Movement patterns and spawning activity of individual nase *Chondrostoma nasus* (L.) in flow-regulated and weir-fragmented rivers

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Summary

Eighteen adult nase *Chondrostoma nasus* (L.) (37.6–48.2 cm FL) from three highly fragmented Belgian rivers were tagged with surgically implanted radio transmitters and manually tracked from the banks of the rivers for 3–34 weeks. Their movements were mainly recorded during the *circum* reproduction period in 2001, 2002 and 2006 in river stretches delimited by physical barriers and / or minimum flow conditions. To reach the spawning grounds, nase displayed different patterns of movements that were mainly influenced by the configuration of the study site, the date of observation and the associated environmental conditions. Nase never cleared any physical obstacle but were able to spawn in minimum flow conditions or just downstream from physical obstacles. Nase were present on spawning grounds in late March in the warmest spring (2001) and from mid-April to early May in the coldest spring (2006). After spawning, a major proportion of *C. nasus* migrated a substantial distance downstream, whereas others remained near their capture site and showed frequent movements, sometimes corresponding to group displacements from one river to another.

Introduction

In European rivers, cyprinids play a major role in riverine ecosystems because of their high abundance (Philippart, 1981; Mann and Penczak, 1986). Their variety of life-history patterns and habitat requirements make cyprinids good indicators of the ecological quality and the structural properties of river systems (Keckeis et al., 1996). The increasing structural changes in many river systems were accompanied by a drastic decline in lithophilic cyprinids (Keckeis et al., 1996; Peňáz, 1996; Nelva, 1997; Lusk et al., 2004). The nase (*Chondrostoma nasus*) is an indicator species for habitat quality in the lower rhithral and upper potamal zones of European river systems and was one of the most affected species (Nelva, 1997). Decline in their populations was mainly caused by construction of dams for a hydroelectric power plant together with the straightening and artificialization of the river banks (Zbinden and Maier, 1996). Moreover, in the major part of its distribution area, nase was also affected by changes in hydrobiological regimes, changes in riverbed morphology at spawning times, persisting water pollution and reduction in food resources (Peňáz, 1996).

Despite the critical state of nase populations in many European rivers, little information exists on its life history and behavioural ecology. Information on individual behaviour, mobility and spawning migrations are extremely limited (Huber and Kirchhofer, 1998). In order to improve protection of the species and to better understand nase sensitivity to the degradation of its environment, knowledge on its space and time utilization in a wide range of disturbed and less disturbed river typologies is urgently required.

The objectives of this paper were to (i) analyse the mobility patterns of individual nase during the reproduction period, (ii) identify the environmental cues that triggered their migration and spawning activity, (iii) localize spawning areas in different river configurations and (iv) evaluate the impact of the river fragmentation and minimum flow conditions on *C. nasus* reproductive biology and use of space. The study was conducted using radio-telemetry in three different rivers of southern Belgium.

Materials and methods

Nase (*C. nasus*) were studied in three different rivers of the Meuse basin (Fig. 1, Table 1): the Ourthe (tributary of the Meuse), the Vesdre (tributary of the Ourthe) and the Amblève (tributary of the Ourthe). Eighteen adults were captured by boat DC electric fishing (DEKA, 2.5kVA). In the Ourthe, n = 5 nase were captured in late February and early March 2001 in a river stretch physically limited by obstacles D and E (Fig. 1). In the Vesdre, n = 7 nase were captured in early February and March 2002 (Table 2) downstream from physical obstacle A (Fig. 1) in a river stretch situated in the confluence area between the River Vesdre and the River Ourthe and physically limited by obstacles A, B and C. In the Amblève, n = 6 nase were captured in early March 2006 in a river stretch influenced by both minimum flow conditions (set at 3 m^3 s^{-1} for a mean annual discharge of 22 m^3 s^{-1}) and physical obstacles F and G (intake weir of a hydroelectric power plant) (Fig. 1). Obstacles A, B and E that may potentially block the upstream movements of nase are presented in Fig. 2 The obstacle G is an insurmountable obstacle.

