



Short communication

Obstacle negotiation attempts by leaping cyprinids indicate bank-side spawning migration routes



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ABSTRACT

Understanding freshwater fish population ecology is a pre-requisite for their conservation, management, and exploitation. Many populations of cyprinids, the largest family of freshwater fish, undertake potamodromous migrations. This has important implications for the conservation and management of their stocks. Habitat and connectivity loss are the main factors threatening these stocks. The fine-scale routes (i.e., banks vs. midchannel) of cyprinid spawning migrations in generally turbid rivers are largely unknown, contrary to other taxa such as salmonids, shads, and eels. In this work, we studied the fine-scale leaping behavior of two cyprinid taxa (*Luciobarbus* sp., barbels) which support commercial and recreational fisheries. We used fish size and leap distance to the margin as indicative of fine-scale spawning migration routes following the river banks vs. midchannel. The results support the idea that these cyprinids migrate close to the banks, and that the larger adults migrate nearer the banks than the smaller ones. This marks a difference between cyprinids and salmonids, showing that knowledge of cyprinid migration routes can help fisheries managers develop improved, more permeable, barriers and less selective fish pass facilities. Particularly, this behavior of cyprinid species can be applied to optimize the design of fish pass facilities: first, by installing fish passes on each bank of wide rivers, where the large lateral distance may make a single facility difficult to find; and second, by using either a single wider entrance or several narrower entrances distributed over a greater distance from the margins so as to cover the more distant stretch used by the younger adults.

1. Introduction

Migration behavior is one of the activities most directly related to fish fitness through survival, feeding, reproductive success, and recruitment (Lucas and Baras, 2001). Riverbanks offer habitat conditions especially selected by fish in certain times of their diel and seasonal migrations. Over the diel cycle, fish perform vertical, lateral, and longitudinal migrations (Baumgartner et al., 2008, and references therein). These cause a lateral segregation, i.e., the variable use of the banks as opposed to midchannel during these movements or while staying in place between movements. While performing seasonal spawning migrations, adult fish avoid the excessive velocities and upwellings in the main channel by moving upstream near the banks (Powers and Osborn, 1985). Eels (*Anguilla* sp.) move almost exclusively bankside, rarely moving cross-channel, as a result showing considerable bank fidelity (Jellyman and Sykes, 2003). Adult salmonids use the banks as a guide to their spawning habitats, as well as taking advantage of the banks' lower water velocities; as an effect of wave drag, large salmon move farther from the bank than smaller ones (Hughes, 2004).

In comparison, much less is known concerning cyprinids migrations, such as those undertaken by barbels (e.g., *Luciobarbus*).

Adult barbels perform lateral and longitudinal movements following winter or spring spates (Baras, 1992). But fine scale (i.e., relative to the bank) cyprinid behavior in turbid rivers is particularly difficult to study. To the best of our knowledge, no study describes the fine scale spawning migration route –i.e., banks versus midchannel use while migrating upstream– of cyprinid taxa. However, with over 2000 species, the *Cyprinidae* is the largest family of freshwater fishes, having species naturally distributed in Eurasia, Africa, and North America (Moyle and Cech, 2004). Cyprinid migration routes have important implications for their conservation and fishery management, with problems mainly related to the impacts of connectivity loss (Lucas and Baras, 2001; Nilsson et al., 2005). Fish-and-obstacle interactions have stimulated research on fish behavior (e.g., Morán-López et al., 2017), but a frequent finding in non-salmonid fishway assessments is that many fish pass facilities have low efficiency (Clay, 1995; Nicola et al., 1996; G.I.C., 2008). Knowledge of the migration routes of cyprinids by fishery managers can lead to the development of improved, more

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permeable barriers and less selective fish pass facilities.

In this study, we used aerial observations of leaping cyprinids to obtain fine-scale spatial information on the underwater behavior of fish in a turbid river stretch. Our previous observations showed that upstream migrating fish, especially the larger individuals, seemed to leap a weir more frequently nearer the margins, resulting in non-random locations of the negotiation attempts. Our hypotheses were that a fish's route towards an obstacle and negotiation attempts may not be independent of the margins, and that there could be associated behavioral differences related to the individual's size. Our predictions were that leap frequency would increase with decreasing distance to the margin, and that the nearer the margin, the greater would be the fraction of larger fish having better leaping capabilities.

2. Methods

2.1. Study area

We conducted the study at the Granadilla weir, located in the Guadiana River in the southwestern Iberian Peninsula (38° 51' 42.5" N 7° 01' 02" W). The waterfall height is impassable either by swimming or leaping for every species in the river (Morán-López and Uceda Tolosa, 2017a). Two *Luciobarbus* barbel species sustaining commercial and recreational fisheries (Antunes et al., 2015), have large migrating populations that leap at the weir: the Iberian long-snout barbel *Luciobarbus comizo* (Steindachner, 1864) and the Iberian small-head barbel *L. microcephalus* (Almaça, 1967). More details are in Morán-López and Uceda Tolosa, (2017a,b).

