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Effect of hydropeaking on migrations and home range of adult Barbel (*Barbus barbus*) in the river Meuse

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Abstract

The non-navigable part of the River Meuse, forming the border between Belgium and the Netherlands, is 60 to 100 metres wide and has an average slope of 0.45 mkm^{-1}. The river has been modified by gravel extraction, bank stabilization, summer dykes and flow modifications. To document fish use of this system, fourteen adult and female (Fork Length: 47.5–57 cm) barbel (*Barbus barbus*) were radio tagged (40 MHz): 5 in May 2001, 3 in October 2001 and 6 in April 2002. From May 2001 till September 2002 fishes were localized weekly throughout the year and daily in April and May to identify spawning grounds and investigate seasonal migrations and home range. In winter, when flows ranged from 250 to 2 800 m^2s^{-1}, barbel were found in the main river bed at all times. No downstream migrations to sheltered parts of the river were observed. In spring, both upstream (0.2 km) and downstream (up to 2.6 km) migrations to spawning grounds were observed. Individual barbel, in the mouth of a tributary, showed different migrations towards spawning areas and holding locations under low flow conditions. Migrations in summer and autumn were directed by changes in flow and habitat suitability. The home ranges of the barbel ranged from 1.05 to 27.3 km and differed significantly in size for different parts of the river. Resident habitat suitability is determined by discharge, water depth, water current and bottom structure. Total home ranges of barbel, occupying a highly structured part in the river with continuous availability of suitable habitat for spawning, resting and foraging were significantly smaller (1490 m) than those for barbel initially caught in areas with less habitat diversity (12.5 km).

Introduction

Spatial and temporal change in habitat use by aquatic species in response to changes in discharge and water level is typical in river systems. While these animals have adapted to the timing, amplitude and predictability of seasonal flows, man-made changes to water courses have resulted in strong variations in water quality, hydrology and marked habitat fragmentation. These modifications have largely affected populations of aquatic invertebrate species (Céréghino and Lavandier, 1998, Growns and Growns, 2001, Céréghino *et al*., 2002, Cortes *et al*., 2002). In particular, these changes have modified the drift of invertebrates (Lauters *et al*., 1996, de Crespin de Billy *et al*., 2002), reduced the availability of key habitats for fish or their access to these habitats (Raat, 1996, Baras and Lucas, 2002, Brown and Ford, 2002, Pretty *et al*., 2003, Vehanen *et al*., 2003).

During the nineteenth and twentieth centuries the River Meuse was dredged in Belgium, banks were rectified and originally 23 weirs and dams were erected for navigation and flow control (Mischa and Borlee, 1989). Presently 6 dams remain of which only a fraction are equipped with operational fish passes (Baras *et al*., 1994, Prignon *et al*., 1998). Additionally, several dams are equipped with small hydropower plants that operate in a discontinuous discharge mode. These plants cause the water level and velocity to vary beyond the range of natural fluctuations. For example, water level fluctuations that typically took place between seasons can now occur on a single day or within a few hours. These marked changes have resulted in the extinction of local populations of diadromous species

(Philippart *et al*., 1988; 1994) and declines in abundance potamodromous species, such as the common barbel (*Barbus barbus* L).

Previous studies have highlighted the behaviour of barbel in rivers with restricted anthropogenic interference, i.e. no man-made obstacle to upstream or downstream movement, no or little change in the natural flow regime and no major loss of habitat (for the River Meuse basin, see Philippart 1977, Baras, 1992; 1994; 1995; Philippart and Baras, 1996). Information on how barbel react to man-made obstacles can be found in Baras *et a*l. (1994) and Lucas and Frear (1997). In contrast, little or no information is at hand on how barbel react to man-made variations in the flow regime, even though such information might be crucial for management of their populations in rivers that undergo flow management and hydropeaking. Flow modification can strongly affect the eggs (Baras and Philippart, 1999), the larvae or juveniles (Baras and Nindaba, 1999) or the adults themselves, although a greater plasticity and resilience of the more agile adults.

