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Radio-tracking: a useful tool for the Aulne Atlantic salmon rehabilitation program

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Abstract

A two-year radio-tracking study of Atlantic salmon was conducted on the Aulne, a small French coastal river. The behaviour of 129 salmon was studied from early July 1999 to mid-December 2000. The objective was to investigate patterns of upstream migration of salmon, in particular through the lower 70 kilometres of the river which is canalised. This enabled us to compare the passability of weirs and how this varied according to the type of fish-pass facility. The technique of the cumulative effect of the obstacles indicates that less than 5 percent of the population is likely to get through the canalised part and reach areas that are suitable for spawning. The most serious obstacles were presented by the weirs located the furthest downstream and two others in the middle of the river. The study also enabled both an estimation of the impact of fishing activities and a comparison of the upstream migration capacities of wild and reared salmon. Radio-tracking thus provides managers with a tool for assessing the restoration plan in order to improve its efficiency.

Introduction

The Aulne is a small coastal river in Brittany in north-west France. A seventy-kilometre stretch of the downstream watercourse has been canalised and includes 28 weirs. The river supports salmon; annual rod catch data indicate relatively constant catches from the early 1950s to the 1970s, followed by a sharp decrease, before levelling off at a low level until the mid-1980s. At this time, a plan was initiated to improve runs of salmon into the river.

To compensate for the decrease, various actions were undertaken. The first one involved restocking with juveniles from spawners captured in their natural environment, mainly in its estuary tributary, the Douffine. This restocking was done from the end of the 1980s, with parr and smolts being released directly into the Aulne, or into its estuary tributary, the Douffine. Another action involved making a census of juveniles production zones. This revealed that most of these zones (74% of the total surface area) were in the natural part of the Aulne, upstream of the canalised section (FDPPMA 29, 1996). The remaining production areas were distributed along various tributaries of the canalised section, mainly in the biggest of them, the Ster Goanez, on which we found more than 12% of the production zones. In addition, an effort was made from 1994 to improve the passability of weirs by building new fish passes. Today, 18 of the 28 weirs on the canalised section of the Aulne have been fitted with modern facilities.

These actions have led to an increase in the number of adults returning to the downstream part of the Aulne, an increase in the number of salmon caught by anglers (Fig. 1) and an increase in breeding potential even after fishing. Nevertheless, the increase of capture figures levelled off in the middle of the 1990s and then decreased again until 2002. Moreover, an initial biological assessment (count of effective spawning and juvenile abundance indices) indicates that there is very limited natural reproduction, especially upstream the canalised part of the river (FDPPMA 29, 2002). Thus, in spite of significant restoration efforts, the results are disappointing.

The main hypothesis for explaining the scarcity of natural juvenile production is a migratory blockage preventing adults from reaching the spawning grounds in the natural part of the Aulne, upstream of the canalised part. Therefore, it was decided to radio-track adults during their upstream migration in 1999 and 2000. The objective was to investigate upstream migration of returning salmon in the Aulne under current environmental conditions and to assess the impact of the numerous obstacles to migration.

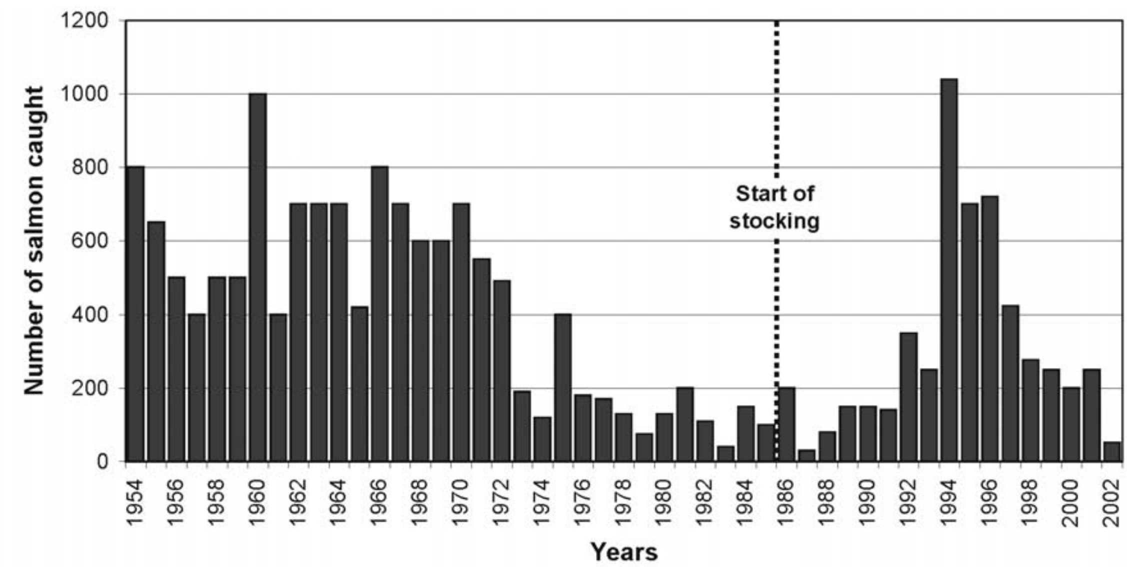

Fig. 1 – Rod catch of salmon on the River Aulne from 1954 to 2002 (source: CSP).