Nase were anaesthetized in a solution of 2-phenoxy-ethanol (0.2 mg l^{-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 (Ovidio and Philippart, 2002). The sex of the nase was determined by visual inspection of the gonads through the incision that was closed by three separate stitches, using sterile, resorbable, plain Vicryl sutures. In order 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). Locations were

Fig. 1. Locations of the study sites in Belgium. Bars across the river represent physical obstacles. Obstacles cited in the paper are labelled from A to G

Table 1
Main characteristics of three rivers where nase (*Chondrostoma nasus*) were radio-tracked

Characteristics	Ourthe	Vesdre	Amblève
Elevation source (m)	507	626	586
Length (km)	175	72	135
Drainage area (km^2)	3672	702	1083
Average slope (m 1000 m^{-1})	2.54	7.8	5.20
Within lower course (m)	30–60	30–50	30–50
Average annual discharge (m^3 s^{-1})	67.4	11.4	21.7
Mean temperature in July (°C)	19.9	19.4	17.1
Dominant Huet (1949) fish zone	Barbel	Barbel	Grayling
Dominant fish species (kg)	Barbel	Gudgeon	Barbel
Level of global water quality	High	Medium	High
Level of fragmentation	Medium	High	Medium

made by triangulation from markers on the banks of the rivers, using mobile FieldMaster radio receivers and loop antennas (ATS Inc.). Locations were made 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 Computer Corp.) and water flow was continually monitored (data from the Water Division) in each river.

Results

Movements in the River Ourthe

Except for small scale excursions of *nase O2, O3* and *O5* in March 2001, all individuals showed restricted mobility near their capture area until mid-March (Fig. 3). On 19 and 22 March, *nase O1, O4* and *O5* started moving downstream during high flood conditions and when the mean daily water temperature increased, varying from 7 to 8.5°C. *Nase O1, O4* and *O5* were lost on 21 and 23 March 4.2, 4.3 and 9 km, respectively, downstream from their capture area. *Nase O3* also moved downstream on 19 March (1.4 km) but homed to its capture site on 20 March and then moved again 1.4 km downstream on 21 March 2001. From 22 to 29 March, during very high flood events and decreasing water temperature, *nase O3* frequently moved several hundred meters in up- and downstream directions. On 30 March 2001, during increasing water temperature (7°C) and high but decreasing flood conditions, *nase O3* gradually moved downstream and was finally lost on 8 April 2001, approx. 8 km downstream from its capture site. *Nase O2* showed highly restricted mobility (daily movements of max. 300 m) until 9 April 2001. On 12 April 2001, during a second high flood event, *nase O2* moved 2.2 km upstream, remaining there until the end of the 2001 tracking session (26 April 2001). In the Ourthe, the distances travelled between successive locations were statistically greater when the river flow exceeded 90 m^3 s^{-1} than during other flow conditions (Scheffe *f*-test, P < 0.001).

Movements in the River Vesdre

In late winter, during high flood and low water temperature conditions, nase frequently moved between two locations, but were never located more than 1 km downstream from obstacle A (Fig. 4). In late March during a substantial increase in water temperature and during decreasing flow conditions, the tagged nase were mainly located in the upper part of the study reach (near obstacle A) and spawning activity was observed in the vicinity of obstacle A from 25 to 30 March 2002, when the mean daily water temperature varied from 9 to 12°C.

During the post-spawning period, *nase V1, V2* and *V3* stayed in the downstream vicinity of obstacle A in the Vesdre until 3 June 2002, then moved together to the River Ourthe, downstream from obstacle B, remaining there until mid-October. *Nase V4* stayed near its capture site until 8 July 2002, then frequently moved from the River Vesdre to the River Ourthe (between physical obstacles A and B; Figs 1 and 2) until mid-October 2002. *Nase V5 and V7* moved downstream in late March and late April, approx. 3 and 1.5 km from their capture site. *Nase V7* probably died after spawning, as the transmitter was found in the river. *Nase V5* was lost during its downstream migration. *Nase V*6 was found in the River Meuse, roughly 6 km from its capture site, then regularly moved up and down between two resting places separated by roughly 2 km. Data analysis suggested that nase movements were not statistically triggered by specific environmental conditions. For *nase V1, V2, V3, V6* and *V7*, distances travelled after the spawning season were higher than those travelled before spawning (Scheffe *f*-test, P < 0.05).

