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# Movement behaviours of potamodromous fish within a large anthropised river after the reestablishment of the longitudinal connectivity

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ABSTRACT

Human activity has caused longitudinal fragmentation of many rivers. Fishways have been installed worldwide, but their successive use by potamodromous species remains poorly documented, particularly in large river ecosystems. Four vertical slot fishways were installed within a 32-km stretch of the lower Belgian Meuse River basin. From 2012 to 2016, n = 532 individuals belonging to 11 potamodromous fish species (rheophilic, limnophilic and large carnivorous) were continuously captured in the most downstream fishway ($M_0$), tagged with an RFID transponder and released upstream. These could be further detected in upstream river part within three fishways ($M_1$ and $M_2$ in the Meuse, and $O_1$ in an important tributary, the Ourthe) that were equipped with RFID detection stations. In the first downstream stretch (13 km from $M_0$ to $M_1$) we quantified an ascending rate until $M_1$ (number of individuals detected in $M_1$/ number of individuals tagged in $M_0$) of 32.9% including all individuals tagged, with a maximum value of 67.2% for chub (*Squalius cephalus*), 40% for pike (*Esox Lucius*) and 35.5% for nase (*Chondrostoma nasus*), and a progression time $M_0$ to $M_1$ of 1.1 days per kilometre (d/km), with trout (*Salmo trutta*) as the fastest species (0.3 d/km). Upstream of the $M_1$ fishway, many individuals of rheophilic species (trout and barbel, *Barbus barbus*) preferred to enter in the Ourthe tributary (detection at the Ourthe fishway) unlike the upstream Meuse (detection at the most upstream fishway in the Meuse), demonstrating a new accessibility to more adapted spawning sites. Most fish were present within fishways mainly in spring during the *circum*-spawning migration, and during summer and autumn for dispersal and/or seeking-refuge. The diel activity cycle varied depending on the species, with detection during the entire diel cycle (e.g. chub and barbel), during the day (e.g. trout) and during the night (e.g. catfish, *Silurus glanis*). The installation of fishways in the degraded river Meuse can be considered adequate for the restoration of the free movement because potamodromous species demonstrated their ability to migrate over long distances (> 20 km) and to reach potential spawning habitats through the reopened access to a tributary.

## 1. Introduction

Potamodromous freshwater fish need to disperse or migrate throughout the year to gain access to reproduction, feeding and refuge habitats and complete their life-cycle (Benitez et al., 2015; Lucas and Baras, 2001). Spawning activity is one of the most common motivators for long-distance migration, but other movements may occur outside the spawning period for ontogenetic and trophic reasons (Benitez et al., 2015; Benitez and Ovidio, 2018; Lucas and Baras, 2001). As diadromous species, some holobiotic potamodromous fish can migrate long distances ranging from several to more than 100 km, depending on habitat diversity and longitudinal fragmentation (De Vocht and Baras, 2005; Lucas and Baras, 2001; Waidbacher and Haidvogl, 1998; Winter and Fredrich, 2003). Nevertheless, many rivers around the world are affected by human activities and the fragmentation caused by obstacles, such as dams and weirs, has a significant impact, as well as habitat fragmentation, habitat homogenisation, straightening and artificialisation of river banks that drastically reduce habitat availability (Dynesius and Nilsson, 1994; Fuller et al., 2015; Fullerton et al., 2010; Nilsson et al., 2005; van Leeuwen et al., 2016).

