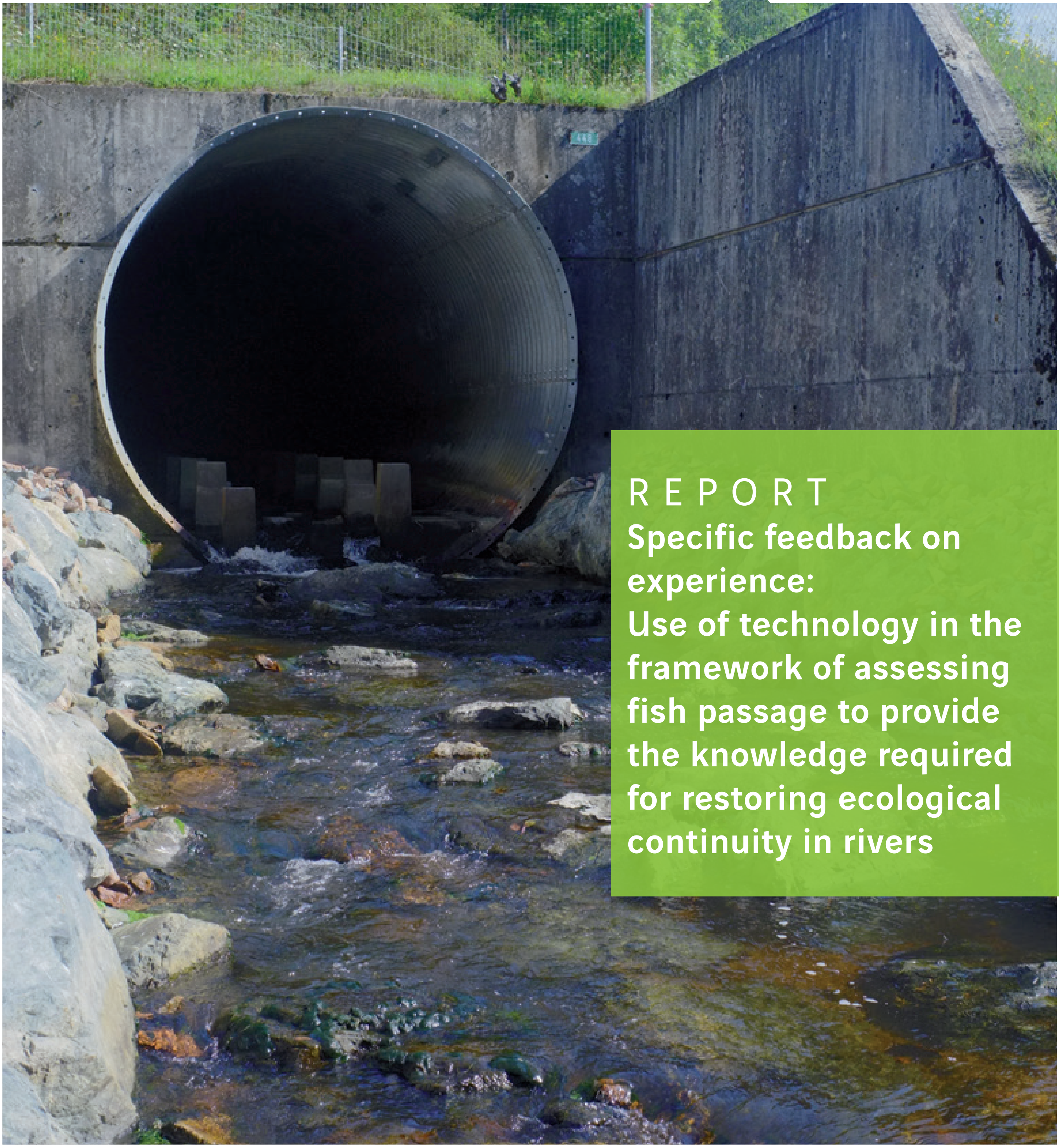
VINCI AUTOROUTES

THE RESTORATION OF ECOLOGICAL CONTINUITY CORRIDORS ON MOTORWAYS

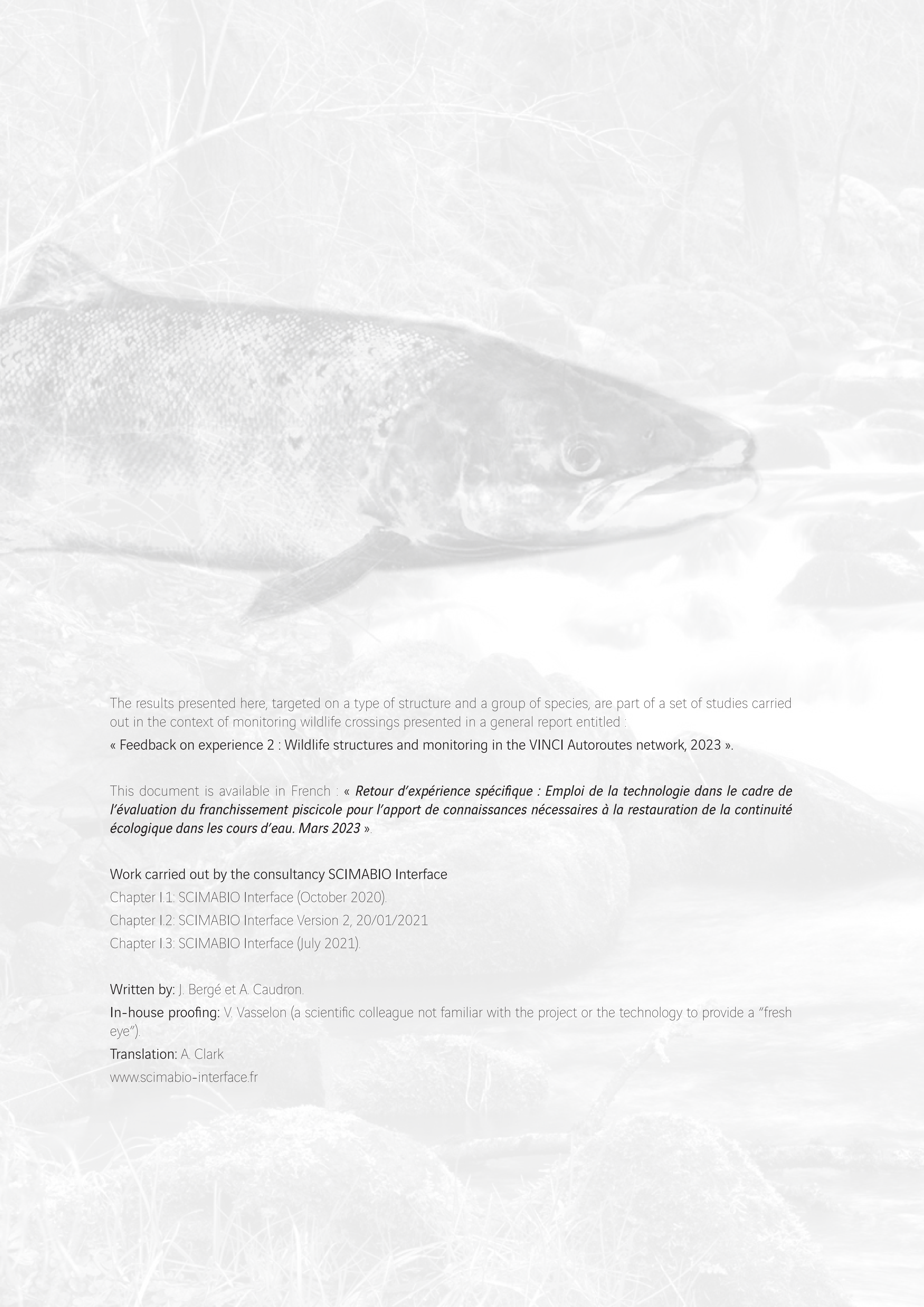
MARCH 2023



REPORT

Specific feedback on experience: Use of technology in the framework of assessing fish passage to provide the knowledge required for restoring ecological continuity in rivers

SCIMABIO Interface
science-management interface for biodiversity conservation



The results presented here, targeted on a type of structure and a group of species, are part of a set of studies carried out in the context of monitoring wildlife crossings presented in a general report entitled :

« Feedback on experience 2 : Wildlife structures and monitoring in the VINCI Autoroutes network, 2023 ».

This document is available in French : « ***Retour d'expérience spécifique : Emploi de la technologie dans le cadre de l'évaluation du franchissement piscicole pour l'apport de connaissances nécessaires à la restauration de la continuité écologique dans les cours d'eau. Mars 2023*** ».

Work carried out by the consultancy SCIMABIO Interface
Chapter I.1: SCIMABIO Interface (October 2020).
Chapter I.2: SCIMABIO Interface Version 2, 20/01/2021
Chapter I.3: SCIMABIO Interface (July 2021).

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www.scimabio-interface.fr

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> “ The adjustments made enable the passage of trout within the range of discharges used for scaling them ”

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I. MONITORING BY RFID TECHNOLOGY - ASSESSMENT OF FISH PASSAGE THROUGH CULVERT OH 448 OF THE A89 MOTORWAY ON THE DUROLLE RIVER (PUY DE DÔME, 63)

According to Caudron et al. (2020)[1]

THE CONTEXT OF THE STUDY

Obstacles to the free circulation of fish in a river may limit access to certain habitats essential to the survival of individuals and be detrimental to the natural functioning of populations. In the last ten years, numerous measures, both reglementary and non-reglementary, have been initiated to restore fish and ecological continuity, and also sedimentary continuity, in rivers in order to reduce the impacts of hydraulic structures on habitats and populations. Trout rivers are particularly targeted by restoration measures. During the course of its cycle life, the Brown Trout can develop migratory behaviour to access breeding, feeding or refuge habitats. Obstacles to migration may therefore impact natural reproduction and the flow of genes, and are likely to fragilize the population in the long term.

The Durolle is a salmonid river in the Puy de Dôme department (Figure 1), situated at the head of a drainage basin, which is home to a functional and abundant trout population. Hydraulic structure OH 448 enables the A89 motorway to cross the Durolle near the village of St Rémy sur Durolle. It is an old structure dating from the construction of the A72 in 1978. It consists of an ARMCO-type corrugated iron culvert that is 104 metres long with a gradient of 1% (Figure 2). It used to be an uncrossable obstacle for the trout due to the flow conditions inside the culvert: excessively high and homogeneous current speeds, lack of rest areas (hydraulic shelters).

In 2016, works were carried out in order to re-establish fish continuity across this structure by enabling the trout to pass through the culvert from downstream to upstream. A unique hydraulic system consisting of a rough-textured baseplate and prefabricated flow-breakers was set up inside the culvert to make the flow conditions of compatible with the swimming capacity of the Brown Trout (Figure 3). The system was theoretically designed to ensure hydraulic conditions favourable to the passage of the trout for discharges between the QMNA5[1] and 2.5 times the modulus[2], i.e., from 0.18 to 2.50 m³/s, with a preferential operating range between 0.78 and 1.19 m³/s. Complementary works were carried out immediately downstream of the culvert to reduce the artificialisation of the riverbed and thus facilitate access for the fish to the adjusted culvert (Figure 4).

A post-works study was performed in order to assess the effectiveness of these adjustments at the biological level by examining the culvert's passage capacity for trout. Upstream

Figure 1 : Location of the Durolle, in the Puy-de-Dôme department, Auvergne-Rhône-Alpes region..

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[1] QMNA5, expressed in m³/s, is a statistical low-water value used in France. It is the mean monthly annual minimum discharge (MMAMD) having the probability of 1/5 (20 %) of not being exceeded in a given year. It is therefore the value of the MMAMD that only occurs on average in one year out of five or twenty years per century. It is a statistical discharge that provides information about the severity of a low-water event.

[2] The modulus is the equivalent in m³/s of the total quantity of water circulating in a stretch of river over an average year.

EXPLANATION BOX N°1

Passive Integrated Transponders or PIT tags are small tags consisting of an antenna and a capacitor combined with an electronic chip that work using a wavelength of 134.2 kH (Illustration 1). They are encapsulated in glass and compliant with biological tagging. They can therefore be used for the internal tagging of animals such as fish.

Illustration 1: Various sizes of transponders (left) that can be used for tagging trout (right).

Each transponder is characterised by a unique code, which enables all the tagged individuals to be identified individually. The identification of the tagged fish occurs when it passes close to a detection antenna (Illustration 2). The transponders do not need a battery to function, their lifespan is therefore unlimited. They are charged passively by induction by means of a magnetic impulse transmitted by the antenna linked to an RFID reader-recorder unit. This impulse charges the transponder capacitor, which responds by emitting its identification number, which in turn is recorded by the reader-recorder along with the date and time of its emission.

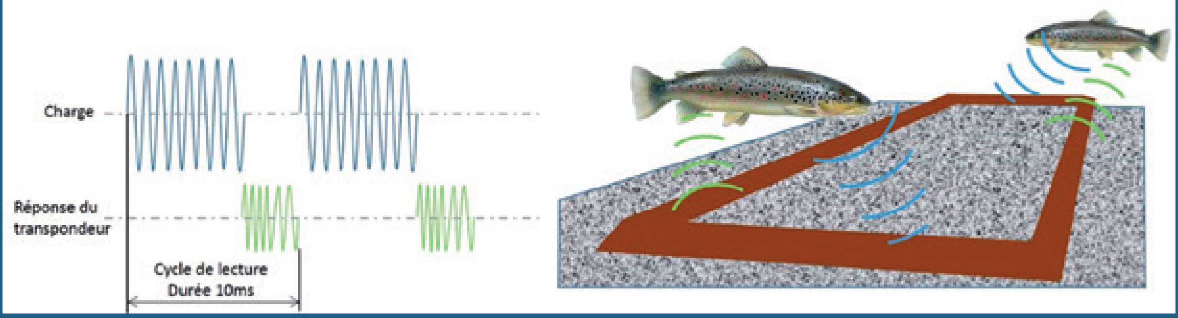

Illustration 2: Illustration of the detection principle of transponders implanted in trout.

The tagged fish can be detected either by means of judiciously positioned fixed antennae (exit of fish pass, natural riffle area), or during active surveys on foot using portable antennae combined with GPS to record the coordinates of the individuals detected..

Figure 2 : ARMCO-type culvert OH 448 in corrugated iron, 104 metres long with a gradient of 1%.

Figure 3 : Unique hydraulic system consisting of a rough-textured base plate and prefabricated flow-breakers.

