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BEHAVIOURAL ADAPTATIONS OF RHEOPHILIC FISH RADIO-TRACKED IN A RIVER HIGHLY FRAGMENTED BY HYDROELECTRIC PLANTS. OUTCOMES OF A PARTIAL REOPENING OF THEIR MIGRATION ROUTES.

MICHAEL OVIDIO

University of Liège, Biology of Behaviour Unit, Laboratory of Fish Demography and Hydroecology.
Chemin de la Justice 10, 4500 Tihange, Belgium

ARNAUD DIERCKX

University of Liège, Biology of Behaviour Unit, Laboratory of Fish Demography and Hydroecology.

JEAN-PHILIPPE BENITEZ

University of Liège, Biology of Behaviour Unit,Laboratory of Fish Demography and Hydroecology.

JEAN-CLAUDE PHILIPPART

University of Liège, Biology of Behaviour Unit,Laboratory of Fish Demography and Hydroecology.

PATRICE ORBAN

Public Service of Wallonia. General Directorate for Agriculture, Natural Resources and Environment. Department of rurality and waterways. Direction of unnavigable waterways. 7 Avenue Prince de Liège, B-5100 Jambes, Belgium

Using water resources for hydroelectricity production influences and limits the quality and quantity of habitat available for use by fishes and influences fish mobility. In the Amblève (River Meuse basin, Belgium), the major part of the river is fragmented by hydroelectric power plants that largely prevent the biological movements of the fish population. In 2007, in the hydroelectric site of Lorcé, a modern pool-type fish pass was constructed, re-establishing the upstream movements of fish after more than 80 years of total obstruction. Sixteen different fish species promptly used the new fish pass and the objective of our study was to analyse their behavioural tactics and spawning activity once released upstream of the dam in a previously inaccessible environment. The study focussed on rheophilic holobiotic species, the nase (*Chondrostoma nasus*), the barbel (*Barbus barbus*), the European grayling (*Thymallus thymallus*) and the brown trout (*Salmo trutta*), which are

highly representative of the fish population of the river. The fish were radio-tagged and intensively located using manual tracking techniques during their circum reproduction periods. The results indicate that most individuals of the different species seem to have found usable spawning areas and exploited a large part of the newly usable river stretch (as well as tributaries) located upstream of the fish pass. However, a major problem was observed during the post-spawning period, when the tracked individuals tried to reach their original departure sites (located downstream of the fish pass). The absence of a downstream migration device combined with the passage of all the water through the turbine severely disrupted their post-reproductive movements.

1 INTRODUCTION

Given the linear nature of freshwater habitats, dams and weirs act as anthropogenic barriers that fragment the river, obstructing the movement of organisms and nutrients, and reducing the amount of available habitat for fishes (Sheer and Steel [1]; Noonan and Jackson [2]). The reconnection of river habitats and river sections is one of the most important measures in river restoration projects and management plans (Roni et al., [3]). In an attempt to counteract the negative effects of habitat fragmentation, a wide variety of devices have been installed at river barriers to restore connectivity and aid with both upstream and downstream fish migration (Clay [4]). Over the past few years, a substantial effort has been made in certain European countries (notably in Belgium) to consider as priority species for restoration of ecological continuity not only the great migrators (salmon, eel, lamprey), but also rheophilic holobiotic species (e.g., barbel, nase, grayling, brown trout,) which are very demanding in their spawning areas and must migrate several dozen kilometers to complete their biological cycle (Ovidio and Philippart [5]). In Belgium, the results of scientific observations of mixed fish passes very clearly demonstrated the validity of installing these devices because on the majority of experimental sites the rheophilic and ubiquist cyprinids were among the most highly represented species in passage recordings.

Although the actual use of passes by fish is rightly considered proof of success of their effectiveness (Noonan and Jakcon, [2]), the question of the actual impact of reopening the river axis on the biological cycle of the different species targeted should also be raised. What will become of these fish, will they manage to find the necessary habitats to accomplish their vital functions, notably to reproduce, and if they do succeed, what becomes of the parent fish in the post-spawning period? In an attempt to respond to these questions, this study tagged and radio- tracked four species of holobiotic fish after their capture in a newly constructed fish pass on a river in a shady zone in the Belgian Ardennes.