Materials and methods

Experimental site

The river Aulne is located in north-west France (Fig. 2). It is 145 km long in all and 70 km of its downstream part is canalised. Its catchment area covers 1,495 km^2. Salmonids predominate in the natural part of the river, and cyprinids in the canalised part.

About halfway along the canalised part of the Aulne (supplied by a catchment area of 1,224 km^2), there is a flow gauging station. The Aulne's mean annual discharge is 21.2 m^3s^{-1}. The river's regime is pluvial. The catchment area is affected by a particularly well-defined ocean climate, with heavy precipitation – about 200 days of rain per year, with mean annual rainfall ranging between 1,000 and 1,200 mm. The water level can rise dramatically (more than 400 m^3s^{-1}) or drop to drastic levels (less than 1 m^3s^{-1}). The lowest levels are recorded from July to September, with the heaviest flows in winter.

The physical/chemical quality of the Aulne's water is generally poor (Troadec and Le Goff, 1997). This appears to be due to the large quantities of run-off containing nitrates and phosphates from agricultural sources.

The 28 weirs in the 70-kilometre canalised part of the Aulne are designed to maintain water depths of one to two metres. They are nearly all chevron-shaped weirs – the point of the “V” being the furthest upstream – and include a lock for boats near the right bank and a discharge gate on the left bank to lower the amount of water upstream. The only rectilinear weirs, at right angles to the bank, are numbers 1, 2 and 6. The reaches between the weirs are between two and three kilometres long on average. The height of the weirs varies between 1.3 and 2.3 m, but usually lies around 2 m.

From 1994 to 1999, 18 weirs were fitted with new fish pass facilities (Fig. 2), generally chevron-type baffle fishways with a downstream pre-barrage. All the fish-passes at chevron-shaped weirs were positioned in the middle of the weir. The pre-barrage, at the foot of the canal, reduces the drop. Two other weirs (numbers 20 and 21), initially fitted with only a notch around 40 cm deep in the middle, have now been fitted with a baffle fishway near the right bank. Even though these facilities were installed before the start of the restoration plan, these two weirs are included in the category of weirs fitted with a new fish-pass.

Seven weirs still have older fish pass facilities, generally pool fishways with overflow weirs. On the Aulne, the pools are too small and cannot dissipate energy well, especially during fast flows. All the pool fishways are in the middle of the weir, with the exception of weir 3, where it is located near the right bank.

Weir 17 does not have a real fish-pass, only a gently sloping ramp without any baffles to dissipate energy and reduce water velocity.

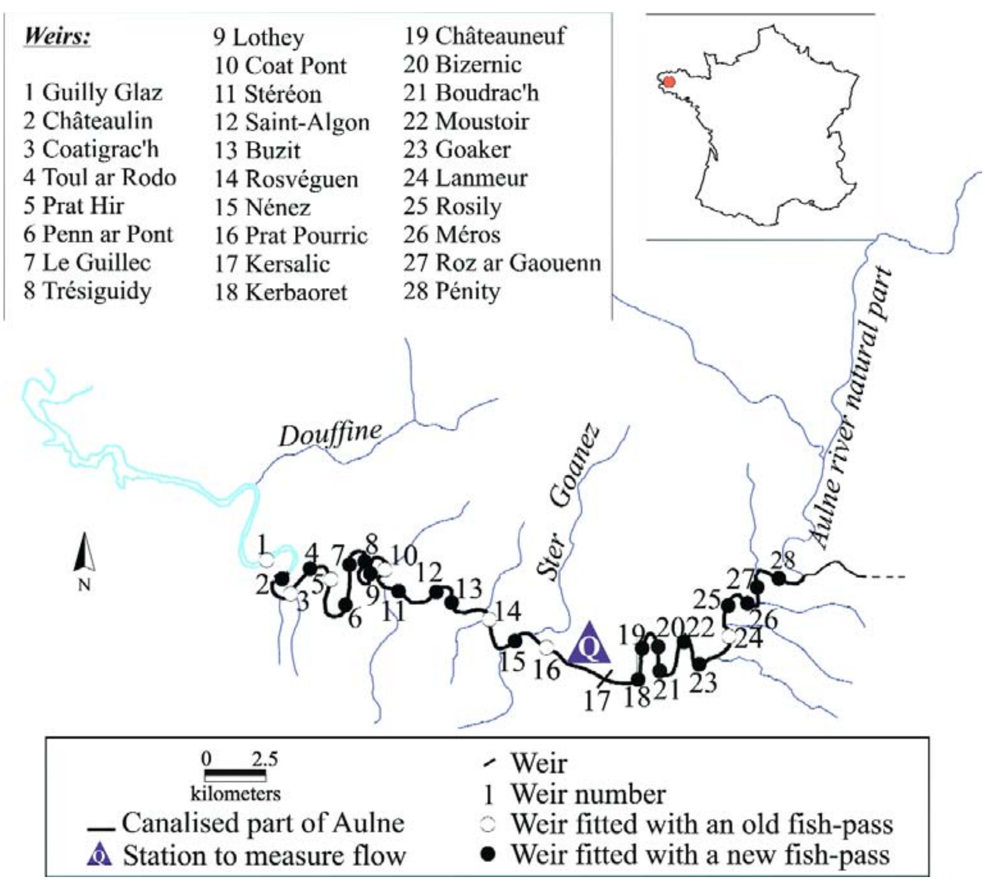

Fig. 2 – Map of the River Aulne, indicating the location of weirs and the different types of fish pass facilities at each.