Figure 4 : Downstream exit of the culvert before (left) and after (right) the adjustment works.

passage was studied over two complete migration cycles using RFID (Radio Frequency Identification) technology, which monitor the movements of tagged individuals by means of passive transponders called PIT tags (see explanation box 1).

DEVICE AND MONITORING STRATEGY

A fixed RFID device was set up immediately upstream of the culvert in order to detect the tagged fish that had passed through the structure during the two years of the study, from July 2017 to August 2019. The device consists of two antennae set up horizontally across the whole width of the riverbed (6-7 metres), leach linked to an RFID reader/recorder to record the identity code of the fish, and the date and time of passage (Figure 5). The constraints of the site (securing of the equipment and electric power supply) prevented us from setting up a fixed RFID device downstream of the culvert to detect tagged individuals entering the structure.

A control tag, programmed to be detected every thirty minutes, was placed near each antenna in order to check that it was functioning correctly. Daily remote transfer of the data by GSM enabled us to regularly ensure how the device was working.

Over the 730 days of the monitoring, the antennae functioned correctly the vast majority of the time: antenna 1 worked 99.2 % of the time and antenna 2 worked 97.4 % of the time.

The detection efficiency of the device was estimated at 99.9 % according to the formula of Zydlewski *et al.* (2006)(2), which means that the probability of a tagged fish not being detected by the device is virtually zero.

The data collected by the fixed device are therefore sufficiently representative to enable reliable analysis of passage through the culvert by trout.

In addition, seven mobile survey campaigns were performed between 2 May 2018 and 1 August 2019 with three objectives:

1. Assess any potential blocking effect of the culvert by trying to detect any possible accumulation of migrant fish downstream;
2. Gather new knowledge on the migration behaviour and sedentarism of Brown Trout;
3. Try to locate any possible tagged trout upstream of the culvert that had not been detected by the fixed device.

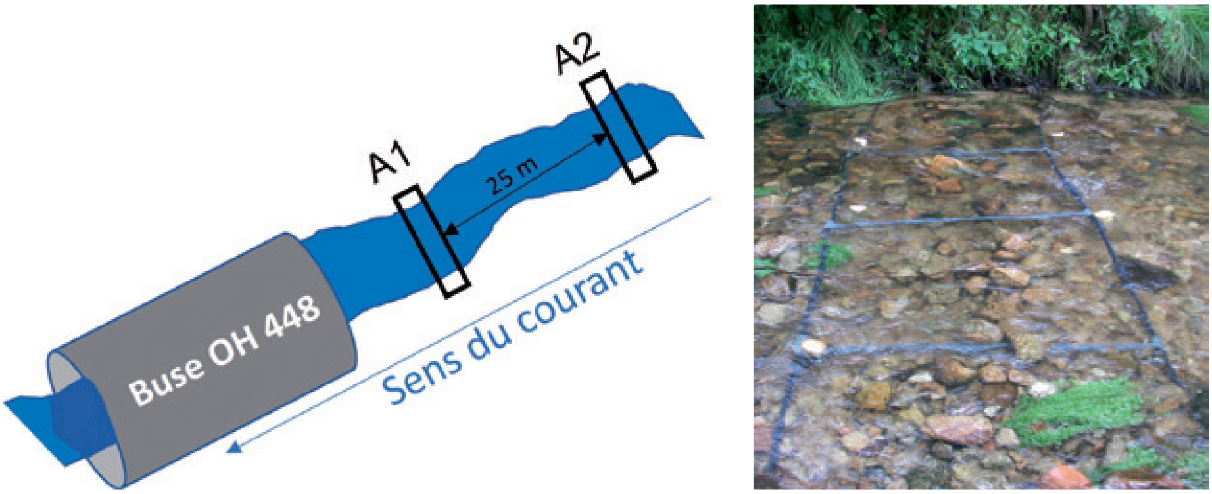

Figure 5 : Left: set-up diagram of culvert OH 448 with fixed RFID antennae. Boxes A1 and A2 represent the fixed RFID antennae placed upstream of the culvert. Right: picture of an antenna set up in the Durolle.

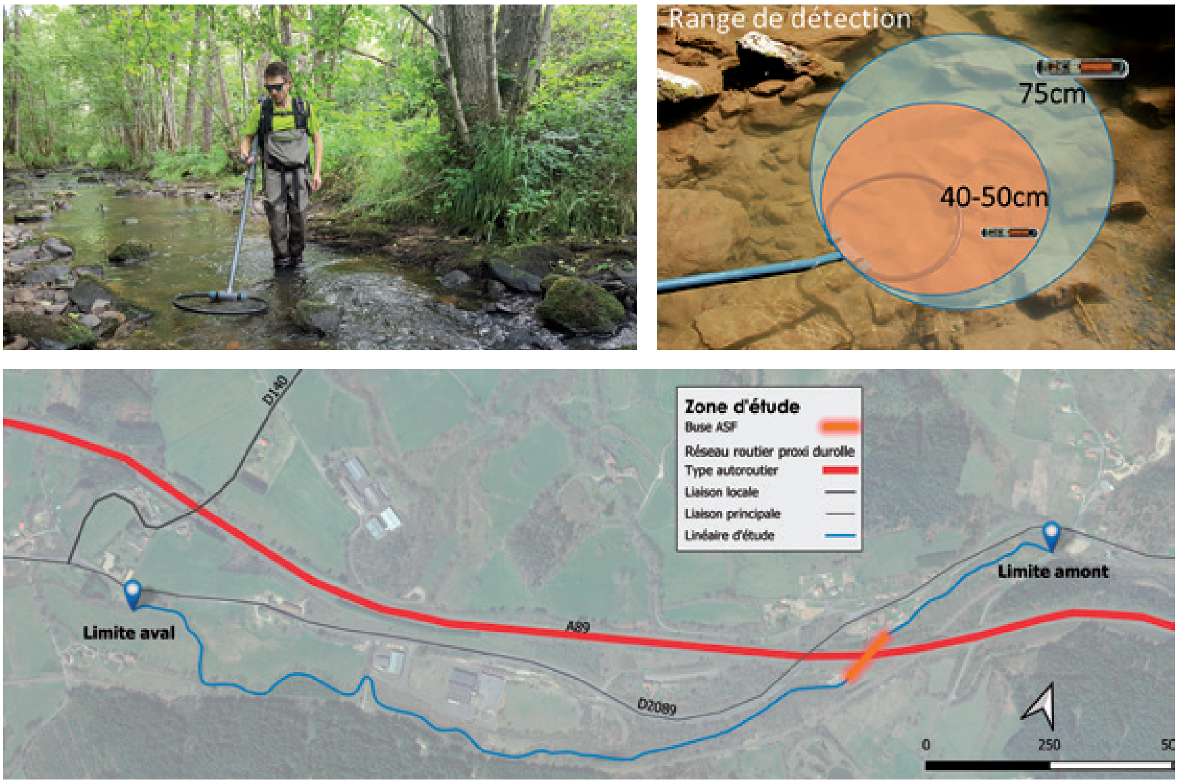

Figure 6 : Reach used for the study, carrying out a mobile survey and detection range of mobile antennae. The limits indicated on the map delineate the route taken during the mobile surveys.

The method consisted in having two operators, each equipped with an RFID reader/recorder and a portable antenna, walk upstream along the river while surveying all the habitats. A GPS device synchronised with the reader/recorders showed the position of each detected transponder with a precision in the order of 5 to 10 metres.

These surveys were performed on a reach of 1680 metres downstream of the culvert, plus 560 metres upstream of the culvert (Figure 6).

BROWN TROUT (*SALMO TRUTTA L.*), THE TARGET SPECIES

During the course of the two years of monitoring, 815 trout longer than 100 mm (total length between 103 and 350 mm) were tagged with transponders (Figure 7). They were caught by survey-electrofishing using a portable fishing apparatus. Each individual was anaesthetised in a eugenol bath, measured (total length to the nearest mm) then tagged with a transponder. To do so, a small ventral incision was made using a scalpel, then the tag was introduced into the peritoneal cavity. After tagging, the individuals were kept under observation in a recovery tank in order to regain their swimming capacity before being released into the river (Figure 8).

The protocol set up is compliant with all the regulations in force in terms of capturing and tagging animals for scientific purposes. The project received the authorisation of the Ethics Committee and the Research Ministry, reference number #10286.

No loss of tags was observed immediately after tagging. The post-tagging retention rate of Brown

Trout for individuals more than 100 mm long is generally close to 100 % (Vatland and Caudron, 2015)(3).

Most of the trout (716 ind.) were captured downstream of the culvert on a total reach of 1680 metres. These individuals were tagged then released in the place where they were caught. In addition, 99 fish were captured upstream of the culvert then transferred after tagging directly downstream of the culvert in order to force upstream migration behaviour. The underlying hypothesis is that the displaced fish will seek to return to their original habitat, and should therefore try harder to pass through the culvert than individuals captured downstream.

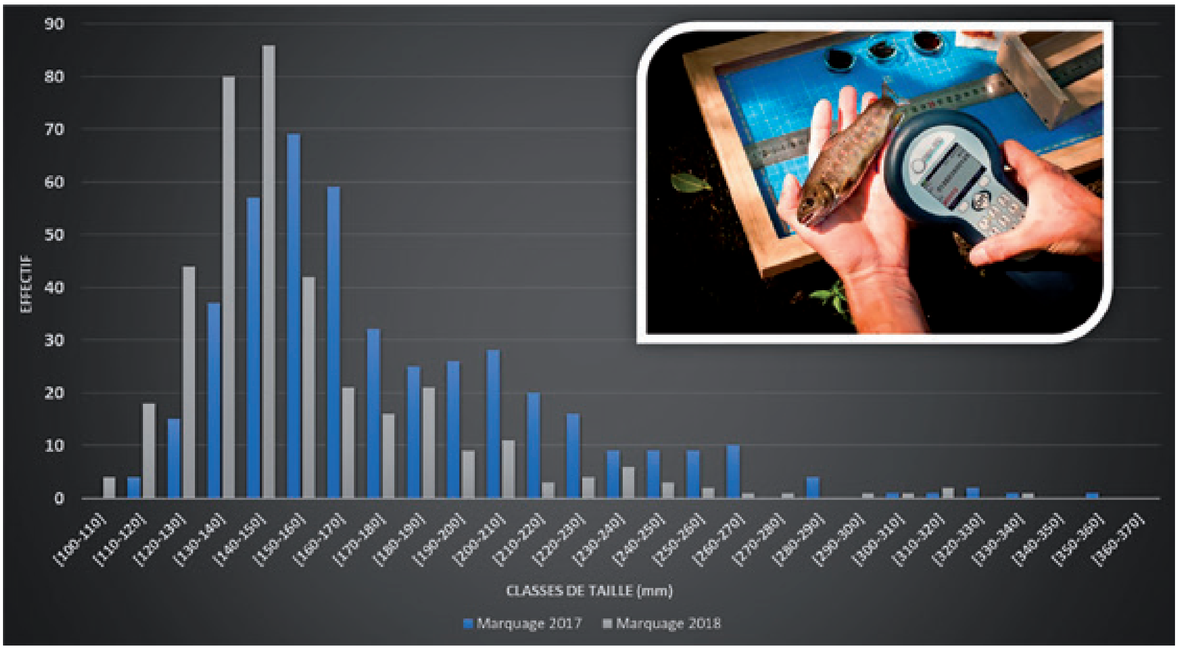

Figure 7 : Population structure of the trout tagged in 2017 and 2018.

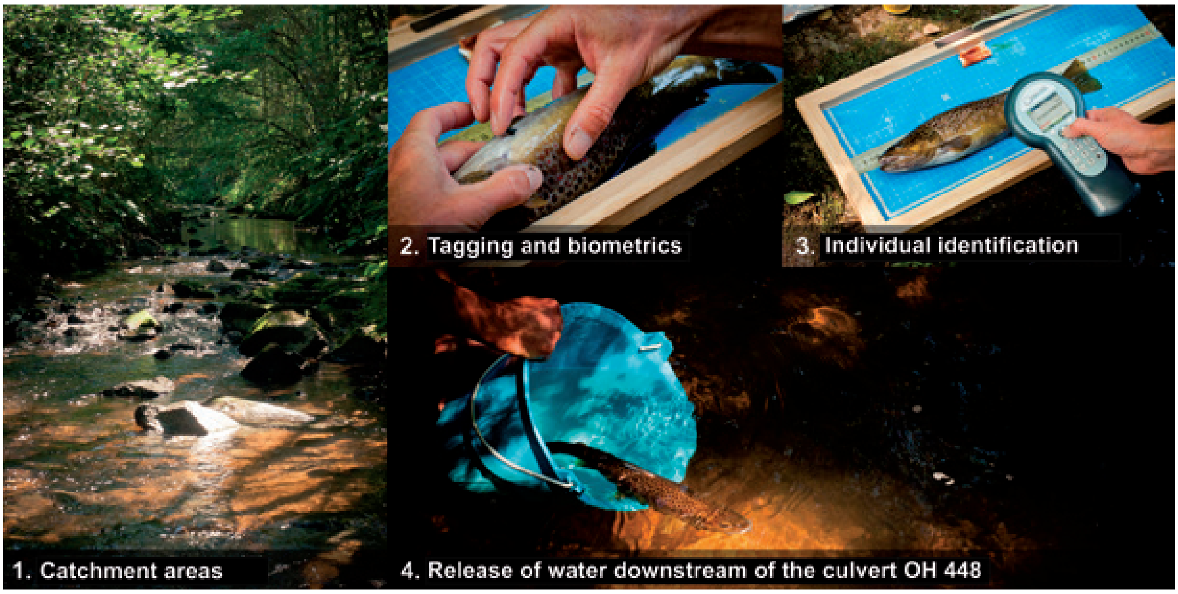

Figure 8 : Steps in the tagging of the trout monitored during ant study: from capture to re-release in water.