2 MATERIAL AND METHODS

2.1 Study site

Since its construction in 1932, Lorcé dam on the Amblève River (Fig. 1) has been impassable outside of rare periods when the turbines were not in operation (repair work, opening of spillways, high floods). At the end of 2007, the dam was equipped with a modern pool-type fish pass with a fish trap.

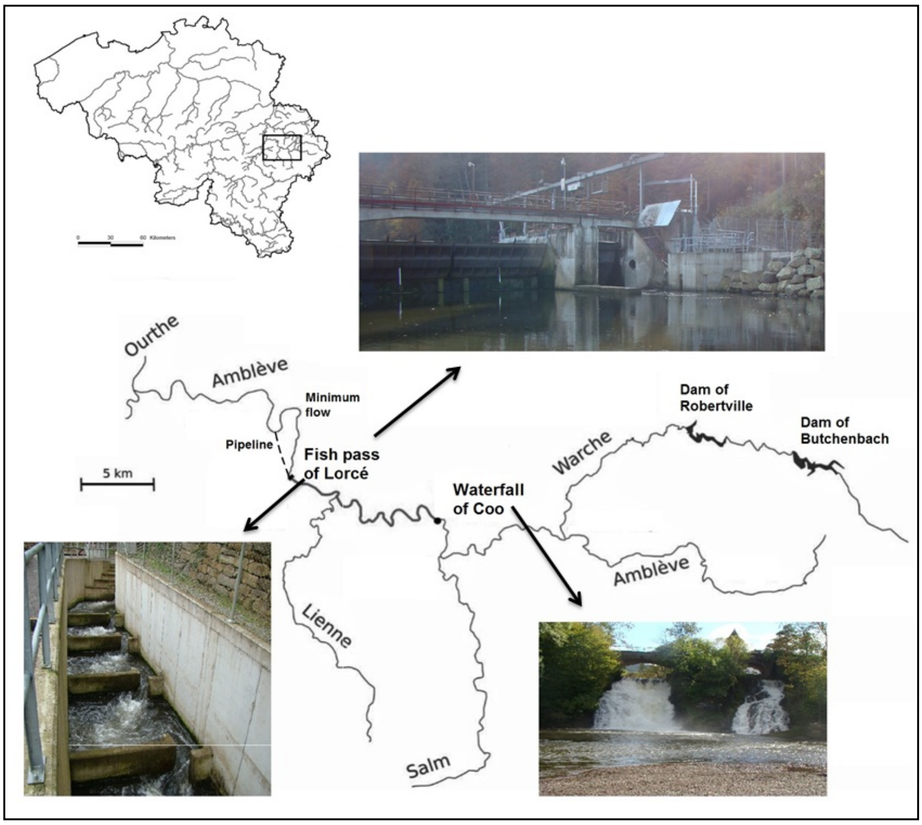

Figure 1. Location of the main points of the study area on the River Amblève (River Ourthe Sub-basin, River Meuse basin).

The fish pass pools were covered with a substrate to simulate the natural river bed. Between 2007 and 2011, 16 different species used the new Lorcé fish pass. In terms of biomass, the dominant species were the barbel (53%), the brown trout (24%), the chub (9%) and the European grayling (4%). The other species accounted for less than 10% of the total biomass captured. Lorcé dam creates a small 50,000-m^3 reservoir, with no accumulation capacity, which feeds a pressure pipeline arriving at the Hé de Goreu hydroelectric power station. The dam has two mobile gates, 24 m wide, creating a drop of Dh 3.3 m. Next to the two regulator gates is an emptying gate whose purpose is to completely empty the reservoir, increase the flood discharge flow and, until 1993, allow 3 m^3/s of compensation discharge to pass as overflow. However, this compensation discharge also turns a micro-turbine (3.5 m drop, 3 m^3/s water flow, 85 kW maximum power; mean annual production, 450,000 kWh). This small turbine is fed through a large trashrack made of vertical bars spaced 4 cm apart. Bypassing the Amblève by a penstock, on an 8-km river reach, reduces the natural flow to a minimum of 3 m^3/s corresponding to the legal compensation discharge. Returning the turbined water to the Amblève at a maximum flow of 26 m^3/s re-establishes a normal flow to the river but locally generates a strong hydraulic contrast (flow, depth, speed).

