USING INTENSIVE MULTIYEAR FISH-PASS MONITORING TO ANALYSE SEASONAL UPSTREAM MOVEMENT PATTERNS OF PATRIMONIAL HOLOBIOTIC POTAMODROMOUS FISH SPECIES IN MEDIUM SIZE RIVERS.

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Belgian rivers are fragmented by numerous obstacles which considerably limit the free access of fish to functional habitats. Fish-passes are major tools used to increase stream continuity and improve connectivity in the upstream direction. Using two modern multispecies fish-passes, this study aims to investigate multiyear abundance of holobiotic potamodromous fish and their seasonal movement patterns in relation with environmental factors. The fish passes were monitored continuously during 5 and 7 years and are located in two Belgian streams: the Amblève ($19.3m^3.s^{-1}$) and the Berwinne ($1.9m^3.s^{-1}$). Results revealed the presence of 20 different fish species, 14 species in the Berwinne and 19 species in the Amblève. For both rivers, in term of occurrence, salmonids and cyprinids species were predominant. A great interspecific and intraspecific variability in capture periodicity and in terms of stimulation by combination of factor environmental was observed. This study highlights the complexity and the omnipresence of holobiotic potamodromous fish movements at different life stages, in medium size river and brings new information on fish passes efficiency and use by these poorly known species.

EXTENDED ABSTRACT

Most fish species develop movement and migration behaviour that allow them to complete their vital functions in various habitats such as feeding, resting and breeding within specific space components. In comparison with amphidromous fish species, patrimonial holobiotic fish species are less studied in terms of time and space utilization. In non-disturbed environments, migratory movements of holobiotic species are usually directed upstream and compensate larval drift of fishes in the downstream direction (Reichard, 2002). But there are a wide variety of movement behaviours in variable directions that are observed in both adults and juveniles and that may occur outside the spawning season but whose knowledge is still limited in many patrimonial species (Ovidio and Philippart, 2002). Many rivers of the northern hemisphere are deteriorated by anthropogenic activities with major impacts on longitudinal fragmentation preventing or limiting access to functional habitats formerly available (Nilsson *et al*., 2005). The goal of fish pass development is to counter inaccessibility of spawning habitat and to increase ecological connectivity of rivers (Bunt *et al.*, 2012). Efficiency studies on fish pass are often limited in time and essentially performed during the reproductive period of limited target species. In two rivers of Southern Belgium, two multispecies modern fish passes (Fig.1) were continuously monitored during several years and yielded very original data for a wide range of fish species. Using intensive scientific monitoring our study aim to analyse i) the efficiency of the fish pass in terms of fish biodiversity and biomass ii) interannual variations of fish capture over consecutive years from the opening of the fish pass to the end of the monitoring iii) the periodicity of upstream movements in both adults and juveniles fish species at the seasonal level and to identify associated environmental conditions.

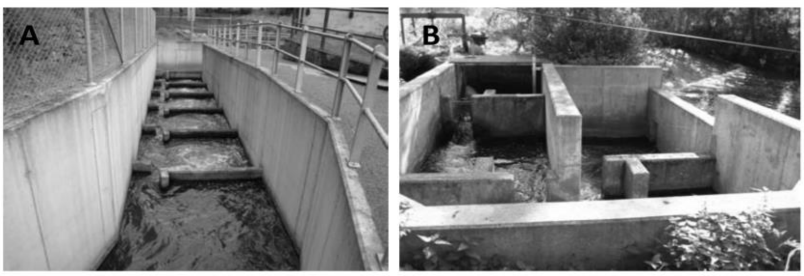

Figure 1: View of the two vertical slot fish passes studied: Lorcé on the Amblève (A); Berneau on the Berwinne (B)

Table 1: Characteristics of the Berneau fish pass (Berwinne River) and the Lorcé fish pass (Amblève River)