To re-establish the longitudinal connectivity in the upstream direction, the use of different fishway models represents a measure for countering the inaccessibility of functional habitats and to increase the ecological connectivity of rivers (Clay, 1995; Roscoe and Hinch, 2010; Silva et al., 2018). The monitoring of fishways by capture trap (Benitez et al., 2015; Kotusz et al., 2006) and video system (Santos et al., 2004) may help to better define the diversity of fish species that use these devices, their behavioural ecology and the dynamics of their upstream

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movements (Benitez et al., 2015). The combination with the use of individual tagging and further detection by telemetry devices (e.g. Radio Frequency IDentification, RFID) makes it possible to measure individual behaviour of fishes (Lennox et al., 2017; Lucas and Baras, 2000). RFID has most often been used in previous studies of fishway efficiency joining adapted behavioural metrics (Noonan et al., 2012; Ovidio et al., 2017) and to quantify fine-scale use as diel activity rhythm of fishway utilisation (Dodd et al., 2017; Nzau Matondo and Ovidio, 2018; Ovidio et al., 2017) at only one fishway level. Moreover Radinger and Wolter (2014) demonstrated that almost 80% of studies on fish mobility were conducted within small rivers ($< 1.5\ m^3/s$) with a duration of study generally less than 200 days.

Connection between rivers and their tributaries or floodplains is essential for the natural functioning of continental freshwater ecosystems but entrance of fish to tributaries after installation of fishways remains poorly quantified (Nunn et al., 2010). In large river ecosystems, such a device may help fish to reach more natural areas located in tributaries, particularly for species with high levels of ecological needs. In industrialised regions, tributaries incorporate functional habitats for refuge and spawning or nursery habitats for the most ecologically exigent species. In the context of river rehabilitation, the main dams of the Meuse have been progressively equipped with multi-specific fishways over the last 20 years. Despite the crucial importance for species distribution, the effect of restoration of longitudinal corridors on riverine fish remains poorly understood, especially in terms of recolonisation of newly available habitats or access to direct tributaries (Cheng et al., 2015; Tummers et al., 2016).

Studies on the successive uses of fishways are scarce, mainly monospecific and have essentially focused on amphidromous species (Calles and Greenberg, 2005; Castro-Santos et al., 2017; Gowans et al., 2003; Lucas et al., 2009) and rarely on potamodromous species (De Leeuw and Winter, 2008). The lowland Belgian Meuse section is fragmented by numerous dams for navigation and/or production of hydroelectricity and it is also canalised with concrete banks, significantly reducing the availability of spawning habitats for rheophilic and limnophilic species with specific requirements. The aim of this study was to analyse the dynamics of upstream movement behaviour of holobiotic potamodromous fish species at different time scales using RFID detection. We focussed our analyses on: (i) the ability of the species to use a continuum of fishways; (ii) the reconnection between an anthropised river and its tributary; (iii) quantification of the adjusted passage efficiency (Ovidio et al., 2017) of one studied fishway; (iv) the progression time of fish within different stretches between fishways and (v) the seasonal and diel movement periodicities.

## 2. Material and methods

### 2.1. Study area

The study was conducted on a 32-km transect within two rivers (Fig. 1): the downstream part of the Belgian Meuse River, a lowland river (average annual discharge = $400\ m^3/s$; catchment area = $36{,}000\ km^2$), situated in the bream fish zone (Huet, 1949) and in the downstream part of the Ourthe River (average annual discharge = $67.4\ m^3/s$; a Meuse tributary) situated in the barbel fish zone (Huet, 1949). These river stretches are canalised and fragmented by obstacles for navigation (including sluices, Fig. 1b), water regulation and hydroelectricity production. The habitat is deep (an average depth of 5 m), homogeneous (muddy bottom with some blocks) and not adapted for spawning of rheophilic species. The river transect studied includes four fishways ($M_0$, $M_1$, $M_2$ and $O_1$; Table 1), which are vertical slot types (Fig. 1c–f). Conversely to the upstream part of $M_2$, the upstream part of the Ourthe ($O_1$) has habitats which are suitable for reproduction of rheophilic species, such as riffle and shallow zones (Ovidio et al., 1998, 2007). According to physicochemical requirements, the water quality is good in both rivers, the Meuse and the Ourthe (i.e. Public Service of Wallonia – AQUABIO). The total number of fish species in the Belgian Meuse is 36 (75% of cyprinids). They belong to different ecological categories: large rheophilic species (2.4% of total individual observed within the Meuse), large limnophilic species (26.3%), large ubiquitous species (18.9%), small rheophilic species (0.1%), small limnophilic species (28.7%), anguillidae (23.4%), large carnivorous species (0.1%) and other species (0.1%).