2.2 Telemetry study

Eleven individuals of four fish species were radio-tracked after their passage in the Lorcé fish pass: the brown trout (*Salmo trutta*), the European grayling (*Thymallus thymallus*), the barbel (*Barbus barbus*), and the nase (*Chondrostoma nasus*). These species are representative of this sector of the Amblève River and the restoration of the hydromorphological quality of their habitats is considered to be a high priority in the Wallonia region of Belgium (Philippart and Ovidio [6]). Fish were anaesthetised in a solution of 2-phenoxy-ethanol (0.2 mgl^{-1}), and a radio transmitter (ATS Inc., 40 MHz, trailing whip antenna) was inserted into the body cavity of the fish through a midventral incision (Philippart and Ovidio [5]). The sex of the individual fish was determined by visual inspection of the gonads through the incision that was closed with three separate stitches, using sterile, resorbable, plain Vicryl sutures. To avoid any adverse effect of long-term post-operative care on their behaviour, nase were released at their exact capture site as soon as they had recovered and showed spontaneous swimming activity (approximately 20–30 min after surgery). The fish were located by triangulation from markers on the banks of the rivers using mobile FieldMaster radio receivers and loop antennas (ATS Inc.). They were located during daytime, with accuracy between 5 and 20 m^2, depending on the distance between the fish and the observer and the width of the river. Tracking started the day after tagging. Fish were located from 3 to 7 days a week. Water temperature was recorded hourly by data loggers (TidBit; Onset Compute Corp.) and water flow was continually monitored (data from the Water Division).

Table 1. Characteristics of the fish radio-tracked after their passage in the Lorcé fish pass.

Species number	Fork length (mm)	Weight (g)	Sex	Transmitter weight (g)	Capture–release date
Trout 1	341	372	F	6g	26/11/2007
Trout 2	326	310	M	6g	26/11/2007
Trout 3	316	300	F	6g	03/12/2007
Grayling 1	425	781	M	6g	30/11/2007
Grayling 2	306	328	F	6g	05/03/2008
Grayling 3	308	262	M	6g	05/03/2008
Nase 1	500	1797	F	14g	04/04/2008
Barbel 1	488	1423	M	14g	04/04/2008
Barbel 2	525	1806	F	14g	21/04/2008
Barbel 3	480	1436	F	14g	21/04/2008
Barbel 4	589	2223	F	14g	21/04/2008

3 RESULTS

After passing the fish ladder, the radio-tagged individuals were released slightly upstream from the dam. Trout 1 (Figure 2 B) left the reservoir upstream of the dam and migrated 600m upstream on 30 November 2007. We lost its signal for a few days but found it again on 4 December in the Lienne, a salmon tributary of the Amblève nearly 12km upstream of Lorcé dam, and it remained in this sector, probably for reproduction until 7 December 2007. By 11 December, it began a downstream migration and on 13 December it was located in the lower reach of the Lienne and on 15 December, in the reservoir 100m upstream of Lorcé dam. Trout 2 was also captured on 26 November 2007 and on 30 November, it was already found in the Lienne 8km from Lorcé dam. It pursued its migration in the Lienne, covering more than 5km in 1 day. Its signal was lost for a few days, then it was found in a tributary of the Lienne on 4 December, covering a total distance of 18km. Beginning in February, it began a slow downstream migration and on 21 February 2008, its transmitter was found on the river bank buried a few centimeters in the earth. The transmitter had probably been moved by a fish-eating bird and/or a small mammal, which implies that it had probably died shortly before.