Here, we provide a first account of the behaviour of barbel in the Border Meuse, which still provides natural habitats but is strongly modified by hydropeaking. The study focused on the home range, migration, habitat use of adult female barbel, as revealed by radio tracking. Female barbel attain sexual maturity at an older age and larger size than males (Philippart, 1977) and they are the true limiting factor of the population. Additionally, the final selection of the spawning site is done by females (Hancock *et al*., 1976, Baras, 1994).

Material and methods

Study area

The so-called "Border Meuse" is a 40-km stretch where the river forms the border between Belgium (left bank) and the Netherlands (right bank), in between the dams of Borgharen (upstream) and Linne (downstream), which are both sited in the Netherlands (Fig. 1). The dam of Borgharen is impassable to fish during periods of low flow. In between these two dams, there is no man-made obstruction to flow or fish movement, thereby making the Border Meuse one of the sole free-flowing stretches of the lowland River Meuse.

The banks of the river were stabilized for flow control over almost the entire length of the Border Meuse. The riverbed was locally dredged and lowered 1 to 3 m but some parts are nearly unaffected. This part of river was not dredged substantially as other parts of the Meuse, because this stretch of the river is bypassed by two lateral canals for navigation. The alternation of pools and riffles is thus largely maintained in the Border Meuse. The width ranges from 60 to 100 m (within summer dykes) and the mean slope is 0.40‰. Depth in pools can be in excess of 3 m during summertime. The substratum is of cobbles rather than gravel, due to high erosive forces in the riverbed. Low base flows are less than 10 m^3s^{-1} during summer and relatively high peak flows can attain 2800 m^3s^{-1} during rainy winters (Heylen, 1997).

The flow regime in the Border Meuse is strongly dependent on the operation of upstream hydropower dams, in particular that of Lixhe, in between the cities of Liège and Maastricht, about 30 km upstream of the centre of the study area (near Maasmechelen, Fig. 1). At the dam of Lixhe, the maximum drop at the weir is 7.5 m and the turbines operate in a discontinuous mode. This results in an alternation of water retention and hydropeaking, especially during periods of low flow. This alternation causes daily changes in discharge and water level (85 m^3s^{-1} or 0.8-1.1 m in April-May 2001 and 2002), but no substantial variation in oxygen content between different habitats in the Border Meuse (Witteveen and Bos, 2000). Changes in discharge are frequently more than 170 m^3s^{-1} or 2.2 m in height within one our.

Tagging and tracking

Female barbel (47.5-57.0 cm Fork Length, 1,580-2,813 g in weight, *n*=14) were captured with electric fishing (DEKA 7000, DC 250-350 V, 4-8 A) during May 2001 (*n*=5), October 2001 (*n*=3) and April 2002 (*n*=6). The adult female barbel were caught in deep (>80 cm) and fast flowing (>1.5 ms^{-1}) riffles, externally identified as female prior to implantation and checked by internal gonad con-