Movements in the River Amblève

Nase A1, A3, A4 and *A5* showed restricted mobility from 3 March to 13 April 2006, as the distance between successive locations rarely exceeded 300 m despite high flood events in mid-March. From 16 to 24 April, during decreasing flow and increasing water temperature ranging from 8.5 to 12.5°C, they moved to a spawning area located in minimum flow conditions, approx. 1.3 km upstream from their capture site and

Fish number	River	Fork length	Weight	Sex	Capture date	End of tracking	Weeks tracked
O1	Ourthe	461	1600	F	22 Feb. 2001	21 Mar. 2001	4
O2	Ourthe	436	1376	F	6 Mar. 2001	26 Apr. 2001	11
O3	Ourthe	432	1225	M	6 Mar. 2001	8 Apr. 2001	5
O4	Ourthe	440	1410	M	6 Mar. 2001	23 Mar. 2001	3
O5	Ourthe	442	1543	F	6 Mar. 2001	23 Mar. 2001	3
V1	Vesdre	400	960	F	7 Feb. 2002	4 Oct. 2002	34
V2	Vesdre	386	948	F	7 Feb. 2002	12 Sept. 2002	31
V3	Vesdre	412	1104	F	7 Feb. 2002	21 Aug. 2002	28
V4	Vesdre	396	976	M	6 Mar. 2002	27 Oct. 2002	34
V5	Vesdre	376	768	M	6 Mar. 2002	29 Mar. 2002	3
V6	Vesdre	436	1290	M	6 Mar. 2002	11 June 2002	14
V7	Vesdre	426	1211	F	6 Mar. 2002	10 May 2002	9
A1	Amblève	465	1696	F	3 Mar. 2006	31 May 2006	13
A2	Amblève	482	1527	M	3 Mar. 2006	31 May 2006	13
A3	Amblève	490	2142	F	5 Mar. 2006	31 May 2006	13
A4	Amblève	430	1634	M	5 Mar. 2006	31 May 2006	13
A5	Amblève	448	1327	M	5 Mar. 2006	31 May 2006	13
A6	Amblève	474	1693	F	5 Mar. 2006	31 May 2006	13

Table 2
Characteristics of 18 radio-tracked nase (*Chondrostoma nasus*)

Fig. 2. Obstacles that may potentially interfere with the free upstream movements of nase (letters refer to a geographical position, figure 1)

stayed there from 6 to 15 days (Fig. 5). Afterwards, *nase A4* kept on an upstream migration to another spawning area located roughly 2.6 km upstream from its capture site (and was located in the same area as *nase A6*). After spawning activity, *nase A4* finally moved downstream from 30 April to 8 May 2006. *Nase A3*, *A4* and *A5* went back to the same site situated approx. 1.5 km from their capture site and stayed there until the end of the tracking period. *Nase A1* showed a similar behaviour 1.4 km downstream. *Nase A6* showed greater mobility from early March to early April, as it frequently moved more than 500 m from one location to another. On 12 April when the mean daily water temperature reached 7.5°C for the first time in the year, *nase A6* moved roughly 3.9 km upstream to a spawning area located in minimum flow conditions, remaining there until 5 May 2006, then moving 3.7 km downstream in 5 days; *nase A6* remained in this place until 22 May, then progressively moved approx. 8 km downstream from its capture site. *Nase A2* moved roughly 2 km downstream just after tagging and remained in the same area until 12 April when it reached a spawning site located roughly 4 km from its capture site; here, *Nase A2* stayed until 6 May 2006, but no spawning events were

observed in this area. It finally moved 4 km downstream in early May after the spawning season. Nase movements in the Amblève River were greatest in the 7–15°C water temperature intervals. A significant difference in the weekly mean distance travelled was observed when grouping the distances travelled between successive locations into three categories of water temperature (<7°C; 7–15°C; >15°C; Kruskal–Wallis, $P < 0.001$).