Research period

The migration of salmon up the Aulne was studied over a two year period, 1999 and 2000. The 1999 study was initiated on July 5 and only covered grilse, salmon that have spent one winter at sea. The 2000 study began with the arrival of the first fish in late February and included both grilse and multi-sea-winter 'spring' salmon, fish which have spent two or more winters at sea. Individual fish were trapped in both years through to the end of October. The daily tracking of fish ended in mid-December, although several fish continued to be tracked at less frequent intervals up to the end of January.

Capture and radio-tagging of fish

The fish were caught in the pool fishway at Châteaulin (weir 2), representing the tidal limit. The fishway's upstream pool was transformed for the purposes of this study into a trap as described by Travade and Larinier (2002).

The fish-pass was shut at least twice a day – during the morning and early evening – and up to four times a day during the busiest migration period to check the trap for salmon. These times were chosen so as to limit the amount of time that fish spent in the trap, as over 85% of fish enter the pass during the daytime (Chanseau *et al*., 1999).

The trapped salmon were anaesthetised using a solution of diluted 2-phenoxyethanol (0.25 mll^{-1}). They were then measured. No injured, small (total length less than 55 cm) or descaled fish were radio-tagged.

In the two years of study, 132 salmon were radio-tagged by inserting a transmitter into their stomachs through a plastic tube. This method was chosen as the most suitable for adult salmon during upriver migration (Stasko and Pincock, 1997; Solomon and Storeton-West, 1983).

All fish were tagged with ATS (Advanced Telemetry System) radio transmitters. These have an external antenna and are cylindrical (60 mm long x 20 mm in diameter). In air, they weigh 20 to 22 g, which is less than 1.5% of the weight of the tagged fish. This is well below the 2.5% threshold above which certain species buoyancy is affected (Baras and Lagardère, 1995). The transmitters operated within the 48 to 49.9 MHz frequency range at 20 kHz intervals. The transmitters have a guaranteed life of 220 days. Actually, almost all worked for over ten months, thus covering the study period. The mortality indication option was chosen from available options. This meant that if the transmitter remained immobile for six hours, the pulse rate changed to alert listeners.

Transportation and release

In all, 79 salmon were released immediately upstream of their place of capture (i.e. upstream of weir 2). However, due to the difficulties encountered by these salmon in clearing the lower obstacles and in order to study the impact of each weir in the canalised section, the other tagged adults were transported and released at different points along the migration route. Thus 4, 7, 10, 3, 1, 10, 7, 5 and 6 fish were released upstream of weirs 3, 5, 8, 9, 10, 11, 14, 16 and 19, respectively. Consequently at least ten fish reached each of the 26 weirs being studied, upstream of the place where they were captured.

The fish transported upstream were placed one at a time in a transport tank containing 180 litres of diluted anaesthetic (0.075 mll^{-1}). A pump permitted to deliver compressed air to ensure the fish had enough oxygen in the water.

Radio-tracking

Automatic listening stations (ALS) were set up at 13 of the 26 weirs studied to record the times of arrival and departure of the tagged fish and thus the length of time spent at each weir and the ensuing migration delays. Between the various weirs along the canalised part of the Aulne and at weirs without an ALS, salmon movement was tracked manually, either on foot, by car or, occasionally, from aircraft. As far as possible, we tried to locate each radio-tagged salmon at least once a day while they remained in the canalised part. For weirs without an ALS, the minimum and maximum lengths of time the fish were held up by obstacles were determined from manual tracking records.

Results

Although 132 salmon were radio-tagged, only 129 were tracked. This is because one transmitter stopped working as soon as the fish was put back into the water and two other fish quickly regurgitated their tag. We obtained information from only 126 of the 129; two salmon were injured during the release operation and a third died soon after tagging, probably as a result of the handling.

Passability of weirs

To assess the passability of the weir, we determined the mean passage percentage and migration delay at each weir. Some fish were captured by anglers just downstream of several weirs and they were not taken into account when evaluating the passability of weirs.

The overall impact of the canalisation was estimated by adding together the impacts of each weir. This assessment was only possible in 2000. Work on the weirs or locks in 1999 required discharge gates at several weirs to be opened, and this atypical operation affected migration of the fish. There were not enough fish at each weir during the 1999 study to be able to reliably estimate how easily the weirs were passed in their usual mode of operation (i.e. discharge gate shut).

In terms of the cumulative percentage of fish clearing the weirs, it appears that 39.6% of salmon are likely to reach the Ster Goanez, the main tributary of the canalised section upstream of weir 15, where 12% of the catchment's salmon spawning grounds are found. Only 4.3% of salmon reach the natural part of the Aulne river (Fig. 3), where most of the spawning grounds are situated. The most obvious obstacles were those furthest downstream on the migration route (weirs 3 to 5 with a passage percentage of 76% to 91%) and two others in the middle section (weirs 16 and 17 with respectively a passage percentage of 31% and 67%).