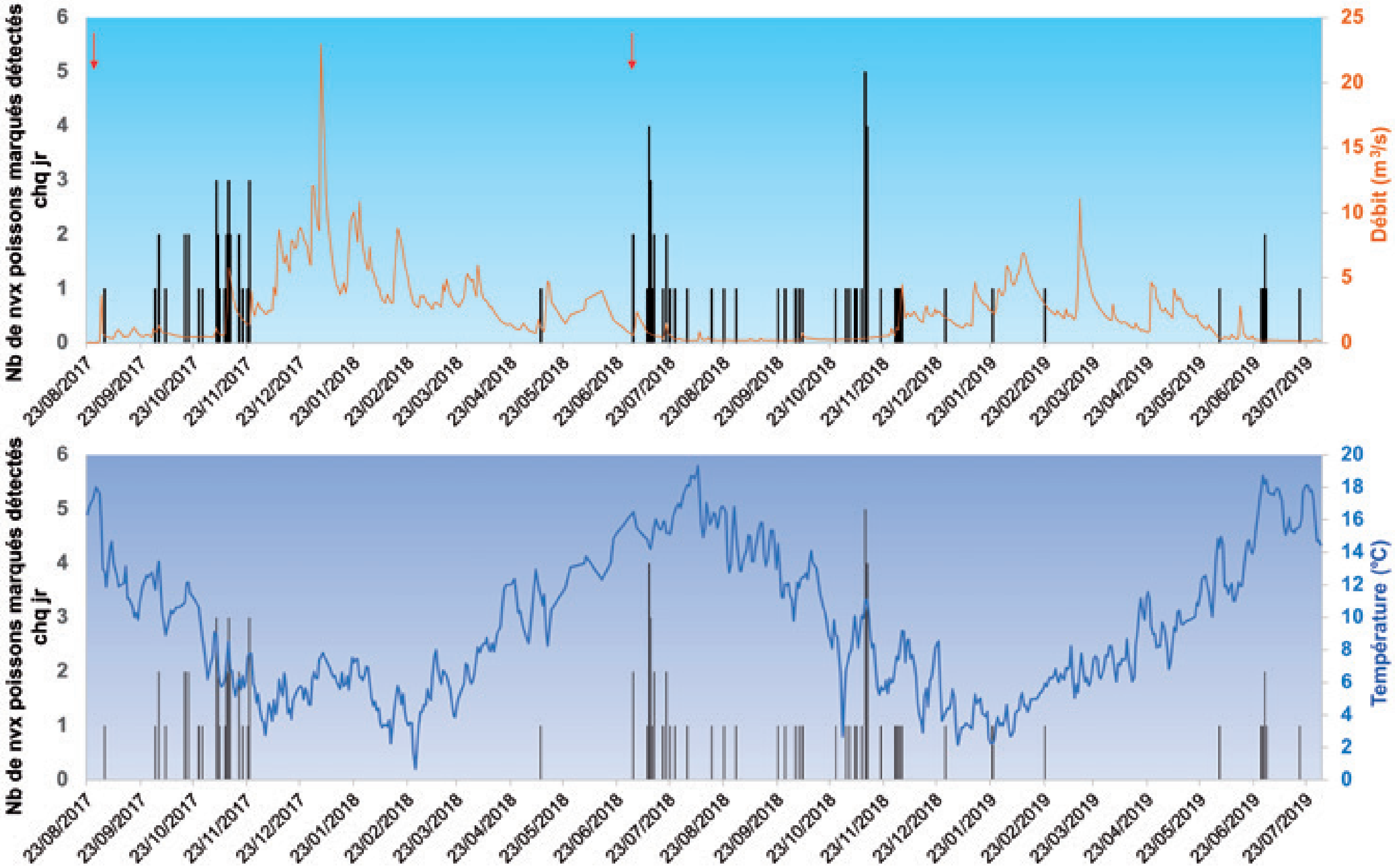

Figure 9: Number of new trout detected each day by the fixed antennae upstream of the culvert and time series of temperatures and discharges during the study period (red arrows = tagging).

PRINCIPAL RESULTS

In total, out of 815 tagged trout, 165 were detected by the fixed RFID device passing through the adjusted culvert and 450 were detected at least once downstream of the culvert by a mobile survey. 200 individuals were therefore never redetected.

The following points indicate that the hydraulic system provides a high capacity of passage through the culvert by the trout:

- 75 % of the individuals captured upstream of the culvert and translocated downstream passed through the culvert;
- A large majority of the individuals transferred passed through the culvert during the first week of monitoring (99 % in 2017 and 53 % in 2018);
- No selection of the culvert in function of the size of the fish sampled (103-305 mm) was observed (Figure 10);
- No accumulation of tagged fish at the bottom end of the culvert was highlighted;
- The adjustments made enable the passage of trout within the range of discharges used for scaling them, QMNA5-2.5*Modulus [0.18-2.5 m³/s] (Figure 9);
- A significant proportion of the passages (11 %) took place with discharges higher than those used for theoretical scaling (> 2.5*Modulus) (Figure 10).
- Other results provide supplementary knowledge on the species' ecology and migratory behaviour:
- The proportion of migrant trout was low as approximately 13 % of the downstream population passed through the structure.
- Most of the trout exhibited rather sedentary behaviour with movements limited around 100 to 200 metres.

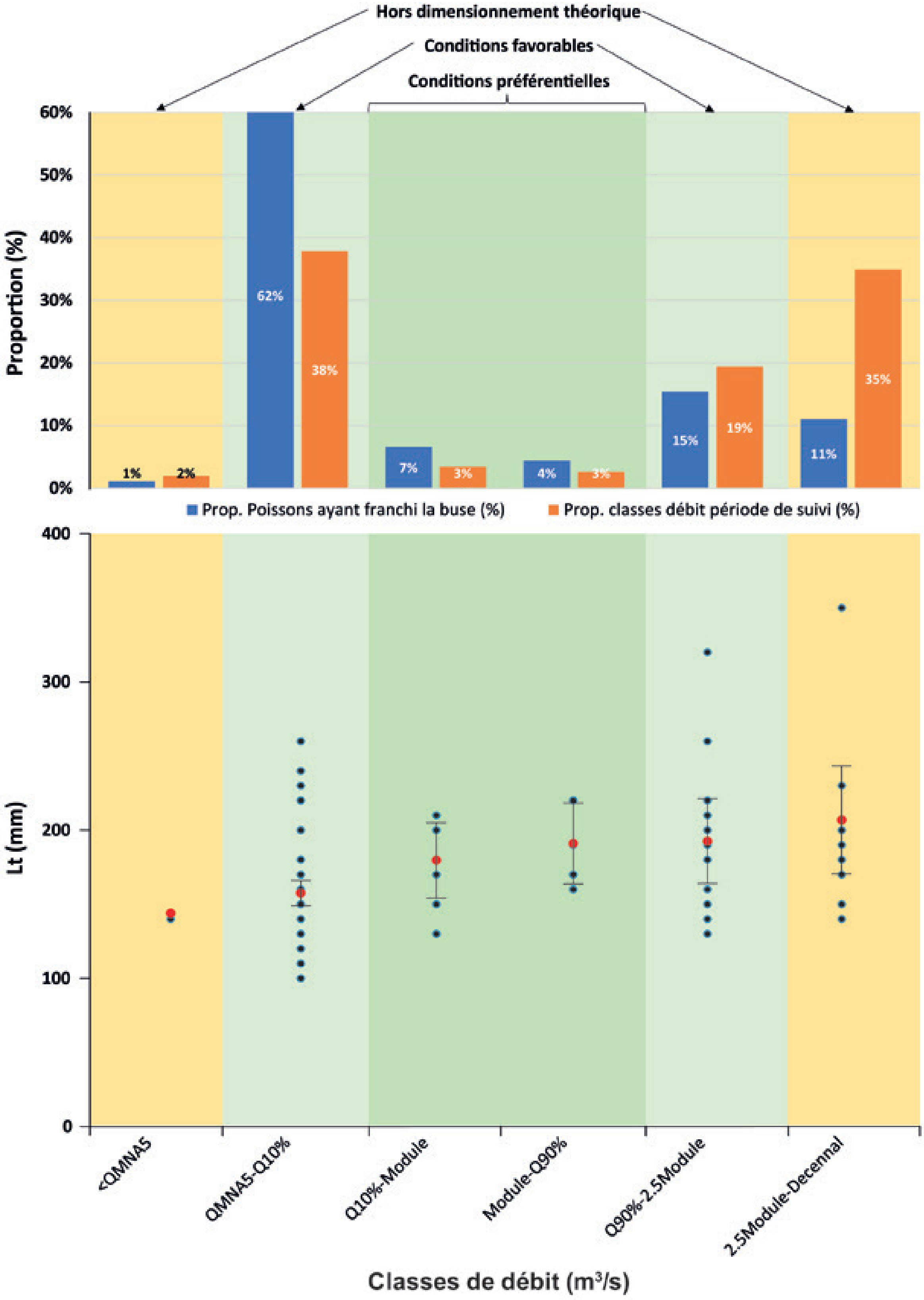

Figure 10: Relations between the passages recorded and the categories of discharges used for the hydraulic scaling of the fish-pass system (green = various discharge ranges used for scaling the system, pink = discharge range outside the scaling of the structure). Distribution of discharges observed during monitoring and proportion of fish that passed through the culvert for each category of discharge (above). Distribution of the sizes of the trout that passed through the culvert in function of the discharge (below).

- The passage period lasted between July and mid-November in both years with a majority of passages (80 %) concentrated in the months of October and November.
- A distance effect with regard to the culvert was observed, with a higher passage rate for individuals having been released within 300 metres downstream of the structure, compared to trout tagged further downstream. It is also interesting to underline that some individuals released approximately 1.5 km downstream of the culvert passed through the structure.
- No clear influence of temperature was noted (Figure 9). However, it is difficult to isolate the respective effects of the discharge and temperature factors since the high-discharge periods correspond to the periods with the lowest temperatures (winter-early spring).

LESSONS LEARNED CONCERNING THE APPLIED PROTOCOL AND THE USE OF RFID TECHNOLOGY

The precise results obtained by RFID technology enabled us to assess passage through the adjusted culvert and to evaluate the efficiency of the hydraulic adjustments carried out.

This technology is particularly appropriate for monitoring fish-passage structures for a considerable number of individuals of various sizes.

The protocol set up, combined with a fixed detection device located immediately upstream of the culvert and several mobile survey campaigns, provided very satisfactory results concerning the passage capacity of the culvert. On the one hand, the double-antenna fixed device showed an efficiency of virtually 100% throughout the two years of monitoring, and managed to detect all the tagged trout which passed through the culvert. On the other hand, the repeated mobile surveys established the absence of a blocking effect by the culvert and provided knowledge about the dispersion of the trout that revealed the mainly sedentary behaviour of individuals within the population.

The monitoring period of two whole years seems to have been necessary because it enabled two pre-reproduction migration periods to be monitored under very varied hydrological conditions. The results confirm the need for an annual tagging campaign of several hundred individuals to ensure a sufficient quantity of data for this type of monitoring.

The large number of trout tagged, i.e., 815 in total, and the length of the reach downstream of the culvert used for tagging, i.e., 1730 metres, seem to be sufficient, but also necessary for encompassing the diversity of migratory behaviours on a small river such as the Durolle.

Finally, the translocation of captured individuals from upstream to downstream of the studied structure seems to be a bonus in a fish-pass assessment protocol such as the one implemented on the Durolle.

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“ During the study, 25 salmon were captured, 24 of which were tagged ”

II. MONITORING BY RADIO-TRACKING - ASSESSMENT OF THE PASSAGE OF ATLANTIC SALMON THROUGH ADJUSTMENTS TO WEIR A89 ON THE RIVER ALLIER (PUY DE DÔME, 63)

CONTEXT OF THE STUDY

The Atlantic Salmon (Figure 11) is an emblematic species of the aquatic biodiversity of the Loire-Allier River Basin. Thise species is currently particularly vulnerable due to a large number of factors acting synergistically. Ecological continuity issues are central to the threats faced by the species, in particular due to the length of the reach of river that the genitors need to swim up in order to attain the first high-quality spawning grounds. Recent studies (1,2), based on the individual monitoring of salmon by radio-tracking, have in particular identified a delay effect caused by several structures. This delay effect, in an increasingly constrictive hydroclimatic context for the species, leads in particular to an increase in summer mortality risks (3).

In this context and in order to respond to reglementary obligations linked to the restoration of ecological continuity, in 2014 VINCI Autoroutes commenced scaling studies for its weir named “A89” (Figure 12) on the River Allier, then the works to make its weir compliant with the regulations, which were completed in October 2017. These works consisted in lowering the ridge of the structure by half and creating a rough-textured double-slope fish ramp (Figure 13).

In 2018, a feasibility study carried out in collaboration with the State services (DDT, OFB[1] regional division and eco-hydraulic unit) and local technical stakeholders (LOGRAMI, FDAAPPMA, APS, CNSS[2]), defined all the methodology of the post-works monitoring, which began in spring 2019 (see Box 2 for an explanation of the technology).

The priority objective of the radio-tracking monitoring (presented here) was to respond to the reglementary requirements and in the end be able to access to what extent the delay effect of Weir A89 on the reproductive migration of the salmon was mitigated.

It should also be noted that, in parallel, the Puy-de-Dôme DDT carried out adjustment works on the weir at Les Madeleines (situated 2.3 km upstream of Weir A89, Figure 14), which were completed in November 2016. These works consisted in excavating the marl rock to create successive pools on two fish-pass branches. For this reason, the scope of the radio-tracking study performed in 2019 also included the Les Madeleines weir in order to estimate the probable gain provided by these works on the migration of the salmon. Nonetheless, for reasons of concision, the results specific to the Les Madeleines weir are not detailed in this document. Further details concerning this study and the results specific to the Les Madeleines weir can be found in the report dated 2020(4) (SCIMABIO Interface).

THE REACH STUDIED

On the River Allier, the study area extends from the Vichy dam downstream (the salmon trapping and tagging area) until immediately upstream (+/- 1 km) of the Les Madeleines weir. The reach studied on the Allier is approximately 53 km long (Figure 14). As from Pont du Château, the monitoring of the tagged fish was carried out by LOGRAMI.

The Dore is also included in the study area, from its confluence with the Allier until the Pont de Dorat DREAL hydrological station (a reach of approximately 21 km).

Within this area, attention was particularly focussed on a more limited sector with a network of several fixed monitoring stations. This sector extends from downstream of the

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[1] *L’Office français de la biodiversité (French Biodiversity Agency)*

[2] *Loire Grands Migrateurs / Departmental federation of authorised fishing and aquatic habitat protection associations / Salmon Protection Asssociation / National Preservation Centre for Wild Salmon.*

Figure 11 : Photographs of salmon transiting the Vichy fish pass (©SCIMABIO Interface, 2019).

Figure 12 : Photograph of Weir A89 (ROE 63404) before works. ©Vinci Autoroutes

Figure 13 : 3D model of the asymmetric fish ramp. Photographs of Weir A89 after adjustment in 2 distinct periods. ©Vinci Autoroutes

Joze weir to upstream of the Les Madeleines weir, i.e., a reach of approximately 7 km.