Characteristics	**Berneau**	**Lorcé**
River	Berwinne	Amblève
Elevation source (m)	270	586
Length (km)	53	93
Drainage area (km^2)	131	1083
Average slope (p/1000)	7.5	5.2
Width (m)	5-10	30-50
River module (m^3.s^{-1})	1.9	19.3
Dh of dam (m)	1.4	3.3
Type of fish pass	Pool-type vertical slot	Pool-type vertical slot
Total length of fish pass (m)	16	67
Pools number	4	15
Dh between pools (m)	0.3	0.25
Discharge fish pass vs. river module	5.3%	2.6%
Dam function	Pond supply	Hydroelectricity

The two fish passes (Figure 1) are situated in the river Meuse basin in the grayling/barbel zone (Huet, 1949). The Berneau fish pass built in 2002 is located in the River Berwinne (mean annual flow = 1.9m^3.s^{-1}, mean daily temperature ranges: 0°C to 22.3°C). The Lorcé fish pass built in 2007 is located in the River Amblève (mean annual flow = 19.3m^3.s^{-1}; mean daily temperature ranges: 0°C to 24.6°C). The trap captures of fish pass of Berneau and Lorcé were continuously monitored respectively from October 2002 to December 2008 and from October 2007 to December 2011. The captured fishes were anaesthetized, identified at species level, measured (mm, fork length), weighed (g) and released upstream of the dam. Water temperature (Ulg-data loggers installed at the input of fish passes) and water flow (data from the DGRNE-Water division, stations in downstream) were continuously recorded during the monitoring period. For analysis in the two fish passes, adult and juvenile distinctions of fish were carried out based on their size (Philippart and Vranken, 1983) and species with a minimum of ten individuals were further studied. The analysis of capture periodicity was made for species combining each individual to its capture week using median (Q_{50}). Finally, we examined the influence of the combined effect of water temperature and water flow on the phenomena of movements. Each trapped fish has been associated with the maximal temperature and the average water flow of the previous day's capture. Temperatures were categorized by degree and the water flow (WF) was categorized into 5 categories (WF1 to WF5) based on percentiles 20, 40, 60 and 80. The individual number for each environmental factor combination including adult/juvenile distinction is illustrated in a levelplot. Non-parametrical statistical tests (Man-Withney) were used to analyze the data at the 0.05 level of significance using the R software.

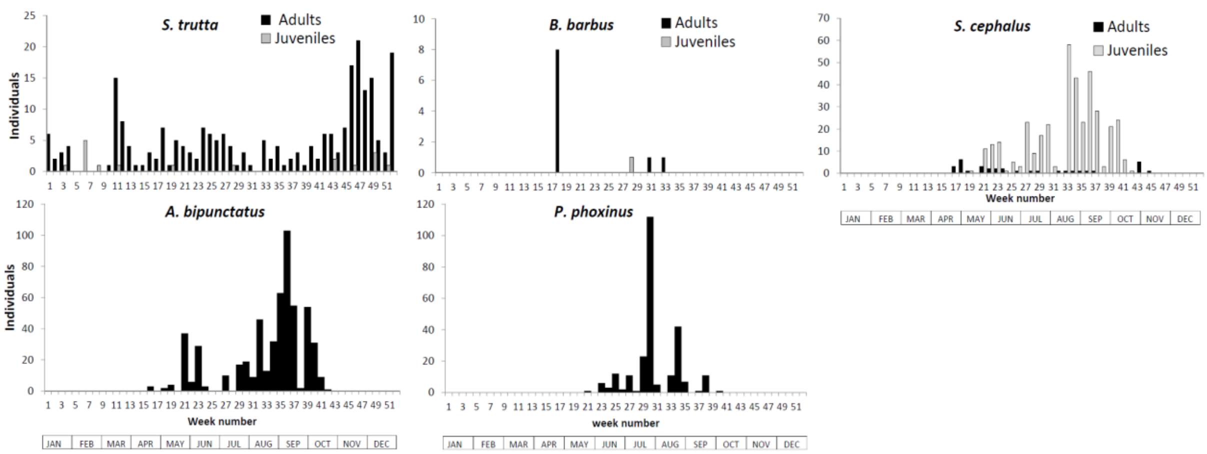

Figure 2: Pluriannual periodicity of capture at Berneau fish pass. Some species are divided into two groups of individuals: adult individuals (black) and juvenile individuals (grey).