Grayling 1 was radio-tagged at the end of November 2007. Between this time and 12 March 2008, this fish moved up- and downstream within a sector situated between 0 and 800m upstream of Lorcé dam (Figure 2 C). On 5 March 2008, two other individuals were tagged and released upstream of the dam. Grayling 1 began migrating toward a spawning area situated between 1600 and 2200m upstream of Lorcé dam. It was joined by two other individuals (graylings 2 and 3) on 30 and 31 March 2008. Graylings 2 and 3 left the spawning area between 10 and 27 April 2008 encountering Lorcé dam, impassable at this period in the downstream direction (spillways closed, minimum flow turbined). They remained in the upstream zone of the dam until the end of the transmitter lifespan. Grayling 1 undertook its post-spawning downstream migration only at the beginning of July and stabilised at approximately upstream of Lorcé dam but finally crossed the dam during a high flood event in August 2008.

Four days after tagging, nase 1 undertook a very rapid spawning migration, which, on 21 April 2008, took it to the foot of Coo falls (15-m-high impassable obstacle, Fig. 1) 17km upstream of Lorcé dam (Figure 2 D). It was localised at the foot of the waterfalls until 24 April 2008 and then very rapidly returned to be localised 2600m upstream of Lorcé dam on 27 April. It then began moving upstream to 14km upstream of Lorcé dam, remaining in this sector until 11 May 2008. It then undertook a post-spawning migration downstream, encountering Lorcé dam, impassable in the downstream direction at this time of the year (spillways closed, minimum flow turbined). It stabilised until the beginning of October 1230m upstream of Lorcé dam. After a brief return slightly upstream of the dam at the beginning of October, it undertook an ascent and stabilised 2900m upstream of the dam until 2 January 2009. It was lost for slightly more than 2 weeks, then was found on 19 January 5km upstream of the dam. It slowly ascended the Amblève and its most upstream location in 2009 was 6.5km upstream of Lorcé dam from 9 to 19 February 2009 when the water temperature had not yet risen above 5°C. Downstream migration then occurred to a sector situated between 2800 and 3000m upstream of Lorcé dam.