A CAPTURE AND HANDLING SYSTEM APPROPRIATE FOR ATLANTIC SALMON

The salmon capture system is situated at Vichy (Allier department) on the right bank of the Allier River. The salmon are obliged to use the fish pass to cross the bridge-dam and are caught in the trap, which is positioned at the exit of the fish pass (Figure 15).

After capture, the salmon are handled in accordance with the various steps presented in Figure 16. The fish is first of all transferred to the holding tank of the handling and tagging unit, which was previously filled with water. The fish is next guided into the anesthetising bath, prepared using a solution of essential oil of cloves that is diluted in the water of the tank to obtain a final concentration that is appropriate for anesthetising the species. Once it is asleep, the handling of the salmon starts with a precise description of the health status and size of the fish.

The following step is the intragastric tagging of the salmon: the emitter is introduced through the mouth then placed directly in the stomach of the fish by means of a double plastic plunger tube. The emitters used measured 50 mm long with a diameter of 19 mm. Their sheathed antenna was about thirty centimetres long. Weighing 24 g, they had a lifespan of approximately 430 days with emission frequencies between 49 and 49.9 MHz. The weight of these emitters was less than 1% of that of the fish to avoid any behavioural disturbance of the salmon(5).

The fish is then placed in a dark recovery tank directly in the Allier and leaves of its own accord after it wakes up.

The protocol set up respected all the regulations in force in terms of capturing and tagging animals for scientific purposes. The salmon were captured in compliance with prefectural decree 3570/2018. The tagging protocol was validated by the Lyon CECCAPP ethics committee and performed by authorised operators, and the project received Research Ministry authorisation, reference number 18567.

ATLANTIC SALMON TAGGED AND MONITORED DURING THE STUDY

During the study, 25 salmon were captured, 24 of which were tagged. One individual whose health status was very worrying was released without being tagged, in compliance with the commitments of the protocol. It should be noted

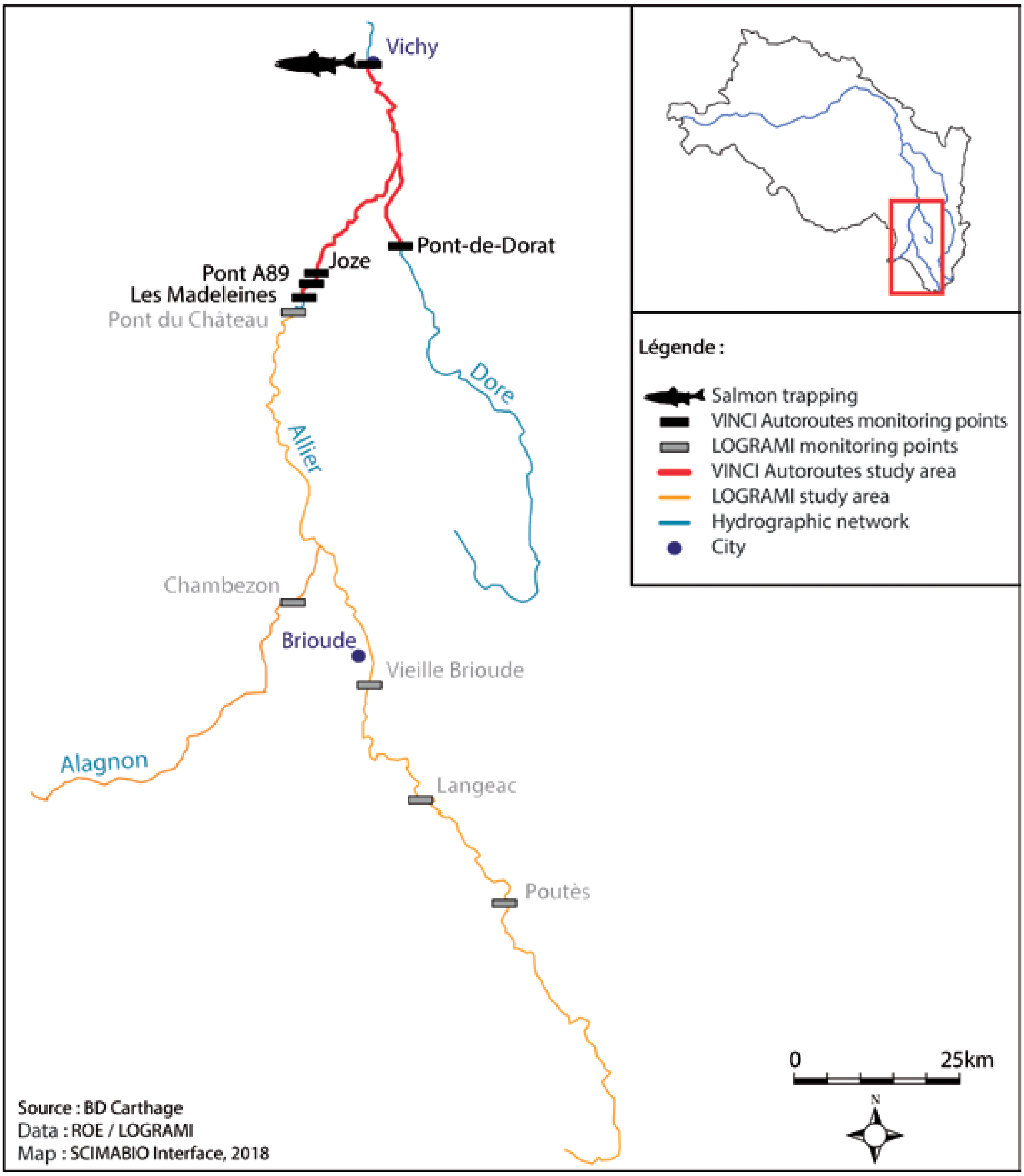

Figure 14 : Area of the 2019 monitoring of salmon by radio-tracking in the drainage basin of the Allier (box).

that 374 adult salmon on upstream migration were counted at the Vichy video-count station by LOGRAMI in 2019 (Figure 17).

The trapping campaign started 26 March 2019. The vast majority of the passages at Vichy took place between late March and early June when the temperature of the water was less than 20°C (Figure 18). The peak of the upstream run correlates with the only major increase in discharge on 26 and 27 April, when 70 salmon passed through in 48 hours.

The majority of the tagged fish (54%) had a health status categorised as medium, as compared to 28% categorised as very satisfactory or satisfactory (Figure 19 left). The age distribution of the tagged salmon was 58% three summers and 42% two summers (Figure 19 right).

Finally, the total length of the tagged fish varied

Figure 15 : Trap for capturing salmon set up in the exit of the fish pass on the right bank of the Allier at Vichy (Photos SCIMABIO Interface)

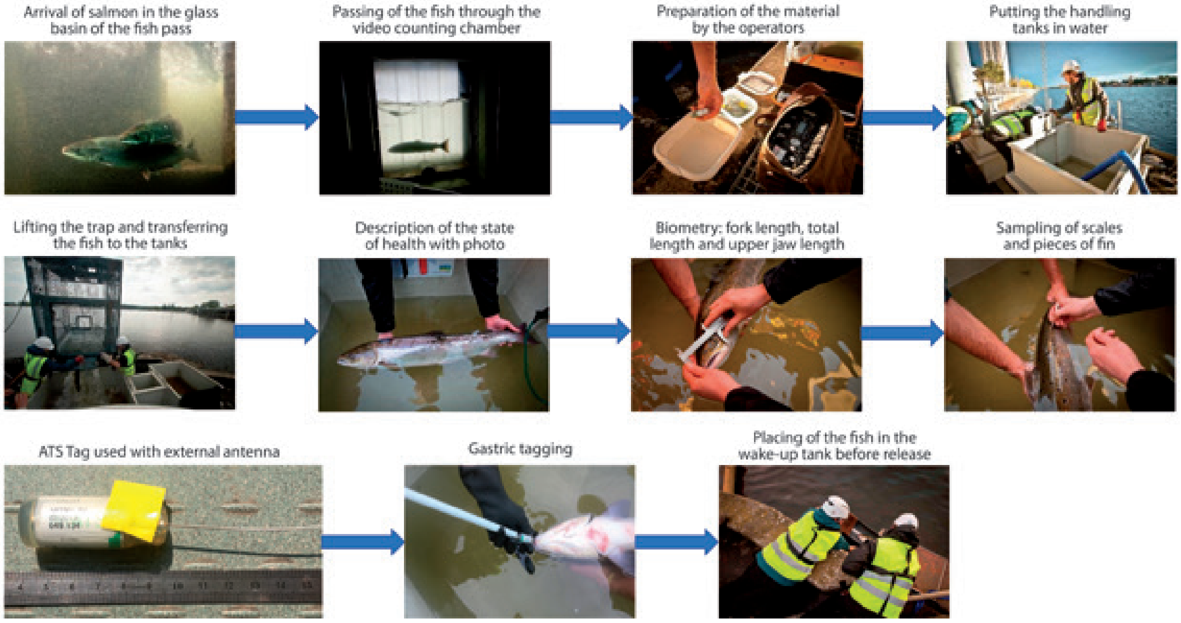

Figure 16 : Illustration of the entire salmon capture and tagging protocol used at the Vichy trap. (©SCIMABIO Interface, 2019).

from 70 à 104 cm with a majority of individuals in size categories 90-95 cm then 75-80 cm (Figure 20).

ENVIRONMENTAL MONITORING CONDITIONS

The hydrological conditions globally showed low to very low discharges almost throughout the 2019 migration season. The discharges observed were systematically below mean discharges for the whole year, particularly during the tagging and monitoring period (Figure 21).

Concerning thermic conditions, the 2019 time series shows that optimum thermal conditions for the migration of Atlantic Salmon were obtained on the Allier during quite short periods during the monitoring, from late March to late May, then early October to early November. For four months, from early June to early October, the

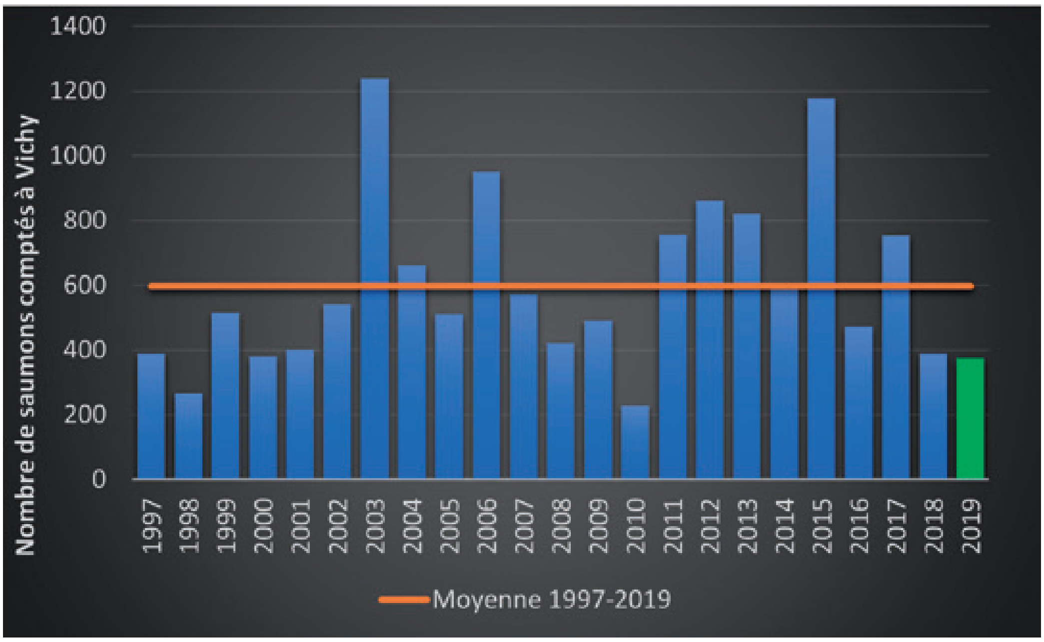

Figure 17: Time series of the number of salmon video-counted at Vichy (data LOGRAMI).

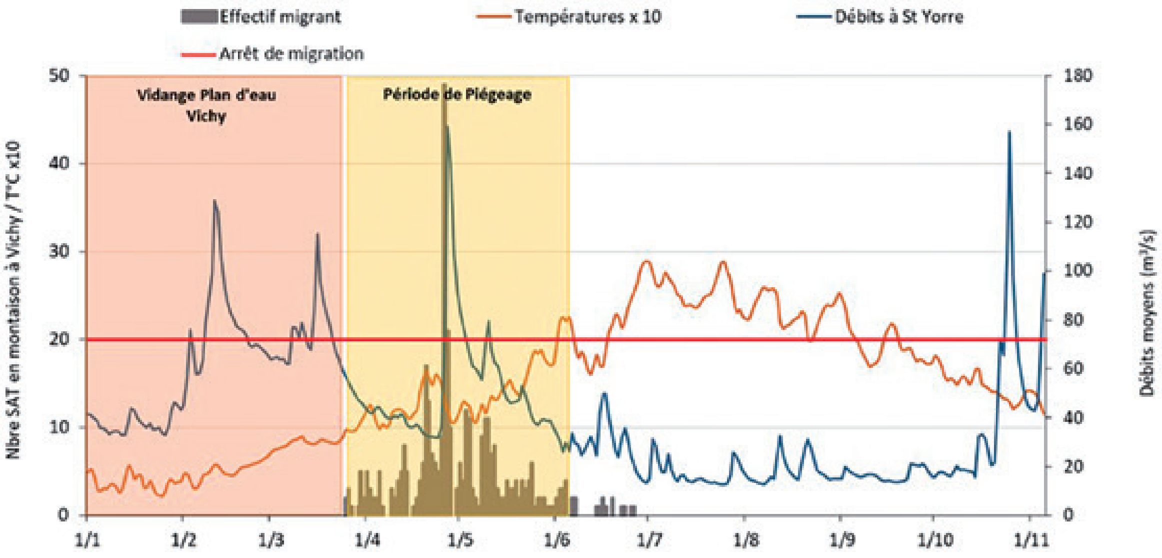

Figure 18 : Distribution over time of migrant salmon numbers at Vichy in 2019 related to discharges and water temperatures (data LOGRAMI and banque HYDRO).

temperatures of the water exceeded 20°C, which is considered to be the migration-stopping threshold (6,7).