The passability of weirs appears to depend on fish-pass type. Leaving weir 17 out of the analysis, it being an obstacle without a real fish-pass, we observed that the mean fish passage percentage observed at weirs fitted with older fishways is lower than at weirs with the more recent passes (73.7%±7.7 compared with 95.9%±1.2). This difference is statistically significant (Mann Whitney: $U=7.0$; $p<0.001$).

The delays noted at weirs fitted with older fishways (9.9±1.7 days) are greater than at weirs with the new fish-passes (3.8±0.7 days). This difference is also statistically significant (Test t: $t=3.20$; $p<0.01$).

It appears that the passability of weirs also depends on their position along the migration route. In 2000, some of the poorest passability ratings were observed for weirs 3 to 5, which are the furthest downstream in the canalised part of the river. In 1999, the lowest fish passage percentage was observed at weir 3 (33.3%). This weir is a special case in that it is the only chevron-shaped weir on the Aulne to be fitted with an older pool fishway placed on the right bank, instead of in the middle of the weir. In 1999, the lowest passage percentage at weirs with recent fishways was at weir 4. The passage percentage at this obstacle was significantly lower than that observed at weirs with a similar design, fitted with the same new fish-pass, but located further upstream on the migration route (Fig. 4): 77.8% at weir 4 compared with a mean of 95.2% for the other weirs (Test-t for a single sample: $t=5.014$; $p<0.001$). The passage percentage at weir 5 was also lower than that at weirs with the same design fitted with the same type of fishway but further upstream along the migration route: 57.1% at Prat Hir compared with a mean of 72.2% at the other weirs. Nevertheless, this difference is not statistically significant (Test-t for single sample: $t = 0.624$; $p = 0.577$).

Downstream migration

In 1999, 14 salmon (35% of the study sample) left the canalised part of the Aulne before spawning and migrated up other nearby rivers (Fig. 5) – eight up the Douffine, an estuary tributary of the Aulne, and six up other coastal rivers with mouths near the Aulne (one up the Camfrout, two

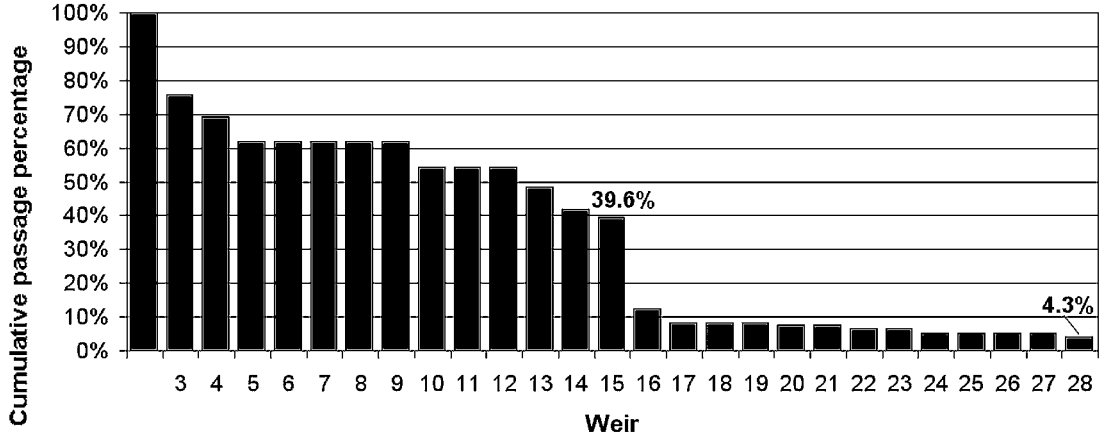

Fig. 3 – Cumulative percentage of salmon clearing the weirs along the canalised part of the River Aulne in 2000.