Discussion

This study provided original observations on nase (*C. nasus*) mobility and spawning activity in three different rivers characterized by a high level of human disturbance. Studied individuals were radio-tagged using surgical implantation. This method has several advantages over external attachment, including avoidance of vegetation entanglement, as well as less interference with swimming behaviour and speed (Winter, 1983; Mellas and Haynes, 1985; Jepsen et al., 2002). In our study area, the utilization of trailing whip antenna was necessary to increase the power of the signal. The susceptibility to complications with such transcutaneous devices in tagged
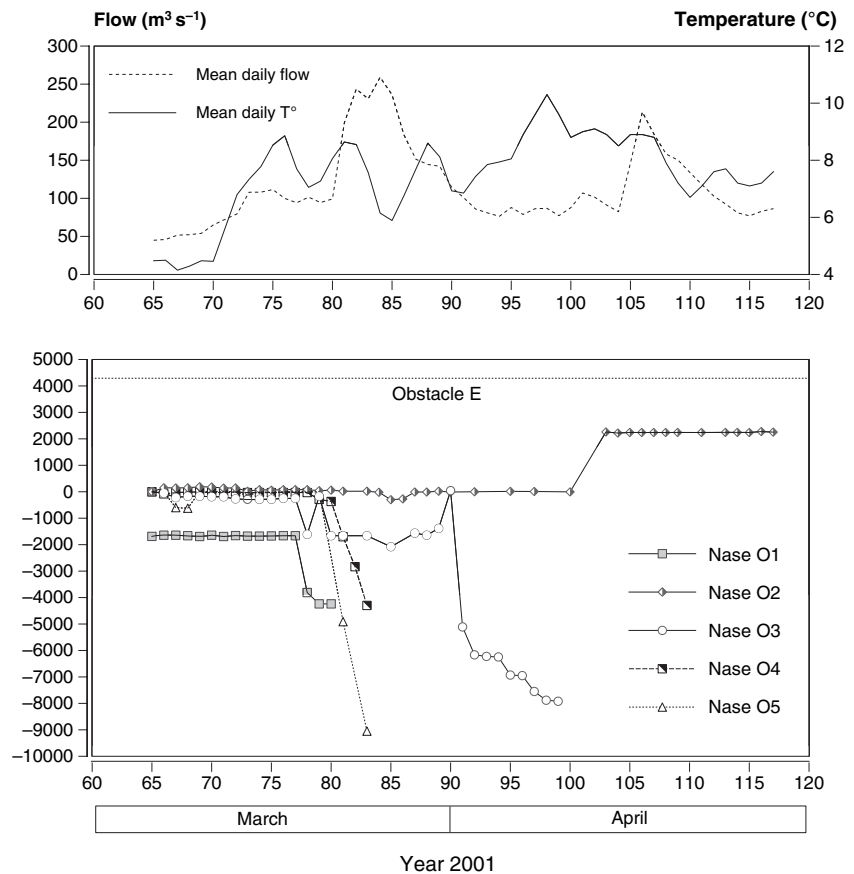
Fig. 3. Variations in water level and mean daily water temperature in the River Ourthe (upper graph) and positions of the radio-tagged nase (lower graph) during the study in 2001. The location point "zero" corresponds to the capture site of most individuals

fishes varies among different species and varying environmental conditions, but in some instances the potential pathway for pathogens created by the passage of the antenna through the body wall may lead to potential infections (*in* Bauer et al., 2005). In the present study, and as already observed with nase and five other fish species (Ovidio and Philippart, 2002), the good condition of different recaptured nase and the absence of infections suggested that such problems did not occur.

Pre-spawning movements

In one of our three study sites (the Amblève), nase were observed to move up to 4 km to reach spawning grounds. In this river, the migrations started between 12 and 24 April during decreasing flow and when the water temperature considerably increased, ranging from 7.5 to 12.5°C for the first time in the year. The synchronized departure of most tagged individuals suggests that these environmental cues are important factors in triggering the spawning movements. Reliance on a combination of stimuli is arguably a more efficient reproduction strategy than responding to a single cue, which could occur on several occasions outside the breeding seasons and could make the fish lose its fitness (Ovidio et al., 1998). Nase tagged in the direct downstream vicinity of physical obstacles in the River Vesdre moved only short distances to reach the downstream vicinity of the barrier, which corresponded to suitable habitat for spawning (shallow water with a gravel bed). Similar observations were made by Zbinden and Maier (1996) in the rivers Murg and Surhe (Switzerland), where nase spawned just downstream from large physical obstacles.