During the course of the year, for two consecutive months from mid-June to mid-August, the temperatures of the water exceeded the critical values for the survival of the salmon and for several days even reached values considered as lethal for the species (Figure 22). .

A MONITORING SYSTEM APPROPRIATE TO THE STUDY AREA AND THE GENERAL RESEARCH QUESTIONS

The monitoring system set up in the study area above all consisted of 7 fixed stations managed by SCIMABIO Interface and FDPPMA63 plus the Vichy fixed station downstream set up and managed by LOGRAMI (Figure 23).

Each fixed station consisted of an ATS 4500S radio receiver-recorder, connected to an aerial loop antenna. For stations without existing security provisions, the equipment was protected by means of a waterproof and tamper-proof metallic case that was buried in order to hide it (Figure 24).

The receiver-recorders were programmed to scan the emitter frequencies with a scan time of 3 seconds. When a radio-tagged salmon entered a detection zone, the signal was detected by the receiver, which automatically logged the date, time (UTC), number of detections and strength of the signal.

The 8 fixed stations situated in the study area functioned throughout the whole duration of the monitoring without any major interruption. For the 4 stations monitoring the A89 and Les Madeleines weirs, the proximity of the antennae upstream and downstream of the weirs enabled a detection efficiency to be calculated for each station: this detection efficiency was between 93 and 100%, depending on the station concerned.

In addition to the fixed monitoring system, mobile surveys were added (by vehicle, on foot or by canoe, Figure 25) to monitor the movement of the fish between the areas covered by the fixed antennae. The mobile surveys were performed 2 or 3 times per week in the study area between the start of monitoring and 15 July.

The surveys were above all carried out in the sector between Vichy upstream and Joze downstream, in order to identify the position and status of the tagged salmon present in this reach of approximately 45 km with no fixed monitoring station.

The aim of the methodological design thus applied was respond to the following questions:

- Evaluation of any possible blocking effect of Weir A89 that could cause a migration delay for the salmon;
- Evaluation of the times taken to cross Weir A89 and comparison of these times with those already obtained in 2009 during a specific study (before adjustment of the weir);
- Comparison of calculated migration times between a control stretch without any

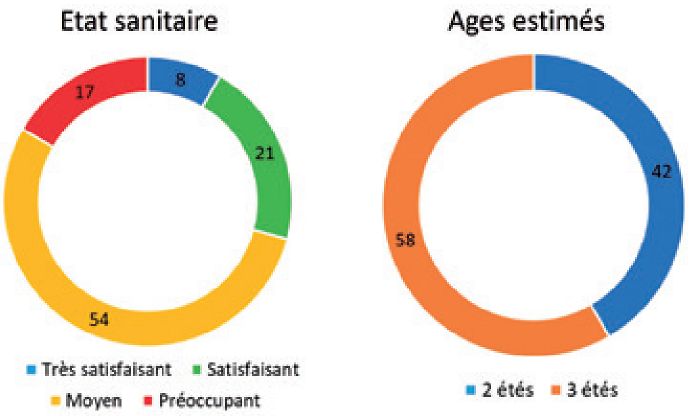

Figure 19: Health status of the salmon trapped and tagged at Vichy in the course of the study (left) and estimated ages by the size/age ratio (Bach et al. 2016) of the same individuals.

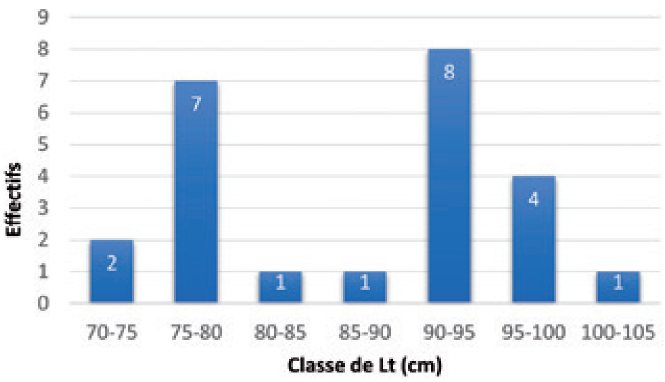

Figure 20: Distribution by size category of the salmon tagged in 2019.

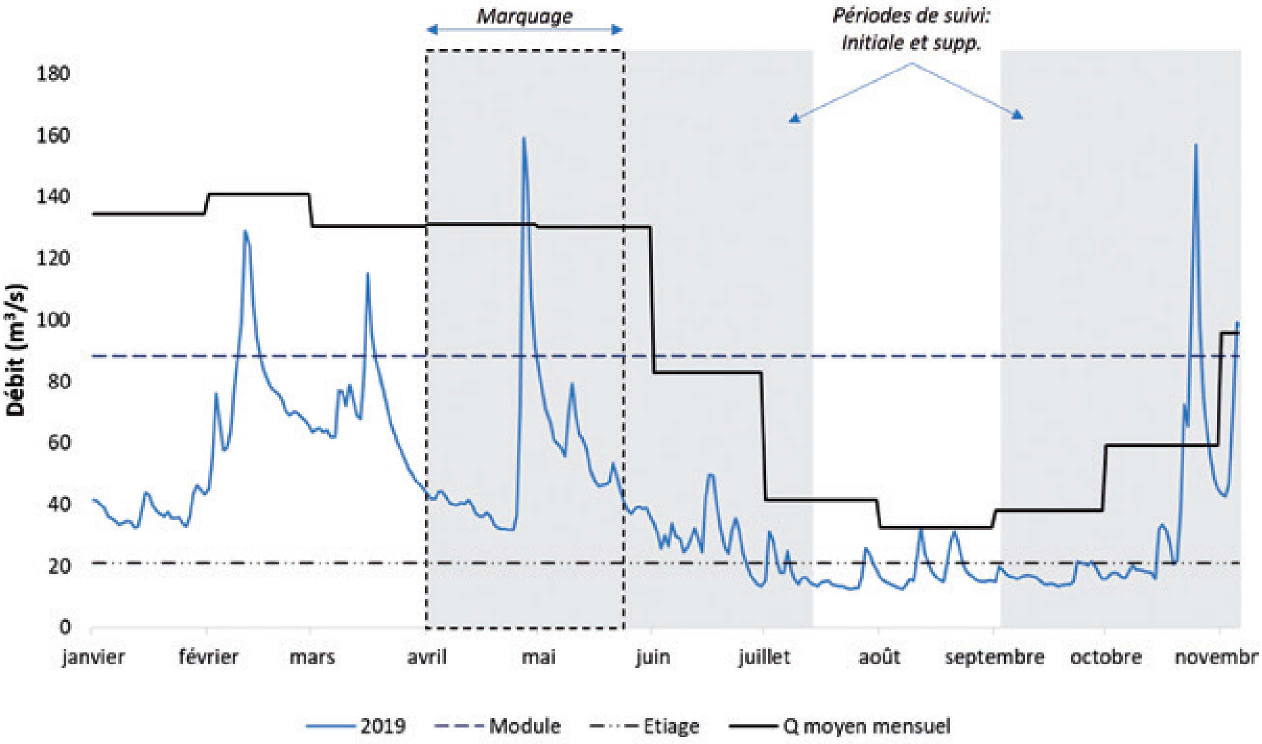

Figure 21 : Mean daily discharges of the Allier in 2019 recorded at Saint-Yorre and statistics characteristics of discharges (modulus, low water level, mean monthly Q).

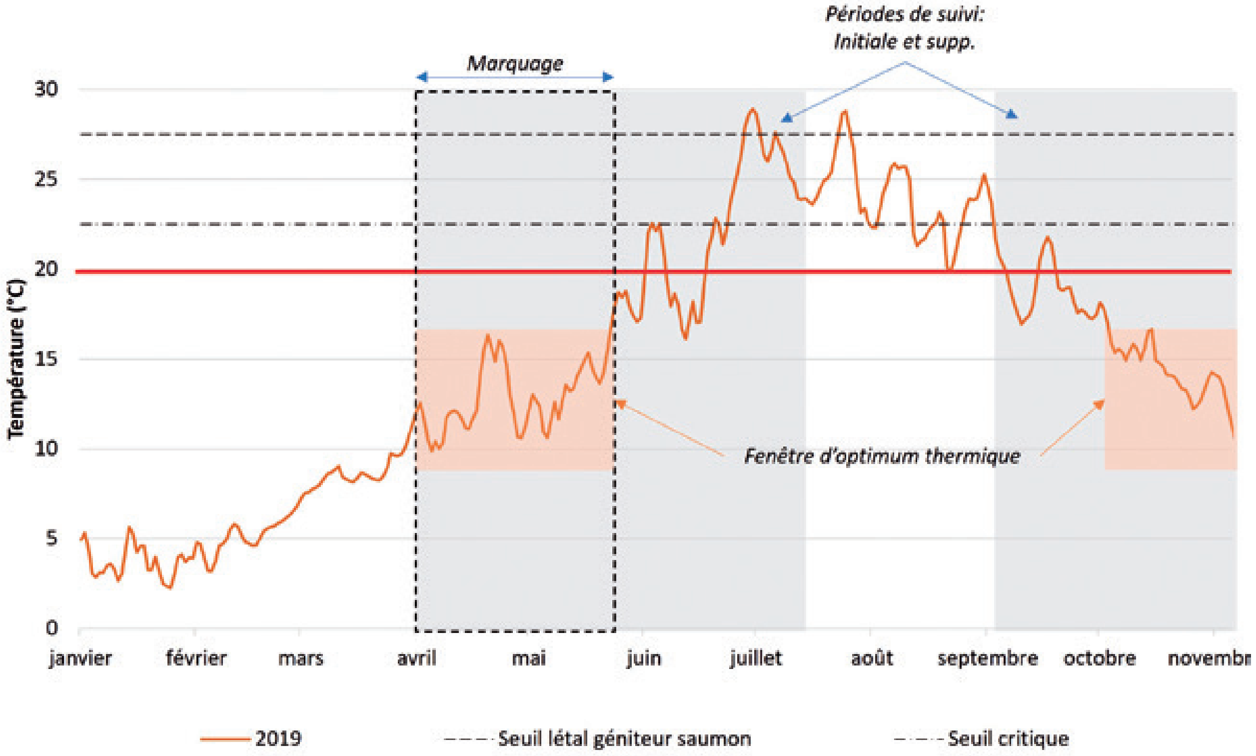

Figure 22 : Mean daily temperatures of the Allier at Vichy in 2019 related to the ecologic requirements of the Atlantic Salmon.

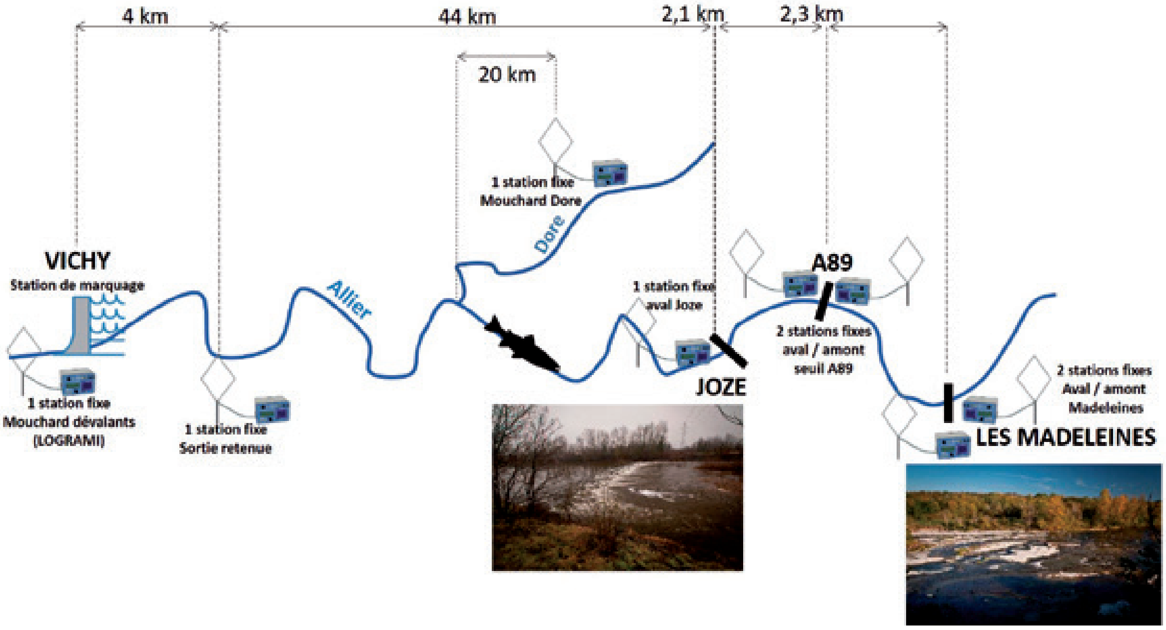

Figure 23 : Set-up diagram of the 7 fixed "Vinci autoroutes" monitoring stations positioned in the study area + the LOGRAMI downstream Vichy station.