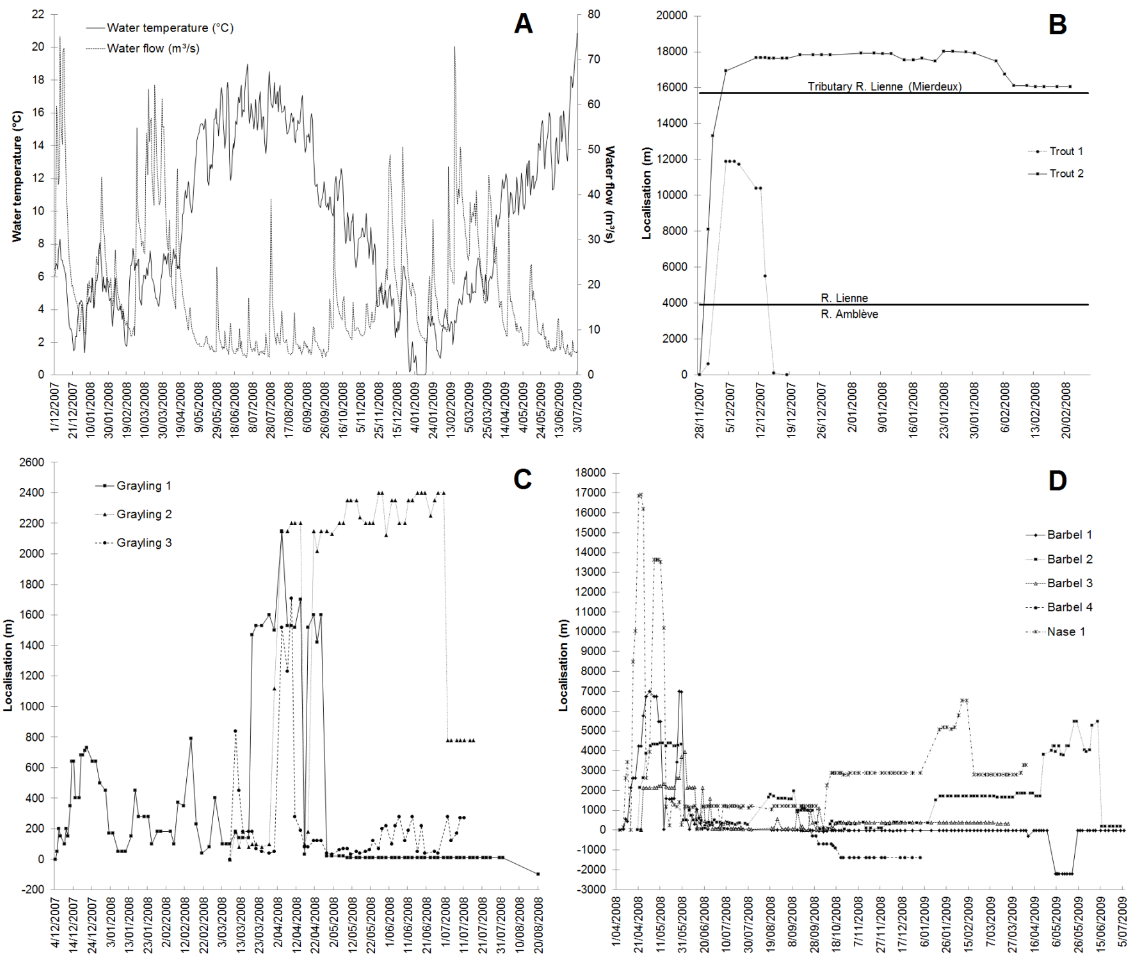

Figure 2. A. Variation of the water flow and temperature in the Amblève during the study. B. Movements of the brown trout. C. Movements of the grayling. D. Movements of the barbel. In B, C and D, point 0 corresponds to Lorcé dam and fish pass presented in Fig. 1.

Barbel 1 was captured on 4 April 2008 and barbels 2, 3 and 4 on 21 April 2008 (Figure 2 D). While barbel 4 was lost for a few days soon after its tagging, the three other barbels rapidly undertook a spawning migration upstream and occupied potential spawning sites situated 2100, 4200 and 7100m upstream of Lorcé dam. Barbel 1 (male) was the most mobile of the three: during the spawning period, it carried out an additional 7100m trip between Lorcé dam and the spawning area. At the beginning of June, at the end of the spawning period, the three barbels undertook their post-spawning downstream migration, and, like the other species followed, encountered Lorcé dam, which was impassable in the downstream direction. During this period, we found barbel 4's signal in the area occupied by the three other barbels, a few hundred metres upstream of Lorcé dam. During the entire summer period, the four individuals remained upstream (from 0 to +2000m) of Lorcé dam. At the end of summer 2008, the four barbels adopted variable behaviours. Barbel 3 remained in an area upstream of the dam until its signal was lost at the beginning of April 2009. Barbels 1 and 4 were localised on 15 and 24 September 2008 downstream of Lorcé dam. Barbel 1 was consistently localised at the foot of Lorcé dam between September 2008 and the end of April 2009. At the beginning of May 2009, it migrated downstream to within 2200m downstream of Lorcé dam. At this time it was on a potential spawning site. On 19 June 2009, it returned to the foot of Lorcé dam and localised there on that day. Barbel 4 descended the Amblève progressively to a site situated 1400m downstream of Lorcé dam and we lost its signal at the beginning of January 2009. Barbel 2 remained slightly upstream of Lorcé dam until the beginning of January 2009. On 19 January 2009, it ascended the Amblève and stabilised until the end of April 2009 in a sector situated between 1600m and 1800m upstream of the dam. At the end of April 2009, it began its reproduction migration, which brought it towards the spawning site already used in 2008, between 4km and 5.2km upstream of Lorcé dam. On 19 June 2009, it was found 200m upstream of Lorcé dam, impassable in the downstream direction, and it stabilised there until the end of the tracking period.