As already questioned for the roach *Rutilus rutilus* in the Belgian Meuse and Scheldt basins (Geeraerts et al., 2007), our observations suggest that nase are not frequent obstacle leapers and that they move relatively short distances to spawn in the rivers investigated. Nevertheless, it is still difficult to state whether this is because they are unable to clear barriers or because the abundance of appropriate spawning areas in the rivers studied (Philippart, 1981) did not force them to move further upstream. Frequent captures of nase in Denil traps and basin fish passes in the main course of the canalized River Meuse (J. C. Philippart and M. Ovidio, unpubl. data) and Rhine (Iffezheim fish pass, unpubl. data) demonstrated that they are at least able to pass such artificial devices when spawning grounds are not available in the vicinity. Furthermore, Lusk (1967), Lampert and Link (1971), Povz (1988), Huber and Kirchhofer (1998) and Mercier (2001) have also recorded extreme movements (from tens of kilometres to more than 100 km) in the Danube, Rhine, Sava and Meuse basins in intensive tag-recapture experiments, suggesting that nase may nevertheless move much greater upstream distances in some instances. Thus, even if the nase seems sometimes able to survive in a sporadic way and to spawn despite substantial river fragmentation (Prokes and Barus, 1995), efficient fish passes may help them to progressively recolonize longer river stretches and may prevent the genetic degeneration of local populations.

Spawning activity

The timing of the spawning period varied from 1 year to another. In the warmest spring (2002), spawning was observed
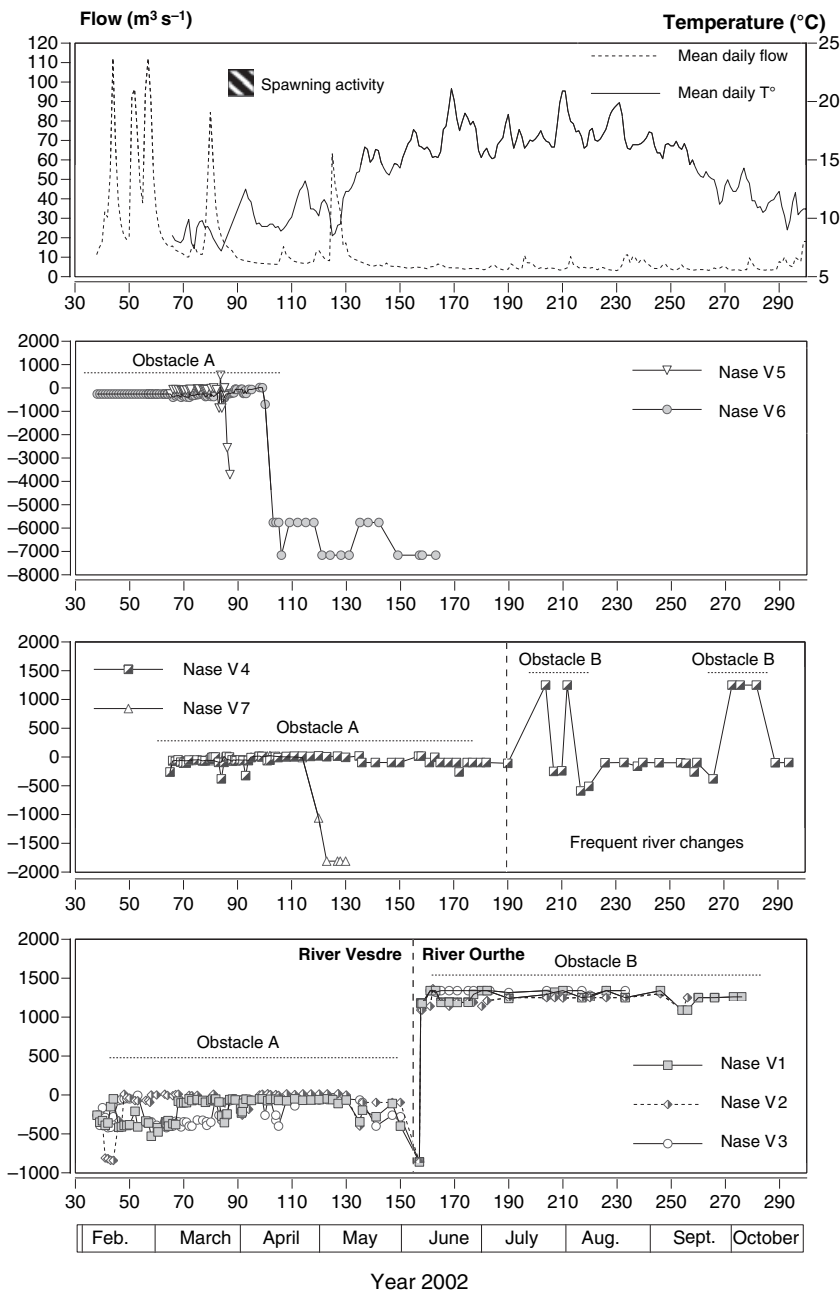
Fig. 4. Variations in water level and mean daily water temperature in the River Vesdre (upper graph) and positions of the radio-tagged nase (lower graph) during the study in 2002. The location point "zero" corresponds to the capture site of most individuals