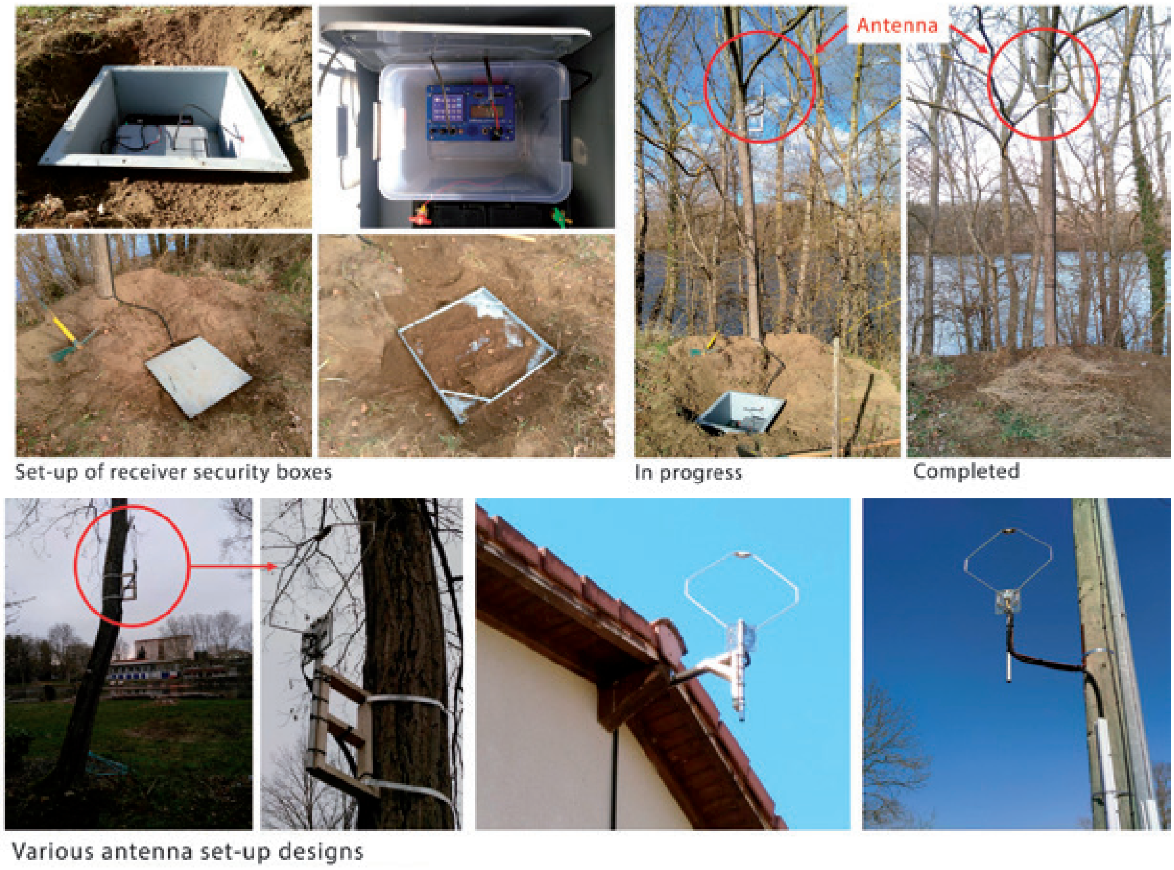

Figure 24 : Photos of examples of fixed station and antenna set-ups.

Figure 25: Photos of mobile surveys on foot and by canoe.

Trapping period:	26 March - 26 May 2019
Effective number of trapping days:	10
Monitoring period (2019):	26 March - 15 July 05 September - 5 November
Complete mobile tracking by boat:	mid-July mid-September
Nb AS trapped:	25
Nb AS tagged:	24
Nb of AS detected at Weir A89:	13 (54% of total number)
Nb of AS on upstream migration in the study area:	11
Nb of AS lost / dead in the study area (from 26/3 to 5/11/2019):	13

Table 1: Key Information concerning the salmon tagging and monitoring operations to study the passage through the A89 and Les Madeleines weirs.

structures (upstream of Vichy dam to downstream of Joze) and a stretch with adjusted structures (downstream of Joze to upstream of Les Madeleines);

- Identification of preferential discharge/temperature categories for passing through.

PRINCIPAL RESULT

The important key figures to bear in mind are summarised in Table 1. The analysis of migration behaviours on the study sector and the passage of Weir A89 was performed on the basis of the 13 individuals out of the 24 tagged that continued their migration after tagging until Weir A89.

Characterisation of the salmon that passed through Weir A89

Statistically, these 13 individuals were no different from the 11 other tagged salmon, whether considering their age, their size, their health status or the temperature of the water at the moment of release.

Migration behaviour in the study area

The 13 passages of Weir A89 were spread over a month and a half between 17 April and 1st June 2019.

The 13 salmon made a rapid post-tagging departure from the recovery tank and did not turn back on the 45 km between the release point and the Joze weir. Similarly, all the fish that arrived at Joze crossed all the structures in the area (Joze, A89 and Les Madeleines) without turning back.

Speed of passage of the weirs

The estimated passage speeds at Weir A89 showed high variability between individuals as the estimated speeds varied between 0.1 km/h for the slowest individual and 1.8 km/h for the fastest individual (mean=0.7 km/h, SD=0.49, Figure 26).

The passage times for Weir A89 were relatively short with a mean of 1:30.

Migration speed compared between the sectors with and without hydraulic structures and between 2009 and 2019

The migration speeds between the sector without hydraulic structures (upstream of Vichy dam to downstream of Joze) and the sector with structures (downstream of Joze to upstream of Les Madeleines) are comparable (Figure 27) with mean speeds of the 0.34 and 0.38 km/h respectively (Kruskal-Wallis $p<0.01$).

The migration speeds calculated for the whole sector with structures showed lower values than the speeds calculated per structure. This result is linked to the behaviour of the salmon, which tend to stay temporarily near the head of the apron just after the structures. This phenomenon had already been observed in 2009.

Discharge and temperature conditions during passages

Passages were observed for a heterogeneous range of discharges between 20 and 110 m^3/s (Figure 28). The discharge therefore seems to have little influence on the passage of the A89 structure.

Concerning temperatures, passages were observed at values between 10 and 17°C. These results confirm the data reported in the literature which indicate a significant slowing of migration above 18°C (Figure 28): 70% of the passages took place at temperatures less than 14°C.

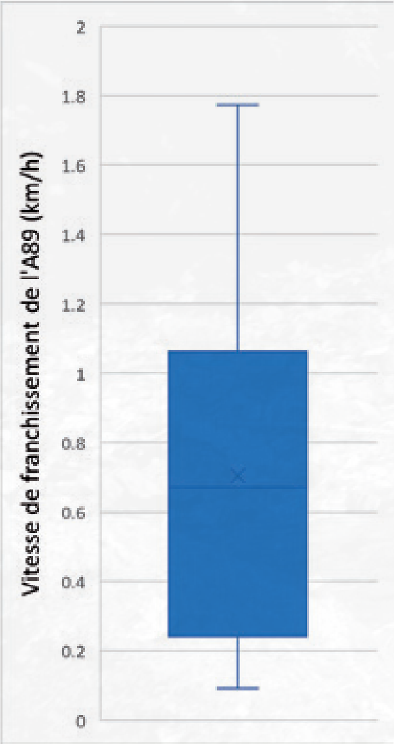

Figure 26 : Boxplot of estimated passage speeds at Weir A89.

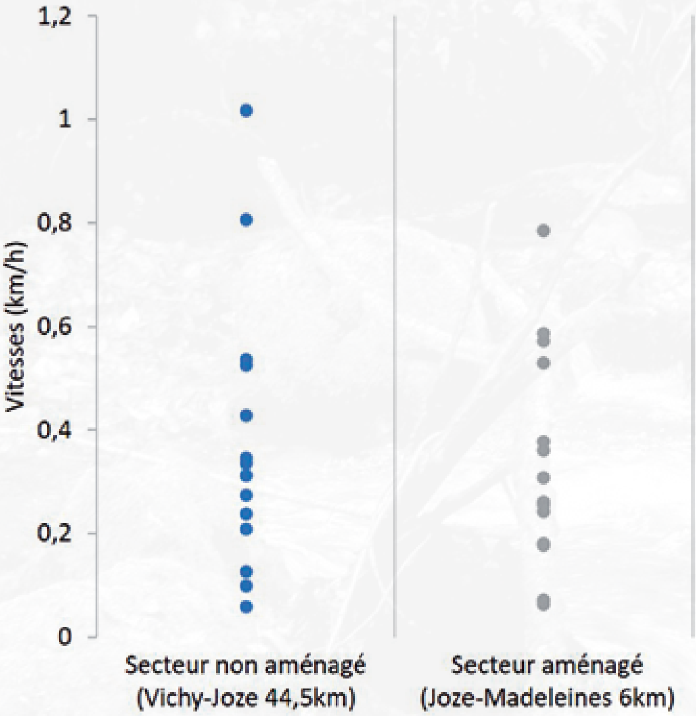

Figure 27 : Distribution of the individual migration speeds of obtained on the sectors with and without hydraulic structures for the 14 salmon detected.

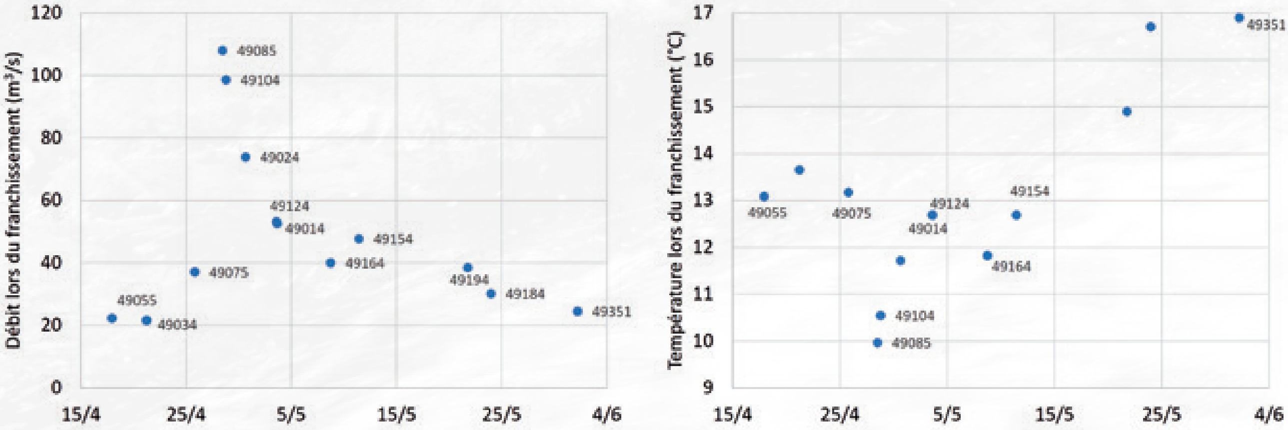

Figure 28 : Discharge and temperature conditions observed during the 13 passages observed at Weir A89.

CONCLUSIONS AND RESPONSES PROVIDED BY THE STUDY

Despite the hydroclimatic conditions and unfavourable migration numbers, it was possible to meet the objectives of the project in terms of the number of salmon tagged, and also in terms of the representativity of the tagged batch with respect to the total migrant batch.

In parallel, this monitoring needed to overcome several technical challenges including, in particular the setting up of 4 isolated fixed stations in the wild, high exposure to the risk of vandalism and a requirement concerning the coverage of the detection zones for Weir A89.

The radio-tracking monitoring of the 24 salmon in 2019 was marked by globally low hydrology, this hydrology being interesting with regard to the objectives of the monitoring because it enabled us to assess the passages of Weir A89 under limiting conditions. Temperatures corresponded to mean conditions currently encountered by the salmon.

The results of the monitoring are within a particular local context that should be correctly understood in order to interpret them. This context is characterised firstly by the long distance from the sea to the study area (the trapped salmon had already consumed a large amount of energy migrating, their external health status was degraded, which is partly and explained by the long journey they had already made). This particular context is also a result of the location of the trapping/tagging station in the Allier basin. Indeed, the Vichy station is situated in an area of plains, marked by a rapid increase in spring water temperatures. The salmon were thus tagged at the high end of the range of comfortable temperatures for the species and moreover released in the backwater of the structure (backwater more than 5 linear km), potentially accentuating the disturbance effect linked to handling. Finally, we should mention that the Vichy trapping system is not optimal in terms of efficiency. It leads to pronounced hesitation among some salmon and consequently causes them to go back and forth numerous times, increasing the delay effect frequently induced by this type of structure.

Out of the 24 salmon tagged, 14 migrated in the whole study area and therefore enabled analysis of the passage through the structures. Concerning Weir A89, 13 individuals were detected and passed through the structure.

The mean estimated passage speeds for Weir A89 showed no delay effect, thus providing clear elements of a response regarding the reglementary obligation (reduction of the delay effect). No blockage was detected at the foot of the structure.

The same observation was established by comparing speeds between the sector with hydraulic structures (approximately 10 linear km) and the sector without structures (approximately 50 linear km).

In addition to mean values, this monitoring, as could be expected, highlighted different behavioural patterns. The variability of these patterns was expressed both between sectors with or without structures and within the batch of tagged individuals. While this variability shows that not all the salmon negotiated the passage of Weir A89 in the same way, it does not call into question the conclusions of the monitoring regarding the post-adjustment elimination of the delay effect.

In terms of strict longitudinal continuity, in the studied sector, the results of the 2019 radio-tracking monitoring seem to show favourable migration conditions for the salmon, without any notable delay effect due to the transversal structures studied (other than behavioural singularities of certain individuals).

We gratefully acknowledge the Puy-de-Dôme DDT, Allier DDT, interregional division and eco-hydraulic unit of the OFB, Bassin DREAL, CNSS, APS, CEN Auvergne, Artière ASA and the Beau Rivage campsite.

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EXPLANATION BOX N°2:

Monitoring by radio-tracking (or radiotelemetry) is based on the utilisation of active tags emitting a radio signal, whose frequency varies from 30 to 200 MHz, which are detected and recorded by a receiver. The radio emitters are fitted with an internal battery. Their lifespan is consequently limited, varying from a few weeks to several years in function of the settings and the type of emitter used.