### 2.2. Fish capture and fish tagging

The study period was 2012–2016 (a five-year period), during which the most downstream fishway ($M_0$, Lixhe fishway in Meuse) was equipped with a capture cage in the upstream pool with a capture limit of fish ± 200 mm. Over the study period, the trap was monitored 2–5 times a week depending on the capture intensity and a total of 3,659 individuals belonging to 20 fish species were captured, anaesthetised in a solution of 4-allyl-2-methoxyphenol (Eugenol $0.1\ ml\ L^{-1}$), identified, measured ( ± 1 mm, fork length) and weighed ( ± 1 g). A total of 532 adult individuals representing 11 large species were individually tagged (Table 2) using biocompatible RFID tags (Texas Instruments, HDX, 134.2 kHz; 32 × 3 mm and 0.9 g in weight). These tags were inserted in a 5-mm-long incision in the intraperitoneal cavity of the fish using a scalpel (Ovidio et al., 2017). According to the occurrence of fish in the cage, tagging of fish took place during the 5-year period of study mainly (73.1%) during the spawning period of fish (Table 2). Tagged fish were released upstream of the capture trap after a recuperation period of a few minutes. Tagged individuals belonged to large fish species of patrimonial and fishery interest, and included cyprinidae (eight species, 85% of the tagged headcount), salmonidae (one species, 7%) and two other families (1 esocidae and 1 siluridae, 8%).

### 2.3. Systems for fish detection and behavioural metrics

To identify the presence of tagged fish within upstream fishways of $M_0$, RFID detection stations (CIPAM®-France) were installed at three fishways (Fig. 1). The first RFID station was located in the fishway of Monsin in the Meuse ($M_1$: 13.1 km upstream of $M_0$), the second was placed in the fishway of Ivoz-Ramet in the Meuse ($M_2$: 32.2 km upstream of $M_0$ and 19.1 km upstream of $M_1$) and the third station in the fishway of Angleur in the Ourthe ($O_1$: 19.3 km upstream of $M_0$ and 6.2 km upstream of $M_1$). The three RFID stations were connected to antennae (size = ± 0.8 × 1.8 m; detection area = 1.5 m diameter) that were placed in the slot of the most upstream pool of each fishway, enabling us to determine upstream presence of fish within the 32-km transect analysed during the study period (2012–2016). Fish passing by the antennae were recorded by the RFID stations, with associated information on the individual code, calendar date and specific time. These data allowed us to determine several behavioural metrics:

- the *ascending rate until $M_1$, $M_2$* and *$O_1$* (total and by species) was defined as a percentage of the number of individuals detected respectively at $M_1$, $M_2$ or $O_1$ stations vs. the total number of individuals tagged at $M_0$.
- the *progression times $M_0$-$M_1$, $M_0$-$M_2$* and *$M_0$-$O_1$* were calculated as the time (in days) per kilometre (d/km) between the release time in $M_0$ and the first detection time in $M_1$, $M_2$ and $O_1$, respectively, per species.
- the *rate of migration route* was defined as the percentage of individuals detected at $M_2$ for the Meuse route and at $O_1$ for the Ourthe route (Fig. 1) vs. the total number of individuals tagged at $M_0$ and detected upstream of $M_1$ fishways (= ind. detected at $M_2$ or $O_1$/ ind. detected at $M_2$ + ind. detected at $O_1$, per species).
- the *diel activity* was defined per species as the number of detection within $M_1$, $M_2$ and $O_1$ fishways per individual and per hour on a daily scale.
- the *seasonal* activity per species was defined as the number of capture at $M_0$ and the number of detection within $M_1$, $M_2$ and $O_1$