4 DISCUSSION

In the four species studied, the radio-tracked individuals expressed actual migratory behaviours after their release upstream of the new Lorcé dam fish pass. The trout exploited a tributary of the Amblève, the Lienne, and even a sub-tributary. The graylings migrated over shorter distances than the trout and most particularly exploited an area of the Amblève situated between 1.5 and 2.5km upstream of the dam. The barbels and nase moved within zones between 2 and 17km upstream of Lorcé dam. One barbel tracked for two reproduction seasons even expressed an interannual fidelity to the spawning site in the newly exploited reach, as we had already observed on another river in the Belgian Ardennes (Ovidio et al., [7]). These highly encouraging results demonstrate that the parts of the river recently made accessible by the construction of a new migratory fish pass can indeed be exploited by fish originating from the downstream of Lorcé dam and that the ascending bahaviours observed are not atypical compared to tagging experiments conducted in similar but less fragmented environments (Baras, [8]; Baras, [9]; Ovidio, [10]; Parkinson et al. [11]; Ovidio et al. [12]; Ovidio and Philippart [13]; Britton and Pegg [14]). The farthest displacements took place during the migration period of the four species reported in the literature, which very certainly is observed in the search for spawning areas. It remains to be seen whether the migrations toward spawning grounds materialise into successful reproduction and good survival levels in the new habitat. Recent tracking experiments (Ovidio et al., unpublished data) indicate that this is indeed the case for nase, which established itself in a new 17km reach, where it was totally absent before the fish pass was constructed.

Although the reproductive migrations in the upstream direction seem to take place normally, the same is not true for post-spawning downstream migration or post-spawning homing behaviours. It should be remembered that this behaviour most often corresponds to a return of the male toward the site occupied before return migration or toward a nearby site, a few days or weeks after spawning. This behaviour is quite typical of the species studied (Ovidio and Philippart, [5]), but the homing phenomenon is often less precise in the nase, which has a tendency to swim farther downstream than its departure point (Ovidio and Philippart, [13]). Radio-tracking upstream from Lorcé dam has clearly demonstrated that all the species tracked undertook post-spawning downstream migration, but this was interrupted by the dam, which, when the spillways are closed and all the water is turbined, makes downstream migration impossible. In this case, for fish in the post-spawning phase, the only alternative to a forced and lethal passage through the turbines is interruption of migration and the use of substitute habitats. This is the behaviour demonstrated in this study. For the holobiotic species such as those studied herein, this delay could cause stress in the individuals concerned since they are forced to exploit a habitat that does not match their optimum. It is difficult to estimate the long-term impact of this on the fish, but one cannot exclude that this type of event may disturb their exploitation of space and affect them for the following spawning season. In anadromous (Atlantic salmon) and catadromous (European eel) species, which are also present in this sector of the Amblève, this situation in which downstream migration is blocked is demographically much more catastrophic since it is imperative that they migrate downstream towards the sea at a very precise period of the year and therefore they have very low tolerance for delays (Martin et al., [15]). Preliminary tracking using radio-tracking on Atlantic salmon smolts migrating downstream (Ovidio et al. [7]) on this same site demonstrated blockages that were probably highly disadvantageous because when actively searching for a passageway, the smolts exhaust a large quantity of their energy resources, which will no longer be available for the continuation of migration and could generate an increased mortality rate. In addition, problems arise of individuals that are sucked into the hydroelectric turbines with all the consequences in terms of injury and direct mortality.

In view of our results, it seems that the new migratory fish pass on the Amblève, after more than 80 years of total blockage, perfectly meets its objective of defragmenting the habitat since it has returned acces to fish of a river reach with a very good ecological potential. However, the biological monitoring reported herein demonstrated that reopening the axis is only partial because substantial problems passing the dam in the downstream direction persist for holobiotic species in post-spawning migration, but even more so for diadromous species in their necessary migration towards the sea. The biological cycle of the species targeted therefore has not been totally re-established. In this context, developing a downstream migration device (an outlet) at Lorcé dam has become a high priority. It is currently being installed and its efficiency will be tested in the coming years.

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