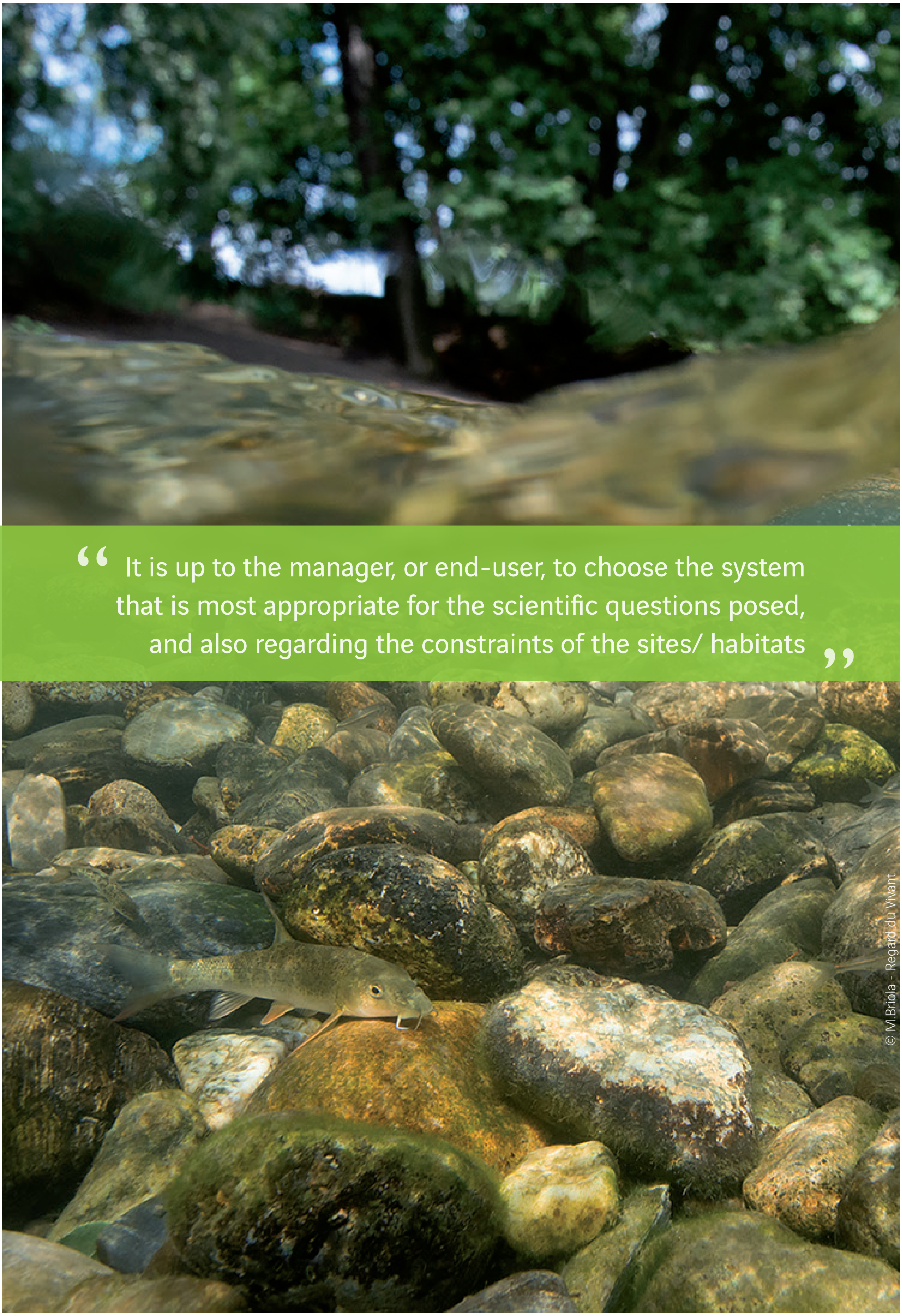
Illustration 3 : Intragastric (left), surgical (centre) and dorsal (right) implantation of active emitters.

The tagging of the fish by means of radio emitters can be achieved in three ways (Illustration 3): intragastric insertion, external attachment to the back of the fish or surgical implantation in the abdominal cavity.
Each emitter is characterised by its own frequency (uncoded emitter) or by a unique identity code (coded emitter), enabling the identification of tagged individuals within the detection range of the receivers.
The receivers can be fitted with one or more aerial or submerged antennae (Illustration 4). They can be used automatically to equip a fixed monitoring station or manually to carry out mobile surveys.

Mobile radio tracking, also called telemetric monitoring, can be carried out on foot or from a boat, vehicle or plane.

Illustration 4 : Examples of fixed and mobile radio-tracking monitoring devices.

In practice, the signal is detected in the form of sound beeps audible to the operator. It is generally first sought using a non-directional antenna then, once the signal has been detected, using a directional antenna, enabling the direction of the source of the signal to be determined and its location to be estimated with variable levels of precision by means of triangulation.
The movements of the tagged individuals are retraced from their successive positions recorded by the fixed stations or mobile devices. Given the long detection ranges concerned (up to several hundred metres), radio-tracking enables fish movements to be monitored on large spatial scales. Its applications include in particular the study of migration patterns, the utilisation of habitats or passage through hydraulic structures.



> “It is up to the manager, or end-user, to choose the system that is most appropriate for the scientific questions posed, and also regarding the constraints of the sites/ habitats”

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III. METHODS APPLIED TO THE MONITORING OF ECOLOGICAL CONTINUITY RESTORATION

INTRODUCTION AND CONTEXT

"Ecological continuity ensures the passage of fish and sediments through the river and other aquatic habitats. It can be interrupted by obstacles such as dams, which result in the disturbance of the transit of sediment and the circulation of aquatic organisms. In France, a strict ecological continuity restoration policy is being implemented to improve the situation, notably by the adjustment of certain structures." (Eaufrance.fr, public water information service, 2021)

The restoration of ecological continuity very often involves carrying out post-adjustment monitoring of structures to assess the efficiency of the measures taken by managers. To do so, several technologies and methods are available to judge the level of restoration resulting from the application of these measures. Indeed, it is now strongly recommended to apply these methods before and after reestablishment of continuity better to assess the biological gains.

Each of these methods responds to precise questions, in particular by including various spatio-temporal scales. Consequently, good knowledge of the conditions and limits of application of these methods is an indispensable prerequisite for defining monitoring protocols, which need to be appropriate to the site studied, and also to the ecological and economic issues of the local area.

In this chapter, we present the methods that can be applied to the monitoring of ecological restoration, mainly for the aquatic environment, although certain of them may also be used to respond to questions specific to terrestrial continuity. The advantages/disadvantages of these methods will be specified at the end of the chapter so that the reader will be able to target the one(s) appropriate the issue concerned.

CONTRIBUTION OF PASSIVE TRACKING OR RFID

RFID (Radio Frequency Identification) has been used since the mid-1980s to study the behaviour of animal populations, well as for the identification of domestic or farm animals (Smyth and Nebel 2013). The principle consists of communication between an electronic chip (called a transponder or PIT tag) implanted in an animal and a reader-receiver which generates a low-frequency magnetic field (134.4 kHz) transiting in an antenna (Figure 29). When a PIT tag comes close to the functioning antenna, it stores the energy and returns it in the form of an individual alphanumerical signal which is received by the antenna and recorded by the reader-receiver. Every passage of a tagged individual is therefore detected, its individual identity code is recorded, the date and time of the datum are recorded then sent to a remote server (see the explanation box in the chapter "Monitoring by RFID technology").In particular, RFID can measure the effectiveness of fishway structures developed on rivers (fish passes, culverts, ramps..., Figure 30) and more broadly to assess the ecological continuity of rivers in which fish migration is likely of be hindered by natural sills or human developments that are difficult to cross. Set up in fish passes (Figure 31), RFID systems can show the efficiency of these developments by providing quantitative information on their attractivity, accessibility and passage capacity, in function of fish species and size category, as well as passage times. In riverbeds, the application of this technology provides information on the behaviour of the fish and the dynamics of populations subjected to various stress factors (fragmentation, hydrology, temperature, prevalence of diseases...). Moreover, the use of 12-mm chips enables the tagging of fish fry or species as small as 55 mm (Richard *et al*. 2013; Vatland and Caudron 2015).

Applications to other fauna groups, both aquatic and terrestrial, are made possible by the miniaturisation of the PIT tags. RFID has been particularly successfully used to assess the effectiveness of under- and over-passes for various species of amphibians, or to measure the movements of certain insects (Testud *et al*. 2019). Detection is either ensured by fixed antennae, or by mobile antennae moved by an operator, in particular to locate resident individuals and better characterise the migratory fraction of the population together with movement distances. The low cost of PIT tags (approximately 2€) and their ease of implantation enables the tagging of several hundred individuals to be envisaged, thus ensuring a good level of statistical robustness for the trends observed at the scale of the studied population.

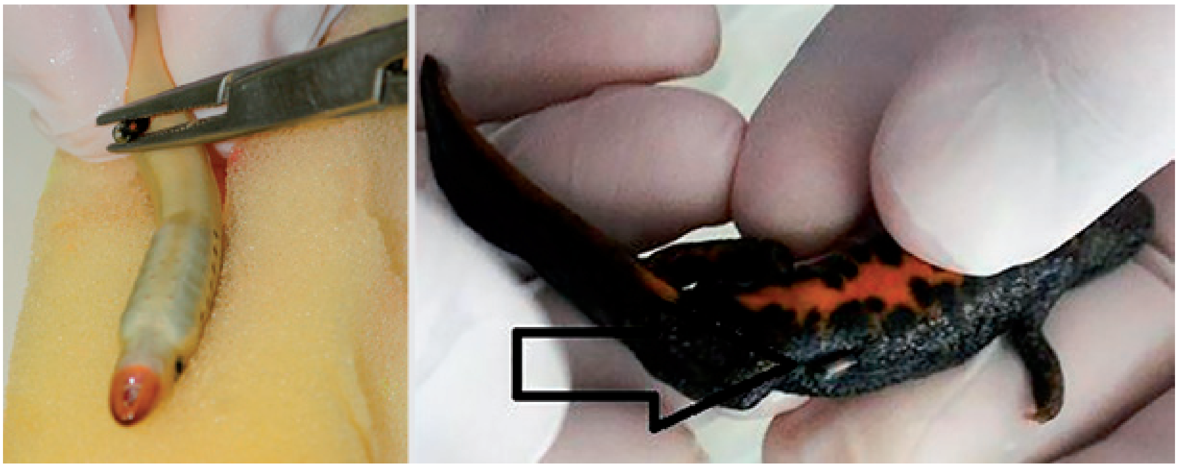


Figure 29: Implantation of a 12-mm PIT in a 13-cm Brook Lamprey (SCIMABIO Interface) and a 10-cm newt (Weber et al. 2019).

Figure 30: Examples of structures whose effectiveness can be assessed by RFID: amphibian underpass (Testud et al. 2019), flow culvert (SCIMABIO Interface study for ASF), fish pass (SCIMABIO Interface study)

Figure 31 : Examples of designs of RFID antennae set up in various habitats (SCIMABIO Interface studies, 2019-2021)

CONTRIBUTION OF ACTIVE TRACKING

As with "passive" RFID tracking, active tracking has been used since the early 1970s to study the movements and behaviour of animals in large habitats, whether terrestrial (forests, biological corridors …) or aquatic (large rivers or lakes) (DeCelles and Zemeckis 2014; North and Reynolds 1996; Julien Bergé 2012). This technology nonetheless differs from passive tracking in that it uses active emitters, i.e., powered by one or more batteries, (Figure 32) which provides longer detection ranges (up to several kilometres), but also limits the life span of the emitters (depending on the life span of the battery).

Active tracking encompasses three principal technologies:

- Acoustic tracking: commonly used in all aquatic habitats, whether freshwater, marine or brackish, where the acoustic signal can travel relatively long distances (< 1km). The emitters function by emitting an ultrasound impulse, with a frequency between 30 and ~300 kHz (Thorsteinsson 2002; Ehrenberg and Steig 2002), which is detected by a hydrophone or acoustic receiver. The distance at which an emitter can be detected depends on its power and frequency, as well as the characteristics of the environment. The detection radius of an acoustic emitter can be affected by a certain number of factors, such as the physical properties of the water, the settings of the detection system or indeed the topography of the riverbed or seabed (Cotton 2010; J. Bergé *et al.* 2011).
- Radio-tracking is preferable in shallow freshwater habitats, where radio signals are capable of travelling greater distances than acoustic signals (Thorsteinsson 2002; Bain 2005). The fish are fitted with a radio emitter and a wire antenna that relays the radio signal. The radio signal propagates through shallow water and in the air, where it can be detected by a receiver based on land or fixed to a plane or boat.
- GPS tracking, a more recent and complex technology than the first two, is appropriate for very large habitats (oceans, big lakes) that cannot be equipped with conventional receivers. The emitters used send the position of the animal using the satellite system, and their size and heavy weight means that they are used with large animals. For example, this technology is used for monitoring the movement of large land animals (pumas , bears …) (Wang, Smith, and Wilmers 2017; Baubet *et al.* 2004) or aquatic animals (whales, sharks …)(Trudelle 2016; Bonnin 2019).

Active tracking systems, especially radio and acoustic systems, can be set up next to structures hindering ecological continuity, notably for fish, in order to qualify and quantify the impact of the obstacle on the longitudinal movement of the studied animals (Figure 33). In the same way, these systems can be used to equip modified structures (whether removed or adjusted to improve their effectiveness) in order to verify their hydraulic transparency.

Generally, it is preferable to use these active technologies, which are costlier than passive RFID systems, when the passageways in the structure are large or numerous, or when investigating the movements of animals in long reaches of river, i.e., outside the narrow field of interaction of the structure with the animals' movements.

It should also be borne in mind that these active technologies can respond to diverse ecological questions including ones that are complementary to those covered by RFID technology and that their utilisation requires greater command of their technology or their operating limits. In general tracking, whether active or passive, requires the intervention of qualified personnel, trained in how to use it, in order to optimise the quality of the expected ecological results.

Finally, in terms of regulations, it should be noted that the tagging of fish with transponders is covered by the 1 February 2013 inter-ministerial decree on the utilisation of wildlife for scientific purposes. The legislation imposes three things:

- Operators must receive specific veterinary training;
- The organisation responsible for the tagging must be an accredited "establishment using animals for scientific purposes";
- The protocol of the project must be

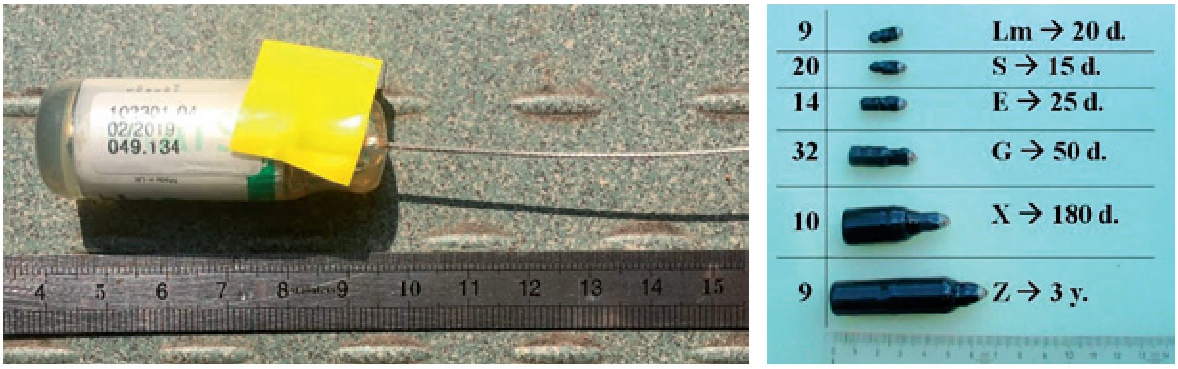


Figure 32 : Examples of emitters used in active tracking: left an ATS© emitter, right HTI© emitters.