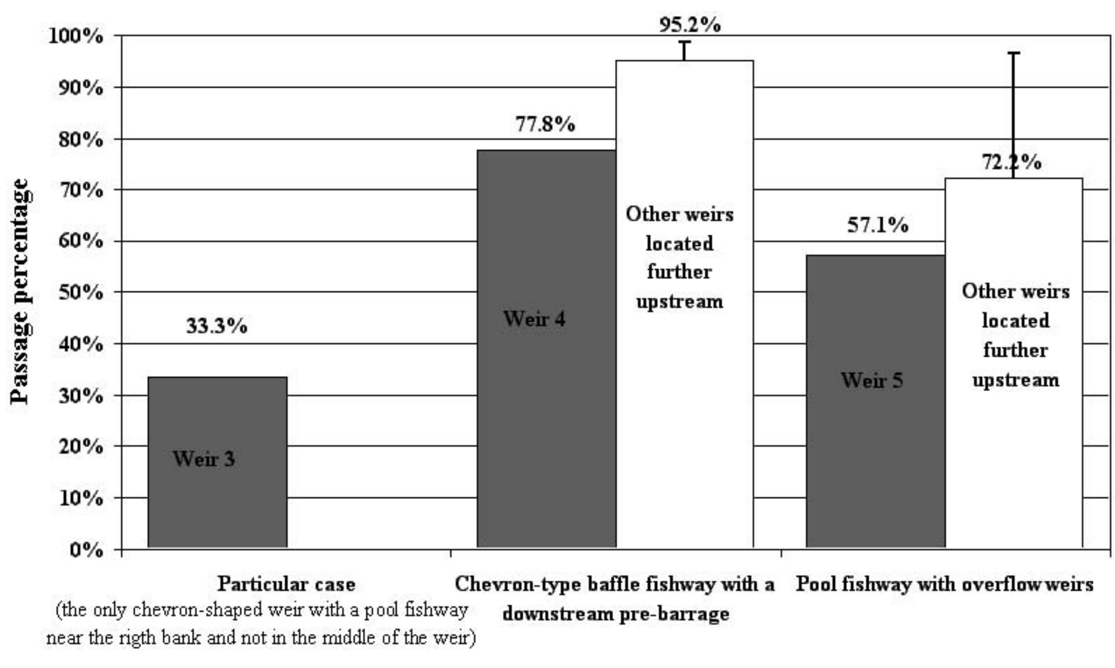

Fig. 4 – Passage percentage observed at the three weirs furthest downstream compared with all other weirs with similar fish pass designs.

up the Elorn and three up the Faou). The eight salmon swimming up the Douffine were held up at the foot of the first dam because its fish elevator was out of order. Most of these fish were subsequently detected in Brest harbour before the breeding period (one fish was found in the Camfrout, one in the Elorn and one in the Mignonne estuary).

Nineteen salmon (22% of the study sample) also left the Aulne in 2000 without having spawned there; only nine were subsequently found in other watercourses. Of these, eight were found in the Douffine and one in the Faou (Fig. 5). Radio-tracking was made very difficult at the time of downstream migration because of a combination of heavy flow, which limited access to the watercourses, and poor weather, which ruled out flying over the study area.

Impact of fishing

The study also enabled us to quantify the impact of angling.

The 40 salmon monitored in 1999 were grilse. Eight of them –20% of the study population– were caught by anglers, with seven being caught immediately below weirs. In 2000, only 4 of the 67 grilse radio-tracked (6%) were caught by fishermen. Three of these were also captured just downstream of a weir, the fourth being caught about 500 m downstream of weir 10. Over the two years, 12 of the 107 radio-tagged grilse (11%) were therefore captured by anglers.

The cumulative percentage of grilse passing the weirs in 2000, based on all individuals, whether or not they were captured by anglers, indicates that 32.8% passed the weir 15 and only 3.5% passed the last weir of the canalised section (Fig. 6). Excluding the grilse taken by anglers, the percentage of individuals passing over the weir 15 was 41.3% and the percentage of those passing over the most upstream weir of the canalised part was 4.4%. Therefore, angling activities reduced by 8.5% the number of potential spawners which passed weir 15 and were hence likely to migrate up the main tributary of the canalised Aulne, and

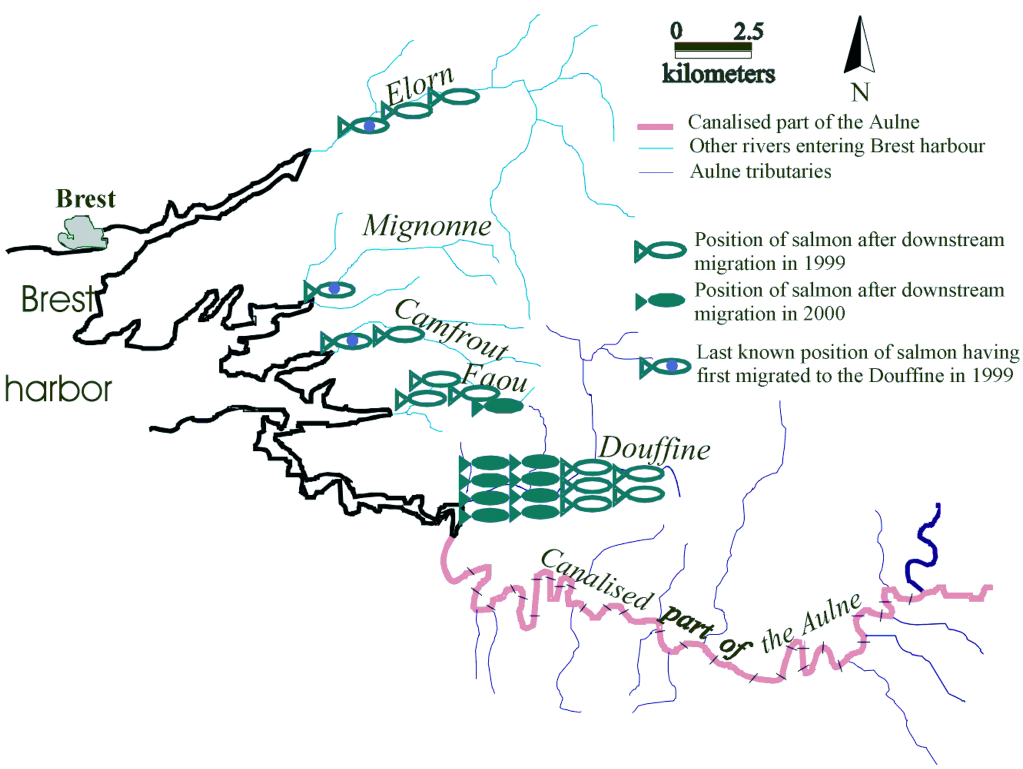

Fig. 5 – Position of radio-tagged fish having migrated down the Aulne before the breeding season.