from 25 to 30 March, whereas in the coldest spring (2006), spawning only occurred between 16 April and 3 May. Spawning occurred in shallow gravel bed habitats with strong current when the mean daily water temperature varied from 7.5 to 14°C. No apparent differences were observed between tagged males and females concerning the arrival date and the time spent on spawning grounds. In the Brumokva River (Czech Republic), Lelek and Peňáz (1963) observed that spawning started at a water temperature of 8°C, attaining its maximum around the peaks of daily temperature (15.4°C) between 13.00 and 15.00 in the afternoon. A greater number of males was found to spawn with only one female. Keckeis et al. (1996) observed spawning of nase in the main channel of the Danube. Compared with spawning migration into tributaries, they suggested that this may be a part of a new behaviour induced by canalizing rivers and cutting off side-arms. The highest abundance of spawners was correlated with uniform gravel banks which have relatively steep slopes (coarse substrata and high currents) (Keckeis et al., 1996). In Switzerland, all identified nase spawning grounds were also situated in shallow water with a gravel bed and high water velocity, but the main spawning events lasted only 2–3 days (Zbinden and Maier, 1996). In the past, spawning schools were often made up of several thousand individuals, sometimes more than 10 000. After 1993, a considerably smaller number of spawners was observed, often consisting of fewer than 50 individuals (Zbinden and Maier, 1996). In the Amblève, the tagged nase left their capture site in natural flow conditions to spawn just upstream in minimum flow conditions. The effects of minimum flow conditions on the spawning ecology of cyprinids are poorly known. However, at the same study site, M. Ovidio and J. C. Philippart (unpubl. data) demonstrated that, contrary to the nase, barbel (*Barbus barbus*) radio-tagged at the same place unusually migrated in the downstream direction to spawn, probably to avoid minimum flow conditions. This behavioural difference is probably related to the
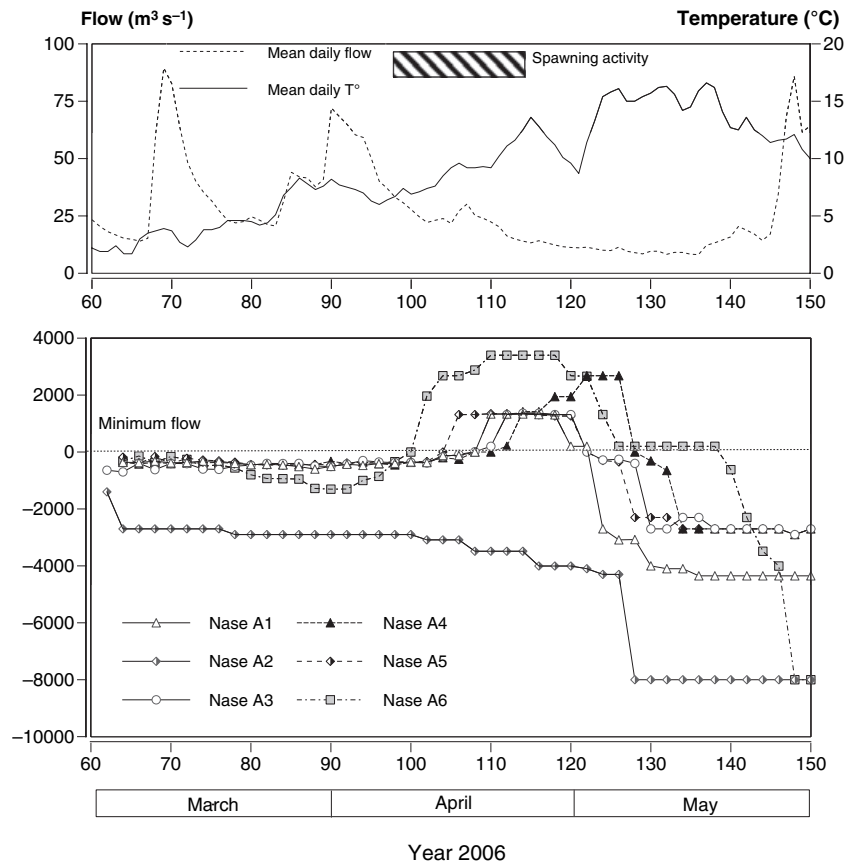
Fig. 5. Variations in water level and mean daily water temperature in the River Amblève (upper graph) and positions of the radio-tagged nase (lower graph) during the study in 2006. The location point "zero" corresponds to the limit between the natural and the minimum flow