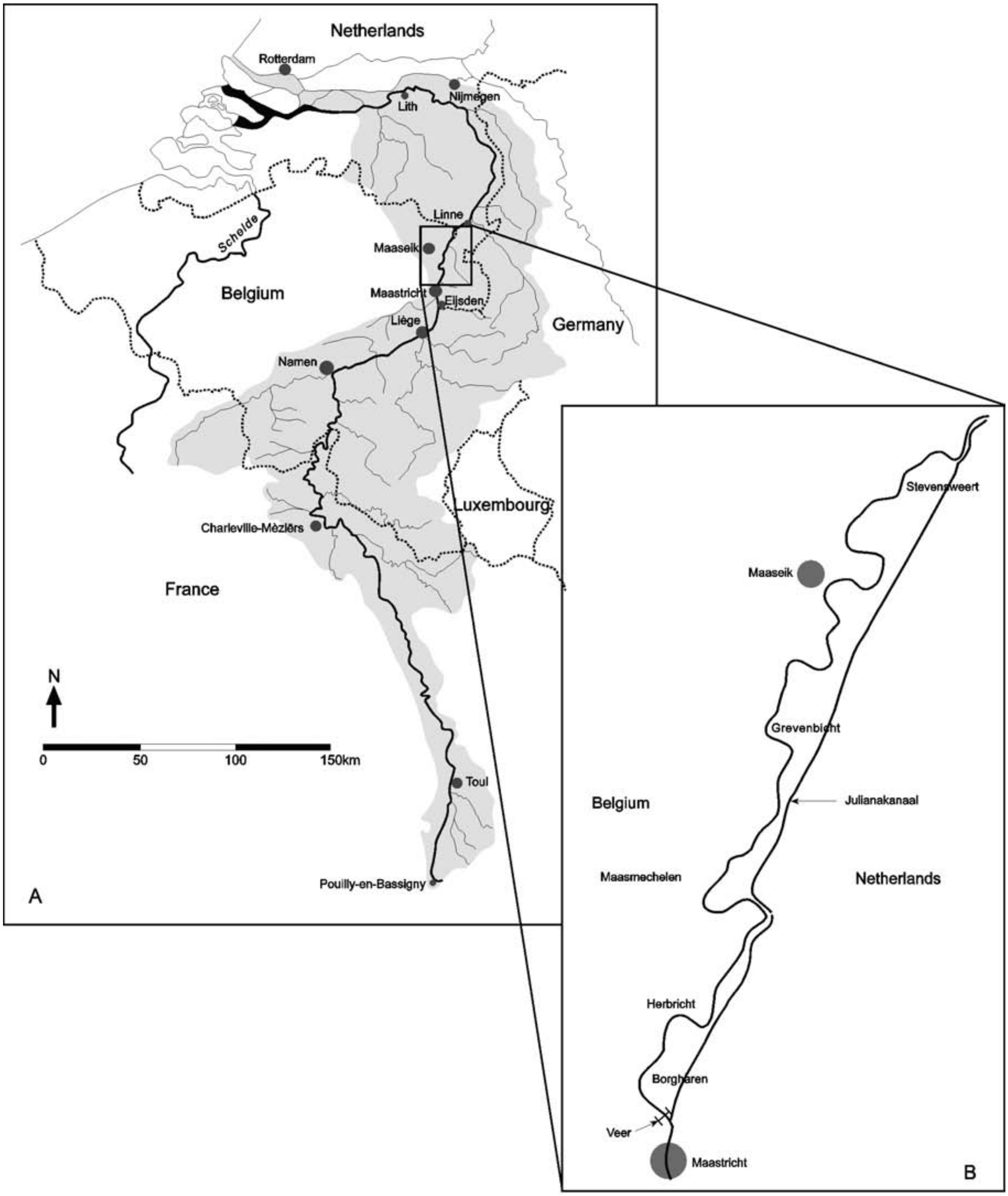


Fig. 1 – Location of the study area on the river Meuse. The Border Meuse is situated between Borgharen (downstream Maastricht) and Maaseik.

trol during implantation of the transmitter. Barbel were exclusively captured in Herbricht (*n*=6) and Maasmechelen (*n*=8) respectively 22 and 33 km downstream of Eijsden (Fig. 1). Maasmechelen is characterised by a steep slope (up to 1.7‰) and the presence of two permanent islands and large gravel bars. In Herbicht, the slope does not exceed 0.45‰, and no permanent island is present, only a few lateral gravel bars. However, this station is at the confluence with the tributary Geul, which is the sole tributary of the Border Meuse that is large enough for adult barbel.

Within the hour following capture, barbel were anaesthetised with 2-phenoxy-ethanol (0.4 mll^{-1}) and surgically tagged with radio transmitters, through an incision opened in between the pelvic girdle and the papilla. The incision was closed with separate stitches made of Vicryl, which absorbs within 6 months (for detailed information on surgery, see Baras, 1992). Radio transmitters (ATS Inc., 40 MHz) were equipped with coil antennae, to minimize the risks of drag, entanglement or pathological outbreak after the barbel had healed (for a synthesis, see Jepsen *et al*., 2002). Radio frequencies were spaced 10 kHz apart, to minimize risks of interference between transmitters, and to permit straightforward manual scanning with a simple receiver (Fieldmaster 16 channels, ATS Inc.). Each transmitter was equipped with an activity tilt, which shifted the tag's pulse rate from 40 to 80 pulses per minute, thereby allowing identification of active and inactive fish. Fish were released in calm places approximately 20 m downstream the capture site.