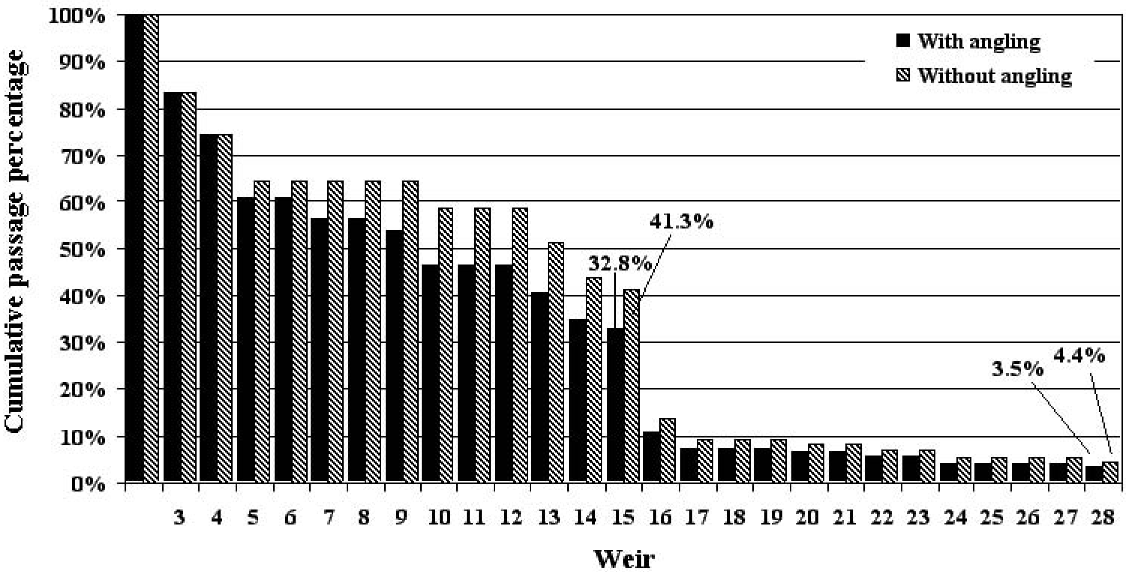

Fig. 6 – Estimated cumulative passage percentage of grilse in 2000 with and without angling.

by 0.9% the number of potential spawners likely to reach the spawning grounds in the upper Aulne.

For spring salmon, the impact of fishing was investigated only in 2000 and only on the downstream section of the Aulne (up to weir 10), since the number of individuals passing over the tenth weir was too small to enable evaluation of a passage percentage for more upstream obstacles. Nine of the 19 individuals radio-tracked –47% of the study population– were caught by anglers. Eight of them were captured just downstream of a weir, the ninth being fished about 400 m downstream from weir 3. The cumulative percentage of spring salmon passing over the tenth weir, based on all individuals, whether or not they were captured by anglers, was just 16.7% (Fig. 7). Excluding the spring salmon taken by anglers, the percentage of individuals passing over the tenth weir was 46.2%. The impact of angling activities is thus greater on spring salmon as fishing reduced by about 30% the number of potential spawners likely to reach the tenth weir of the canalised section.

Comparison between wild and reared salmon

Most of the hatchery-reared fish released to the river have been marked with an adipose fin clip. Only some of the 0^+ parr released in 1995 and 1997 and some of the 1^+ smolts released in 1997 have been introduced without such marking. We can be sure that salmon without an adipose fin were hatchery-reared fish but the opposite is not true, as salmon with an intact fin might be either reared or wild. Scale reading of all individuals tagged in 2000 enabled us to determine the number of years fish had spent in the river and the number of years they had spent at sea. With this additional information, we were able to determine the origin (wild or reared) of most (69/86) of the individuals studied in 2000. No scales were taken from individuals tagged in 1999. Thus comparison of wild and hatchery-origin fish is limited to just those 69 tagged during 2000.

The first comparison between wild and reared salmon concerns weir clearance. The number of obstacles with normal configurations (i.e. with discharge gate closed) cleared by fish was on average

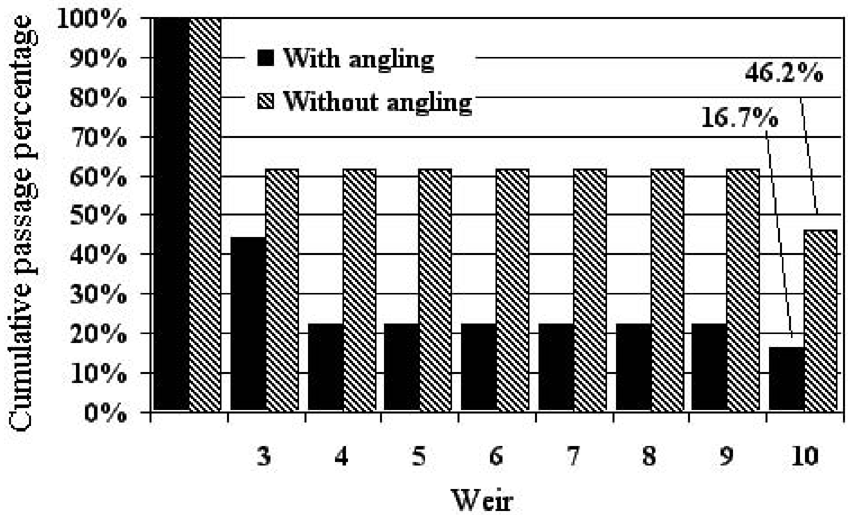

Fig. 7 – Estimated cumulative passage percentage, up to weir 10, of spring salmon in 2000 with and without angling.

