the upstream and downstream (acclimation) tanks at the National Laboratory for Civil Engineering (LNEC). The flume tilted portion is 10 m long with a slope of 8.5%; (b) cross-section of cross-walls used for the high discharge (E1 and E2); and (c) for the low discharge (E3 and E4) experimental designs.