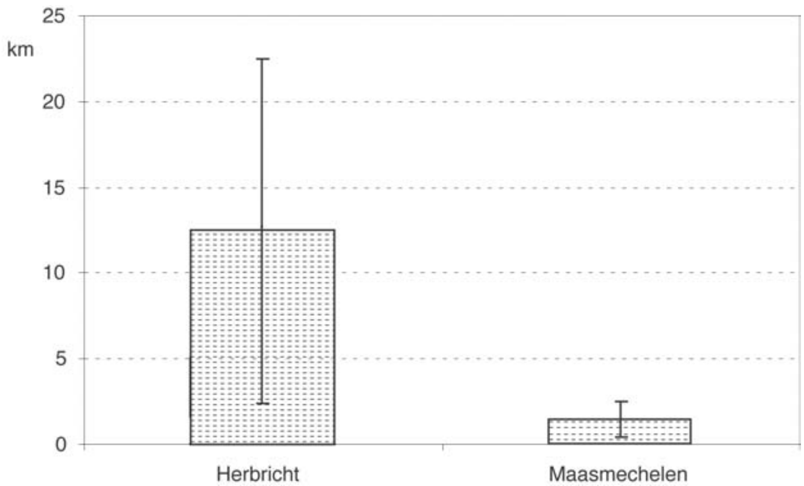
From May 2001 to September 2002, fish were tracked at weekly intervals, as this interval was shown to allow accurate estimation of home range in barbel (Baras, 1998). However, during the spawning period (April-May) fish were tracked every day, since females might spend no more than one or two consecutive days on the spawning grounds (Baras, 1994; 1995). Searches were made on foot or by car from the elevated riverbanks for 18 months. Upon detection of a signal, its position was determined by triangulation with a loop antenna, which gives a sharp null peak. Information of 11 fishes tracked for at least 12 months has been processed (Herbricht *n*=4, Maasmechelen *n*=7).

Home range was defined as the distance between the upstream-most and downstream-most locations. Home range and distances moved by barbel were measured by reference to landmarks, the position of which was determined by GPS (nearest 6 m). Data on the hourly discharge at Lanaken (between Borgharen and Herbricht, Fig. 1) were provided by the Flemish administration (AWZ). Data on water temperature were derived from RIZA at Eijsden. Because year round habitat use of the barbel often showed a distinct, binary nature, logit regression was used to detect and quantify major changes in habitat utilisation of individual fishes in relation to discharge (Statistica, StatSoft).

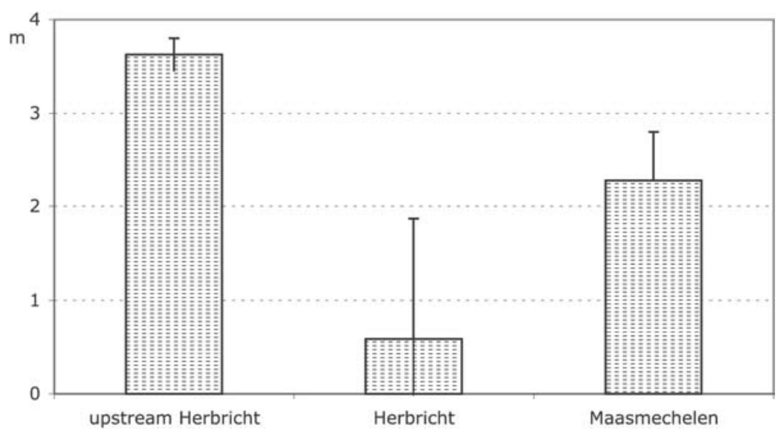
Results

The behaviour of barbel varied substantially depending on capture location. The fish from Herbricht showed long-range seasonal migrations, whereas those from Maasmechelen remained all year round in the vicinity of their capture site. Migrations during high peaks were not observed. Low peaks sometime force individual barbel to move to deeper resident habitats. The average annual home range was 1.5 km in Maasmechelen (1.05-4.0 km), and 12.5 km in Herbricht (5.9-27.3) (Fig. 2a). Therefore, we describe the annual movements of these fishes in separate paragraphs.