5.7±1.7 for wild salmon as opposed to 8.0±1.9 for reared ones; this difference is not statistically significant (Mann Withney: U=71.0; p=0.574).

It is also possible to compare the percentage passage obtained for each weir, by limiting analysis to weirs with normal configurations, visited by at least five individuals from each category. This allows comparison for weirs 3 to 16, but there was no difference between wild and reared salmon (Wilcoxon: Z= -0.059; p=0.953) (Fig. 8).

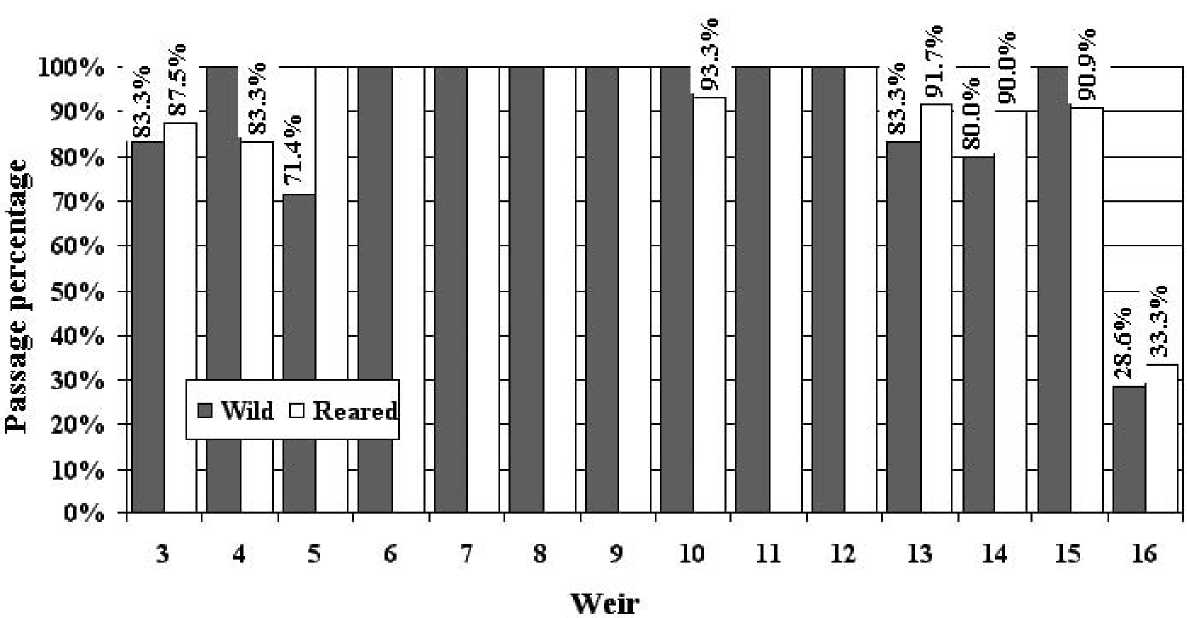

Fig. 8 – Comparison of passage percentage between wild and reared salmon up to weir 16.

Analysis of the fate of the fish (Table 1), divided into four categories (downstream migration before breeding, survival on the Aulne until breeding, caught by anglers and dead), indicated a statistical difference between wild and reared salmon (Chi-squared test: χ^2=25.9; p<0.001). More reared individuals undertook a downstream migration and more mortality was observed among wild fish. The greatest part of mortality appeared in summer (43%), with low flow and high temperature for salmon (until 23°C).

Table 1 – Fate of wild and reared salmon radio-tracked during 2000.

Destiny	wild	reared
Survival on the Aulne until breeding	9 (42.9%)	17 (35.4%)
Downstream migration before breeding	2 (9.5%)	12 (25.0%)
Caught by anglers	1 (4.8%)	6 (12.5%)
Dead	9 (42.9%)	13 (27.1%)

Mortality was also noted after injuries during weirs passage attempts, particularly where rocks are abundant just downstream of weirs (28.5%). Lastly, several cases of mortality (28.5%) occurred just after flow increase.
However, if the comparison is limited to just two categories (survival on the Aulne until breeding and absence of survival on the Aulne until breeding), there was no statistical difference between wild and reared salmon (Chi-squared test: χ^2=0.511; p=0.475).