2.2. Data collection

We collected data on jumping behavior through video images taken in late April 2011 at midday. These data correspond to adult fish leaping under optimal conditions of water temperature (21 °C). These data include the maximum frequency of cyprinid jumping behavior observed in the last decade (2007–2016), along seasonal (March to May) and daily (dawn to dusk) time scales. We observed in this long term monitoring scheme that the maximum number of barbel leaps per minute in the right margin of the Guadiana River was 150 in 2011, whereas the decade mean maximum was 55.1 ± 93.3 . Therefore, we carefully selected the conditions of data collection (year, site, date, and horary) in which fish were highly motivated to migrate and leap (Morán-López and Uceda Tolosa, 2017b).

We used a SONY DCR-SR290E digital camera (video rate: 25 frames s⁻¹; focal distance: 25.9 mm; maximum aperture: f/1.8) to film the leaping behavior. We positioned the camera on a tripod above the water near the bank of the river ca. 40 m downstream of the weir. We orientated the camera perpendicular to the weir and flow, and raised it to the middle height of the obstacle with the aid of a bubble level and a laser rangefinder (Nikon LASER 550A S). Based on a preliminary study, we adjusted the zoom level to cover a field of view of approximately 7 × 4 m; this is a compromise between horizontal amplitude of spatial coverage of the obstacle and fish size on the images. The video frames included a section of the facility of known dimensions, allowing us to scale the image pixels to absolute metric measurements. We measured the fall height ($h = 1.62$ m) and plunge pool depth ($d = 0.85$ – 1.05 m). We extracted video frames of 1024 × 576 pixels for complete fish trajectories. We registered total fish length and horizontal and vertical coordinates of the fish snout in the frame reaching the maximum height, where the fish's velocity approaches zero ($n = 260$). We determined the precision of the method by filming a free falling 239 mm diameter ball, giving $CV = 4.6\%$ ($n = 68$); this represents approximately 1 cm in a barbel of average length. Bias is not to be expected from coordinate measurements because of the random nature of the errors, but fish lengths may be underestimated, for which reason we used a conversion coefficient developed from capture data at the weir

(more details in Morán-López and Uceda Tolosa, 2017a,b). Sex or species of the barbel individuals were not distinguishable from the video frames. Sex differences in leaping capabilities are not to be expected (Kondratieff and Myrick, 2006). Captures and photographs made at the weir showed the two species to be comparable in population size, length distribution, and sex ratio (Morán-López and Uceda Tolosa, 2017a). Thus we considered them together as the *barbel* species group because multispecies approaches have a demonstrated utility in quantitative assessments for conservation management (Bonn and Schröder, 2001; Dallimer et al., 2009; Schwenk and Donovan, 2011; Morán-López et al., 2017).

2.3. Data analysis

The goals of our analyses were to describe and compare the horizontal spatial distribution relative to the margin of leap height and total fish length. We used Kolmogorov-Smirnov tests to check the normality of the variables leap height (LH), leap distance to the margin (LD), and fish total length (TL). We used a least squares regression analysis to measure the linear dependence between LH and TL. We used in the horizontal spatial analyses the LH and TL locations. We applied one-way analyses of variance to test for differences in LH and TL between LD classes: proximal (< 1.5 m), medium (1.5–3.0 m), and distant (> 3.0 m). We used Fisher's LSD post-hoc tests to analyze differences between the aforementioned classes.

3. Results

We found that the larger barbels were more frequent and leaped higher closer to the bank, and that their size and leap height were reduced farther away from the bank. The Kolmogorov-Smirnov tests showed LD not to be normally distributed ($d = 0.1929$; $p < 0.01$), the remaining variables being normally distributed ($p > 0.20$ in both LH and TL). Regression analysis showed LH and TL were related ($F_{(1,258)} = 25.629$, $p < 0.001$), and had a positive partial correlation ($r = 0.30$; $p < 0.01$). The LD classes differed in LH ($F_{(2,257)} = 3.01$; $p 0.05$; Fig. 1a); there were differences between the distant and both the medium (Fisher LSD; $p = 0.019$) and the proximal (Fisher LSD; $p = 0.032$) LD classes, but not between the proximal and medium classes (Fisher LSD; $p = 0.507$). The LD classes differed in TL ($F_{(2,257)} = 4.98$, $p < 0.01$; Fig. 1b) as a result of the difference between the proximal and distant LD classes (Fisher LSD; $p = 0.004$); the remaining classes were not different (Fisher LSD; $p > 0.05$). The distant class was characterized by fish of smaller TL (Fisher LSD; $p < 0.05$) reaching lower LH (Fisher LSD; $p < 0.05$).

4. Discussion

Freshwater fish such as cyprinids use different lateral river habitats, from the banks to the middle of the channel, depending on biological and ecological constraints. It is known that the use of banks is important for many fish species, particularly when they are in certain developmental stages, size classes, diel or seasonal periods, or under particular physical conditions (Rifflart et al., 2009). Large taxa such as chub, barbel, perch, and shad also benefit from bank proximity, particularly in order to avoid the faster river currents (Arahamanian, 1982; De Vocht and Baras, 2005; Rifflart et al., 2009). Many studies have demonstrated the importance of bank habitats for different species and assemblages at various spatial scales (e.g., Morán-López et al., 2005, 2006, 2012).

In the context of a spawning migration study, we observed that barbels contacted the weir mainly by the margin. Margins are commonly accepted as being the main “landmarks” used by freshwater fish –together with flow– for orientation during upstream migrations (Larinier 2002). Moreover, we observed that the greater the distance from the margin the lesser the number of negotiation attempts, and the

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