Two of the six barbel tagged in Herbricht, near the mouth of the Geul, could only be tracked four less than three days. The other four barbel moved in between this tributary and the River Meuse. Typically, habitats in the tributary were colonized during spring and early summer, until the water level dropped substantially in July-August. Two barbel that showed strong residency in the Geul then left the tributary, entered the Meuse and moved downstream several kilometres (5.9 and 27.3 km). A third barbel moved in and out the tributary during spring. It moved as far as 6.7 km upstream. The fourth barbel moved 10 km downstream to the station Maasmechelen. Hence, barbel



a)



b)

Fig. 2 – a) Average home range of barbel in the station Maasmechelen (n=7) and Herbricht (n=4). Error bars indicate standard deviations. b) Average maximum depth in cross sections in the river Meuse upstream Herbricht, from Herbricht to Maasmechelen and at Maasmechelen. Error bars indicate standard deviations.

that originated from the same area spread over about 35 km during summer or nearly the total length of the free-flowing part of the Border Meuse. The length of the migrations is strongly related to the presence of deeper riffles or pools in the river. Upstream Herbricht and in Maasmechelen deeper holding places are present. From Herbricht up to Maasmechelen maximum depth at low discharge (10 m^3s^{-1}) is in average only 0.6 m (Fig. 2b).

In contrast, the fish captured near Maasmechelen (*n*=7) showed restricted movements at all times of the year. During autumn and winter, under low temperatures and high flows, barbel (*n*=4) showed almost no movement. They consistently remained in deep runs with large boulders unless flows exceeded 800 m^3s^{-1}, when they moved to riparian shelters. The shelters were flooded willow trees or big boulders on flooded riverbanks. In spring, barbel (*n*=11) moved over distances ranging from 50 to 2600 m and gathered in the pools and runs along one of the permanent islands when water temperature in the morning reached 13.5°C. Five to seven days after migration towards the spawning site, all barbel moved back to previously used habitats up- or downstream the spawning site. During late spring and summer, when flows decreased, the barbel in Maasmechelen also made restricted movements. For some (*n*=6), there was an obvious relationship between discharge and movement. For example, one of the barbel consistently moved between locations when flow reached 250 m^3s^{-1}, which accounted for its movements in between successive locations (Fig. 3). Another example is of two barbel that were tagged in April 2002 in a newly formed connection between a lateral gravel pit and the main stream. When minimum flow dropped below 150 m^3s^{-1} both barbel moved to residence places 1.6-2.6 km downstream or 4 km upstream respectively. When the minimum discharge exceeded 150 m^3s^{-1} again, both fishes migrated back to the gravel bank and entered the gravel pit. Three days later, when the minimum water level dropped again below 150 m^3s^{-1} both barbel returned to the places they occupied during the former low-flow episode. In contrast, other fish behaviour did not exhibit such clear-cut relationships (Fig. 4).