Discussion

The canalised part of the Aulne appears to represent a major obstacle to migrating adult salmon, since only 4.3% of the tagged fish were able to reach the natural part of the Aulne where most of the areas favourable for breeding and growth of juveniles are found. This result is even more alarming given that it was based on the radio-tracking investigation in 2000, a year with exceptionally heavy flows which helped the fish to progress. During most of the salmon migration period, monthly mean flows were around twice that of reference flows. This difficulty in clearing the canalised sector appears to be partly due to the poor performance of the old fish pass facilities which were badly installed and are too small. The worst clearance results, both in terms of percentage passage and migration delay, appear to be at the weirs which are still fitted with outdated fish passes, or at weir 17 which doesn't have a proper pass. The effort made to date for the restoration plan have not been useless as fish passage is somewhat better at weirs fitted with new fish pass facilities. Moreover, the problem of passability is particularly evident on the downstream part of the migration route at the first three weirs studied (3 to 5). Weir 3 (Coatigrac'h weir) is fitted with an older fishway which is not only too small but is also positioned near the bank, while the weir itself is chevron-shaped. At the Toul ar Rodo and Prat Hir weirs, even though the fishways are positioned in the middle of the weirs, they are less passable than similar weirs further upstream, fitted with identical fishways. The nature of the obstacle and the fishway design cannot fully explain the poor clearance results observed. Other environmental factors could limit the progression of salmon in this part of the river. Salmon are used to rough water and might hesitate to migrate upstream through this canalised section where flow is light and the water of a poor quality. This is partly perhaps why several salmon migrate downstream before the breeding period.
As previously shown in studies on other European rivers (Chanseau *et al*., 1999; Gerlier and Roche, 1998), radio-tracking can be very useful for evaluating the impact of in-river obstructions on salmon migration.

Gentle insertion of radio transmitters into fishes' stomachs via the oesophagus did not prevent fish being caught by anglers. This has previously been reported for other studies, for example on the River Tummel (Gowans *et al*., 1999), on the River Pau (Chanseau *et a*l., 1997, Chanseau *et al*., 1998) or on the River Scorff (Prévost, 2002), as well as during the 2 investigations conducted on the Aulne (Croze *et al.,* 2000, 2002). Angling appears to have had a noticeable impact on the stock of radio-tagged grilse in 1999 and 2000, as up to 20% of the stock was caught. Likewise, fewer adults reach the main tributary of the canalised part and the natural part of the Aulne because of angling. However, fishing does not appear to be the one factor limiting the widespread presence of one-sea-winter adults in areas favourable to breeding: without this activity, the percentage of one year old sea salmon reaching the Aulne river remains very low. The impact of angling on the spring salmon population was found to be far greater, as half of the fish were caught before reaching weir 10. As angling limits the number of fish successfully clearing this weir, this will reduce the numbers of fish able to reach even the reproduction areas located on the main tributary of the canalised sector.

Suggestions that the origin of the salmon returning the Aulne, whether wild or hatchery-origin, might affect the migratory behaviour of the fish were not borne out by this investigation. In terms of the capacity to clear obstacles, the performances of wild fish and reared fish were quite similar. Indeed, there was no difference in the mean number of weirs cleared by the two groups of fish, or the clearance percentages observed at the various weirs. The use of reared salmon does not therefore appear to be responsible for the very low success rate in passing the canalised sector.

On the other hand, differences were observed between these 2 categories with respect to the fate of individuals. The percentage of salmon descending the Aulne in 2000 was greater for reared individuals (25%) than for wild ones (9.5%). This phenomenon might be at least partly explained by the choice of release sites for the young stocked fish. Even though most of them were freed on the Aulne, several thousand smolts were released up to 2001 on the estuary tributary of the Aulne, the Douffine. In 2000, it was observed that all of the salmon descending the Aulne then ascending this tributary were reared salmon. These eight fish might thus come from batches released on the Douffine which were returning to it after having mistakenly entered the Aulne. Mortality, apart from fishing, appears to be less significant for reared fish (27%) than for those assumed to be wild (43%). This result might be partly explained by a greater percentage of reared fish among those descending the Aulne, since individuals which had left the Aulne could obviously not die there. On the other hand, the proportions of individuals which survived up to the reproduction period did not appear to be different when wild populations and reared ones were compared. The reared individuals are thus just as likely to reproduce as wild ones.

In conclusion, this radio-tracking study explains why there is a lack of wild juvenile salmons on the spawning grounds in the natural part of the Aulne upstream of the canalised part. The lack of young fish is due to the difficulties that salmon face when trying to reach these breeding areas, particularly those on the natural part of the river. The percentage of adults likely to reach the natural part is too low to enable sufficient natural reproduction in this catchment area. This poor result is probably due to the environmental conditions caused by canalisation, with a multitude of weirs along the canalised part and sluggish flows which undoubtedly intensify problems due to poor water quality. This study also revealed the high impact of angling, especially on spring salmon, and showed that use of reared individuals cannot explain the lack of passability of the canalised part, nor the low amounts of natural fry produced on the Aulne.

The study has thus provided managers with a means of assessing the restoration plan. We recommend that several steps are taken to pursue this plan: (1) new fish-passes should be built at weirs 3 to 5, at weir 17 and at all weirs fitted with old fishways, (2) the migration environment should be improved by improving water quality and increasing the flow speed, for instance by opening weirs and (3) fishing activities should be prohibited during the spring salmon migration period.

Radio-tracking was used on this watercourse to aid decision-making. It was used not only to assess the salmon restoration plan for the Aulne river, but also to point out likely alternatives to authorities, to help maintain one of the salmon populations that, in the past, enabled the biggest catches in all of Brittany's waterways.

Acknowledgements

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