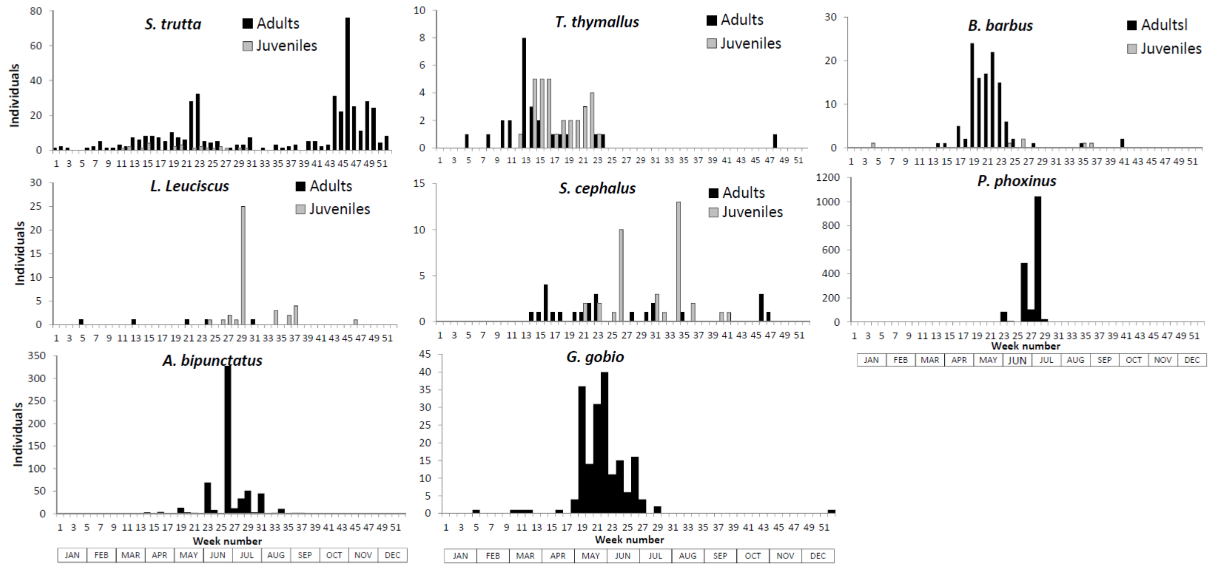

Figure 3: Pluriannual periodicity of capture at Lorcé fish pass. Some species are divided into two groups of individuals: adult individuals (black) and juvenile individuals (grey).