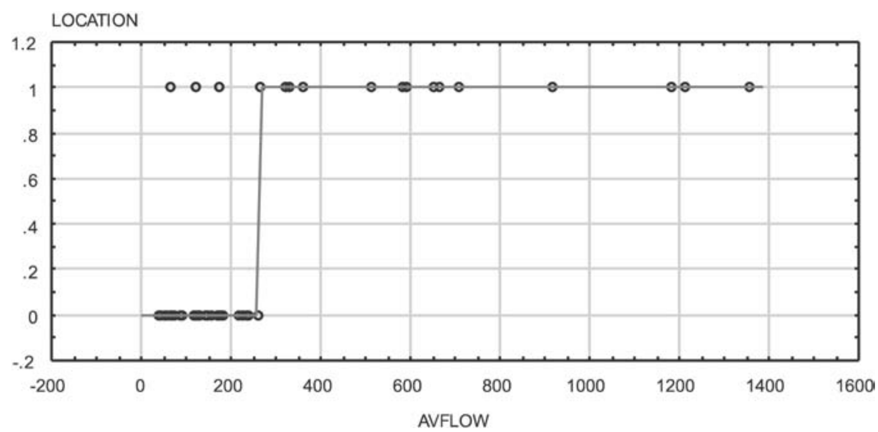


Fig. 3 – Two dimensional function plot with logit regression where average discharge (avflow in m^3s^{-1}) explains 75% (Barbel 2, N=60) of the variance in the occupation of the macrohabitats (locations coded 0 and 1).

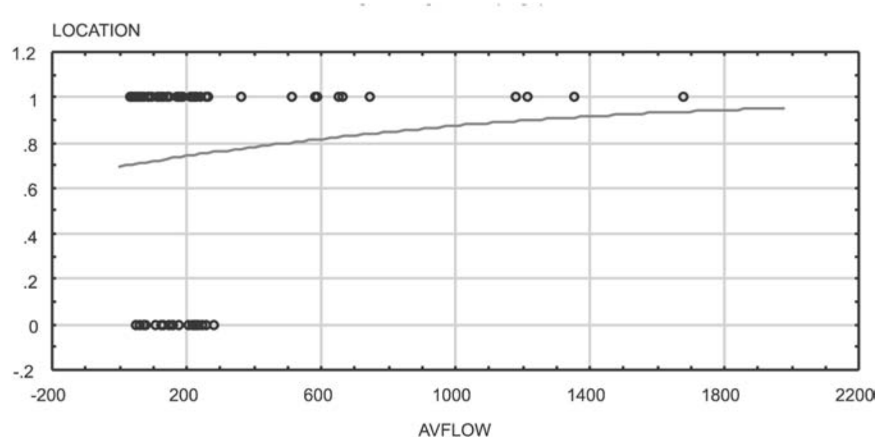


Fig. 4 – Two dimensional function plot with logit regression where average discharge (avflow in m^3s^{-1}) explains only 2% (Barbel 5, N=83) of the variance in the occupation of the macrohabitats (locations coded 0 and 1).

Discussion

The striking feature of this study is that the mean annual home range in Maasmechelen (1.5 km) was almost identical to the values that were determined for barbel in the undisturbed River Ourthe, either by conventional tagging or radio tracking (1.17 km in both cases) (Philippart, 1977; Baras, 1992; Philippart and Baras, 1996). Baras (1992) suggested that restricted home ranges in the River Ourthe were due to the availability of suitable habitats for resting during summer time and wintertime, thereby implying no need for long-range migrations in autumn or early spring. The same applies to station Maasmechelen, where both deep calm places and shallow fast-flowing places are available all year-round. This year-round availability of suitable places was only compromised under low summer discharge when water temperature exceeded 25°C and under very high winter flows, when some residence places became unsuitable and barbel moved towards the calmer places near the banks. Similar lateral and longitudinal movements were observed in the barbel tracked in the River Ourthe following spates during winter or spring (Baras, 1992). When flow decreases in summer, the individual differences in habitat selection suggest that the occurrence and the length of these movements is largely dependent on the habitat occupied under higher flows rather than on the value of discharge itself.