fact that the barbel spawns under the gravel bed, whereas the nase spawns on the surface of the gravel bed; the latter is therefore influenced by deposits of fine materials that cause a decrease in the oxygenation of the lower layers of the substratum in the sector bypassed in minimum flow (Guillaume, 2006). Furthermore, by spawning in minimum flow conditions, the nase eggs have a lesser chance of being washed away by high flow conditions. These may reflect distinct adaptive changes in behavioural strategies between the two species after the surrounding milieu has been disturbed.

Post-spawning movements

In our study, post-spawning activity of tagged nase was characterized by a clear tendency to move several kilometres downstream, both in individuals that migrated upstream to reproduce and those that did not actually migrate before spawning and reproduced in the vicinity of a physical obstacle. Similar observations were made in the River Aare in Switzerland where nase dispersed over a greater area after spawning (Huber and Kirchhofer, 1998). Post-spawning downstream movements are frequent in freshwater fish (e.g. *Salmo trutta*, *Thymallus thymallus*, *Barbus barbus*; Ovidio and Philippart, 2002), but this generally corresponds to precise homing to the river area exploited before spawning. Here, this was not the case for the nase, as they generally moved far downstream, sometimes leaving the tributaries to move into the main course of the Meuse. This behaviour may be associated with a sort of space-use strategy on the part of the species, but it can also simply correspond to free-flowing movements of weakened individuals after exhausting spawning events. The nase obviously invest a great deal of energy in reproduction and suffer a higher mortality rate afterwards (Luskova et al., 1995).

The remaining nase tracked during late spring, summer and autumn in the confluence site between the rivers Vesdre and Ourthe showed a space-use strategy characterized by alternating short-range up- and downstream movements through a well-defined deep run habitat (depth, 0.6–1.2 m; mean water velocity, 25–70 cm^{-1}) and long-range movements corresponding to changing rivers (but the nase still used the same deep run habitat in the Vesdre and Ourthe). Intermediate depth use in this study can be seen as a trade-off between risk avoidance and food occurrence for a grazer fish. As was observed in the River Aare (Huber and Kirchhofer, 1998) and River Sieg (Fielenbach, 1996), the home-range size was larger in the warmer season than during the winter. Intensive tracking clearly demonstrated that nase move in shoals over long distances, as three individuals were observed migrating together from the River Vesdre to the River Ourthe. The nase shoaling mechanisms are currently unknown, except for reproductive behaviour (Prokes and Peňáz, 1978; Dedual, 1990 *in* Huber and Kirchhofer, 1998). Huber and Kirchhofer (1998) suggested that outside the spawning season, nase are non-territorial and aggregate at the most favourable habitats within the river. Nase adults form single-species shoals. However, juveniles and immature fish form multiple-species schools. During growth, fish may move progressively from shoals of one type of habitat to another. This illustrates that during its growth period, *C. nasus* uses space within an original shoal structure (Philippart, 1981) Complementarily, this study further demonstrated that, in some instances, nase move in groups of individuals from one river to another.

In conclusion, this study clearly demonstrates the important vulnerability of nase living in highly fragmented environments, as they show poor ability and/or motivation to clear the slightest physical barriers to reach potential spawning grounds

in the upper part of the rivers. Such poor ability to clear physical obstacles by different cyprinids species was also suggested by recent telemetry studies (Geeraerts et al., 2007; Horký et al., 2007; Ovidio et al., 2007a) and contrasted with the largely higher capacities of brown trout *Salmo trutta* and European grayling *Thymallus thymallus* to clear similar barriers (Ovidio et al., 2007b). Such results reveal the importance with the highest priority to consider the restoration of free movements of rheophilic cyprinids in fragmented environments.

Acknowledgements

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