From October 2002 to December 2008, 1507 fish belonging to 14 species were captured in the fish pass of Berneau in the Berwinne River and 3207 individuals of 19 species were captured between October 2007 and December 2011 at Lorcé in the Amblève River (Table 1). The number of fish per year varies from 149 to 378 individuals (4 to 9 species/year) at Berneau and 265 to 1189 individuals (13 to 17 species/year) at Lorcé. Salmonids (*Salmo trutta* and *Thymallus* thymallus) and rheophilic cyprinids (*Barbus barbus, Chondrostoma nasus*, *Squalius cephalus* and *Leucisucs leuciscus)* represented the majority of biomass (>80%). In terms of numerical abundance, the small cyprinids are the most species captured and are represented by *Alburnoides bipunctatus* (n=548 and 600, 3 to 472/year), *Phoxinus phoxinus* (n=249 and 1562, 2 to 921/year) and *Gobio gobio* (n= 3 and 118). Other species were more occasionally captured like *Salmo salar*, *Oncorhynchus mykiss, Abramis brama, Blicca bjoerkna, Cyprinus carpio, Perca fluviatilis, Anguilla Anguilla, Gasterosteus aculateus, Barbatula barbatula and Cottus gobio*. Size comparisons of fish captured revealed the size ranging between 46mm and 760mm at Berneau versus between 48mm and 640mm at Lorcé. Eleven species were represented by a minimum of 10 individuals, of which five species (*S. trutta*, *B. barbus*, *S. cephalus*, *P. phoxinus* and *A. bipunctatus*) were present at Berneau and Lorcé. For salmonids, *S. trutta* is mainly present in adult stage (Lorcé, Q_{50}=259mm, IQR=75mm; Berneau, Q_{50}=305mm, IQR=70mm). For rheophilic cyprinids, *B. barbus* are mostly in adult stage: Berneau (Q_{50}=467mm, IQR=175mm) and Lorcé (Q_{50}=498mm, IQR=51mm). *S. cephalus* is generally captured in juvenile stage (Lorcé, Q_{50}=143mm, IQR=313mm; Berneau, Q_{50}=112mm, IQR=36mm). For small cyprinid species, *P. Phoxinus* (Berneau, Q50=56mm, IQR=11mm; Lorcé, Q50=59mm, IQR=8mm) and *A. bipunctatus* (Berneau, Q_{50}=82mm, IQR=18mm; Lorcé, Q_{50}=85mm, IQR=13mm) are captured in similar size range and these species showed no significant difference between range sizes of individuals captured (Mann-Whitney test, p=0.55). The pluriannual periodicity of capture fluctuated during the year for both fish passes (Figure 2 and 3). We observed that some species are captured at a specific period, the spawning migration (*T. thymallus*, *B. barbus*, *G. gobio*) or outside of the reproductive season (*P. phoxinus*, *A. bipunctatus* in summer). *S. trutta* is caught throughout the year in Berneau (Q_{50}=31th week, IQR=29 weeks) and Lorcé (Q_{50}=26th week, IQR=24weeks) fish passes with no-significant difference in periodicity between both (Mann-Whitney U-test, p=0.77). Adult individuals show two peaks of capture, a first peak in the spring and a second peak in the autumn during the spawning period (44th to 49th week for both fish passes). We found that the capture periodicity of juvenile is generally shifted in time compared to adult periodicity with a capture peak in spring for salmonids and in summer for cyprinids. Analysis of influence of environmental factors showed that salmonids movements were generally stimulated when the temperature is ≤10°C and the water flow is high (from WF4 to WF5) with differences for juveniles (T° between 10°C and 16°C and flow between WF2 to WF4). By contrast, rheophilic cyprinids (*B. Barbus*, *S. cephalus* and *L. leuciscus*) and *G. gobio* were enhanced when temperature is between 16°C and 19°C and flow is low (from WF1 to WF3) with also differences for juveniles (T° between 18°C and 23°C and flow between WF1 to WF2). Finally, small cyprinids (*P. phoxinus* and *A. bipunctatus*) moved when the temperature is between 18°C to 25°C and the water flow is lowest (WF1).

The majority of studies relating the control fish pass mainly focused on the period of fish spawning migration or on a specific period of the year. The contribution of this study is to bring a pluriannual and multi-specific approach. The abundance of holobiotic species in the fish-passes demonstrated their apparent ecological needs to move in the river system such as amphidromous species to reach spawning, refuge or feeding habitats, even if the distance they move is rationally not as long in their environment. For both fish passes, the first complete year of control is the best year in terms of biomass and we observed a substantial interannual variation with a tendency to decrease in the fish biomass per year. It is very likely that positive results of the first control years are an immediate opening effect after many years of fish blocking. The interannual variability in captures demonstrates the importance of long-term monitoring in order to assess the real effectiveness of fish pass and increase understanding of fish dynamic populations. The periodicity of captures shows that fish passes are used throughout the year including three major capture peaks (spring, summer and autumn) and fishes are caught in very varied ranges of temperature and water flow (1°C to 26°C and very low water flow to very high water flow) depending on fish species and class sizes. In conclusion, this study has demonstrated that fish-passes are finally used extensively by a wide variety of local species belonging to highly diverse ecological categories. These results reinforce the objective of some European countries that provide passage for all fish communities (Jungwirth *et al*., 2000; Slavik *et al*., 2009). In this context, accommodating all movements of a wide range of species and sizes of fish is becoming increasingly important in fishway design.

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