Other authors described movements over shorter or longer distances for *Barbus* spp.. In particular, the Mediterranean barbel *B. haasi* and *B. sclateri* are fairly resident in small Spanish rivers, with an average home range approximating 100 m (Aparicio and de Sostoa, 1999; Prenda and Granado-Lorencio, 1994). In contrast, Lucas and Frear (1997) reported seasonal movements of up to 20 km for *B. barbus* in the River Nidd (England). The compilation of a series of experiments in the River Ourthe (1988-1999) indicates that female barbel can also move short (a few hundred metres) or long distances (up to 20 km) (Baras, 1992; Philippart and Baras, 1996). Additionally, females that were tracked up to three years in a row showed consistent fidelity to the same spawning grounds and summer holding areas (Baras et al., unpubl. data), regardless of whether these were close or far from their residence areas. This may result because some habitats become unsuitable either because of high water velocities under high flow conditions in winter or reduced depth in summer. Hydropeaking, generating significant fluctuations in flow, results in major changes in physical conditions of the fish habitat. River stretches with high variation in stream morphology are less affected by the hydropeaking. The availability of refugia, during high and low flow conditions is particularly crucial for stream fish (Valentin *et al.*, 1996).

Barbel tends to select habitats that were as close as possible to their preferences (Baras, 1992; 1995), whatever the distance between these habitats. In the Border Meuse, both the Maasmechelen and Herbricht stations offer a wide variety of habitats which might accommodate the habitat preferences of barbel, either for residence areas or foraging areas at all times of the year. At least, this is the case under normal flows. Under very low flows, as those produced during the episodes of water retention in Lixhe, places with depth greater than 0.8 m (i.e. the preferred depth for the residence areas of adult barbel) can be found in sufficient number during summer in Maasmechelen, but are more rarely present in Herbricht. Additionally, the riffles in Herbricht are much shallower than those in Maasmechelen and their depth does not exceed a few centimetres during the episodes of water retention. Furthermore, the mouth of the Geul stream is largely impounded and shallow during summer, thereby discouraging or preventing the movements of large fish under very low flows. Finally, water temperature in the Border Meuse frequently exceeds 23-25°C during summer and during water retention, an additional warming by at least 1°C can occur. Such warm temperatures are in excess of the preferred thermal range of large adult barbel (Baras, 1995). In the River Ourthe, barbel were found to exhibit behavioural thermoregulation at temperatures in excess of 22-23°C, either through time-budgeting or through the utilisation of areas of cooler water. No such possibility exists in the Border Meuse, so thermoregulation can only be achieved by long-range movements to deeper or faster flowing stretches.

The Border Meuse offers a wide range of gravel bars that might serve as spawning grounds for barbel under a particular range of flows. The variations in water level and velocity that result from the hydropeaking at Lixhe have direct and indirect consequences on the adequacy of these habitats. As shown here, drops in water level are likely to cause barbel to stop spawning or to abandon the spawning grounds. The marked variations in water level are also likely to dry up places where eggs were laid, thereby resulting in the death of the all offspring in these habitats. Finally, the variations in water velocity that result from hydropeaking schemes are likely to result in the siltation of gravel bars. The barbel is a lithophilous pit-spawner: eggs are laid in 5-10 cm deep pits dug by the female in the cobble-gravel layers, so siltation might complicate the digging by spawners or reduce the intra-gravel flow, thereby jeopardising the eggs.

Maasmechelen is the sole station in the entire Border Meuse that provides a sufficient diversity of habitats for barbel all year round, including during the episodes of water retention at Lixhe. This station offers permanent islands and gravel bars with contrasting depths, which offer suitable spawning grounds and nursery habitats for barbel under the entire range of water level fluctuation. Two consecutive surveys (2001 and 2002) where the abundance of young-of-the-year barbel was examined in the Border Meuse, concluded that the Maasmechelen station hosted the highest density of 0-age barbel (De Vocht *et al*., in prep). Hence, it is possible that this station is the sole sanctuary for this species in the Border Meuse. Other sites, such as Herbricht, offer some of the key habitats, but they cannot host self-a sustaining population of barbel.

To protect barbel it is thus imperative that habitat diversity in Maasmechelen is preserved and that future dredging schedules spare this area. The barbel is representative of the community of rheophilic fishes that use similar habitats. In particular, the spawning habitats are known to be shared by chub *Leuciscus cephalus*, river bleak *Alburnoides bipunctatus* and grayling *Thymallus thymallus*. In the long term, more attention should be dedicated to suppressing the hydropeaking, either by changing the type of turbine in Lixhe or by decommissioning this dam.

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