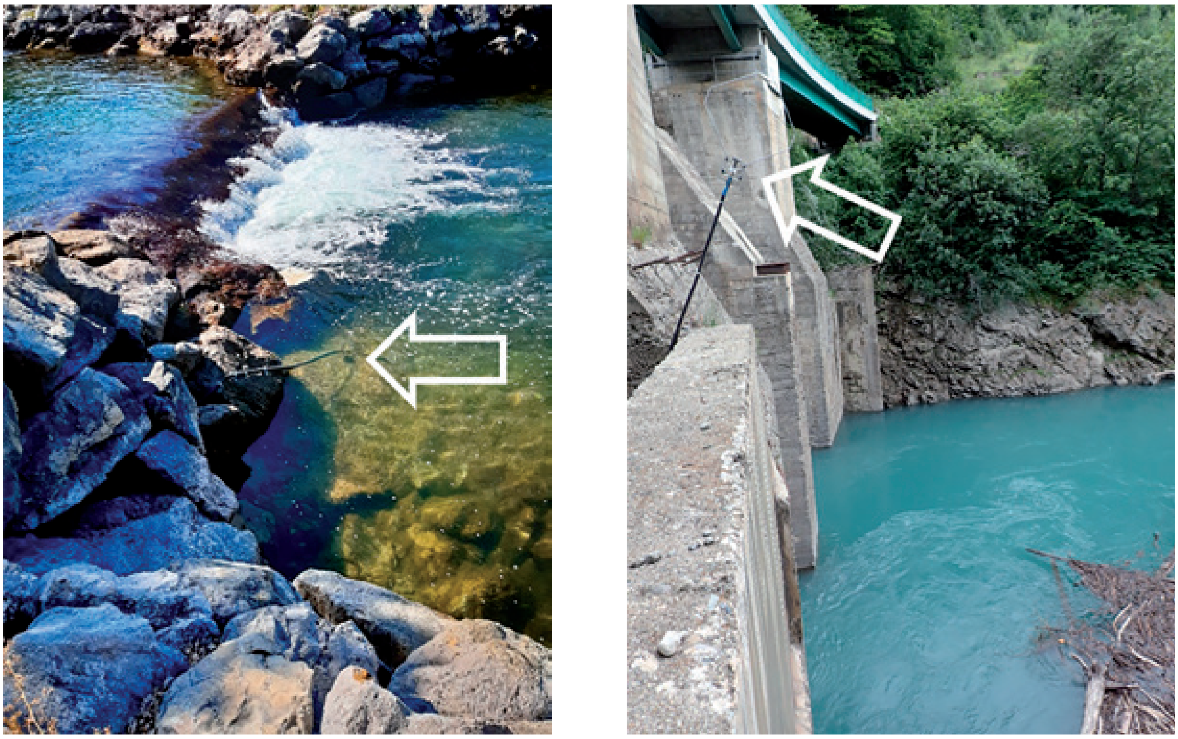


Figure 33 : Examples of set-ups of telemetric antennae on obstacles to ecological continuity. Left, an aquatic radio antenna; right, an aerial radio antenna. (SCIMABIO Interface, 2014-2021 studies.

authorised by the Ministry of Research after validation by an animal experimentation ethics committee.

UTILISATION OF VIDEO COUNTING SYSTEMS

The observation of fish migration flows through fish passes was developed in France as from the mid-1980s in order to obtain quantitative information on stocks of genitors of large migratory species, such as the Atlantic Salmon (*Salmo salar L.*), in large river basins such as the Loire, Dordogne or Seine (Larinier *et al.* 1994). Underground visualisation chambers fitted with a lateral observation window were developed to this effect (Figure 34), along with software solutions intended to reduce the processing time for the footage based on image processing algorithms (Dartiguelongue 2020).

With the multiplication of the number and above all types of fish passes set up in rivers, the needs regarding the application of video-counting tools have changed greatly since the 2010s. New hardware solutions have appeared, with the aim of providing waterproof, more compact and modulable tools so that they can be integrated more easily into fish-pass structures, including existing ones (Figure 35). The arrangement of the cameras, placed face-to-face and also staggered, enables great depths of water to be filmed despite their proximity to the channel of visualisation of the fish (Figure 36). In parallel, the continuous improvement in the performances of the computing and video acquisition tools has enhanced the quality of the images produced and optimising analysis times, in particular with the advent of artificial intelligence and deep learning (Figure 37).

Currently, the existing tools enable opportunities for using video counting to be greatly diversified, and it is now no longer limited to large structures present on big fish-migration rivers. Numerous recent applications have demonstrated the capacities of video counting to respond to operational questions such as assessing the passage capacity of fish passes (Lambremon and Campton 2018), in particular when several devices are set up in series on the same river, as on the Sèvre niortaise river (Abdallah, Vigier, and Der Mikaélian 2020) or the Somme.

In parallel, the quality of the images produced by the new tools enables valuable complementary information to be acquired, including the identification of small, rare species (such as the Rhone Streber, *Zingel asper*), the description of the fish’s external health status or even individual recognition of the fish (from the specific appearance of their skin or particular morphological signs). Finally, these images can be used for purposes of awareness-raising or communication in order to inform people about the fish populations living in our rivers and targeted by actions intended to protect them (firstly by adjusting the hydraulic structures).

UTILISATION OF FLOW ANALYSIS TOOLS

When studying fish populations, the possibility of acquiring quantitative data has always been a technical challenge. The same applies when investigating the passage capacity of an obstacle in a river (dam, weir, culvert, bridge apron ...), a subject in which knowledge of the passage flows of one or several species is central. The challenge is all the greater because the tools that can be used to acquire this knowledge must not result in any behavioural bias likely to distort the assessment. This state of affairs implies that direct capture techniques (for example with a net) cannot be used for this purpose.

It was therefore necessary to develop other, less intrusive, tools and make use of technologies enabling passage flows to be observed and counted without having to handle the fish (James 2016). Obviously, the fact of having to act under the water does not facilitate the task. Une of the major constraints encountered in subaquatic research is the turbidity of the water, which first of all greatly reduces the possibilities of using video cameras outside the context of fish passes. Starting from this constraint, the tools intended for studying fish flows can be separated into two groups:

1. Tools that are indifferent to (or very tolerant of) turbidity and therefore capable of working with a high level of depth of field: electrical resistivity counters, multibeam echosounders and acoustic imaging cameras;
1. Tools whose efficiency is directly linked to the turbidity, and which consequently require the cross-section of the fish passage to be greatly reduced in order to be able to count and identify them: video cameras and infrared scanners (see the video counting section).

Among the tools in Group 1, acoustic cameras are the ones that currently offer the greatest utilisation potential for counting fish flows in rivers (Figure 38). Indeed, resistivity counters, whose operating principle is based on the difference in conductivity between the water and the fish, have shown the limits of their application in the field. They involve the necessity of making the fish pass close to a succession of electrodes (utilisation impossible in large rivers) and cannot discriminate between the different

Figure 34 : Left, underground viewing chamber at Sauveterre on the Rhône (Compagnie Nationale du Rhône); right, underground viewing chamber at Poses on the right bank of the Seine (Voies Navigables de France).

Figure 35 : Set-up of a video counting system in an existing fish pass. Utilisation of solid deflectors to ensure the quality of the hydraulic intersection.

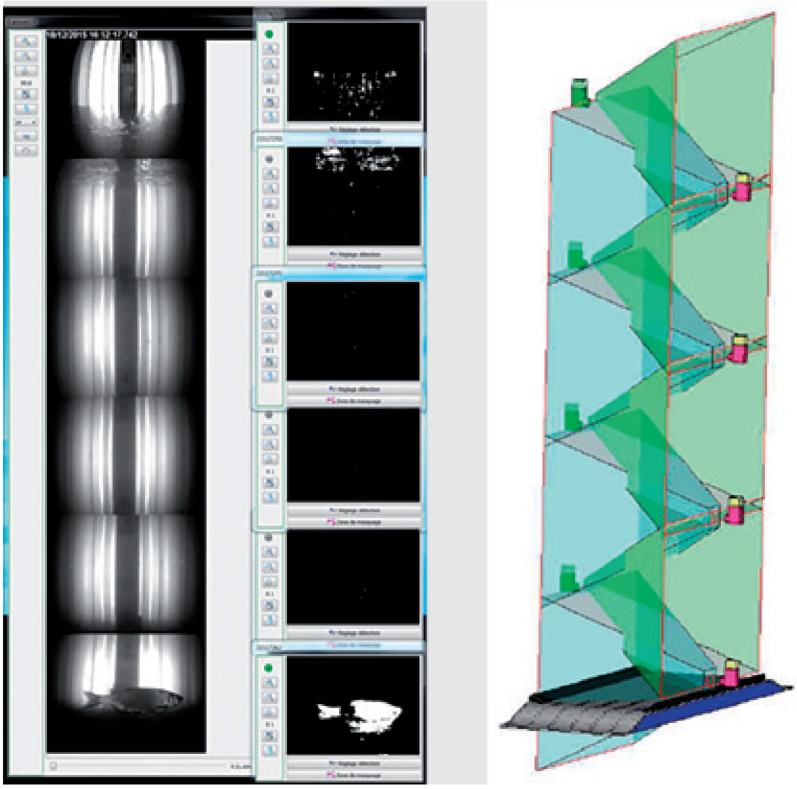
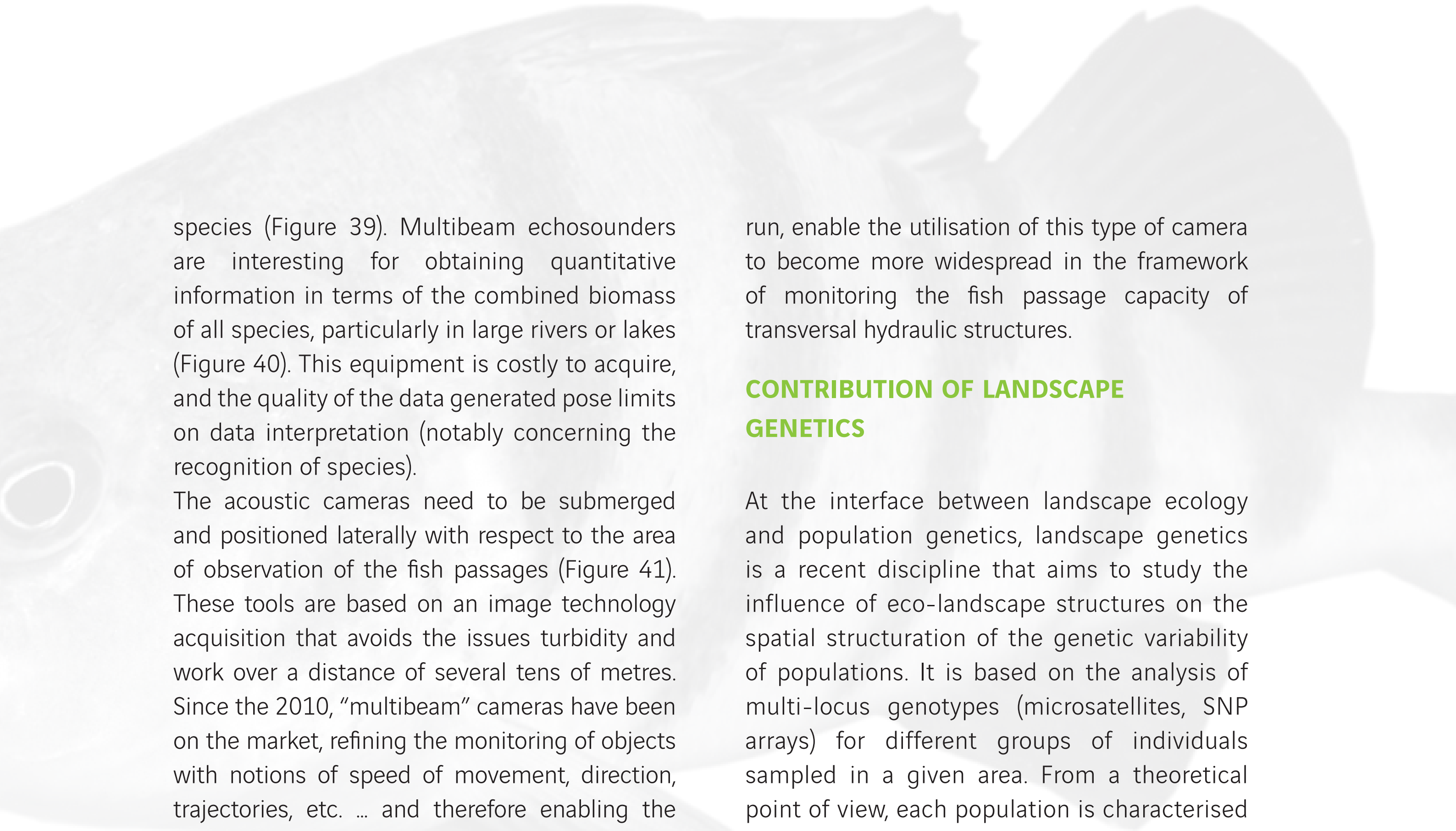


Figure 36: left, image reconstituted using a system consisting of 2 coffers opposite each other fitted with 4 cameras placed in a staggered arrangement filming a depth of water of 2.5 metres; right: 3D projection of the fields of view of each of the 8 cameras.

Figure 37: Examples of colour images produced by a video counting station set up on the Somme (SCIMABIO Interface – FDAAPPMA 80).



species (Figure 39). Multibeam echosounders are interesting for obtaining quantitative information in terms of the combined biomass of all species, particularly in large rivers or lakes (Figure 40). This equipment is costly to acquire, and the quality of the data generated pose limits on data interpretation (notably concerning the recognition of species).

The acoustic cameras need to be submerged and positioned laterally with respect to the area of observation of the fish passages (Figure 41). These tools are based on an image technology acquisition that avoids the issues turbidity and work over a distance of several tens of metres. Since the 2010, "multibeam" cameras have been on the market, refining the monitoring of objects with notions of speed of movement, direction, trajectories, etc. … and therefore enabling the description of behaviour (Martignac *et al.* 2015). Their frequencies have also increased, enabling finer reflection of sound waves and therefore a better depiction concerning the shape of the fish's body, and also the possibility of measuring the sizes of objects. Currently, the highest-performance cameras on the market have a maximum frequency of 3 MHz and offer, in certain conditions, the possibility of simultaneously observing passage flows and discriminating between the species present (Figure 42). However, at high frequency the camera's field of view is significantly reduced, which poses considerable constraints for acquiring exhaustive data on passage flows.Acoustic imaging cameras are therefore currently the most effective tool for obtaining quantitative data on fish passages, but they still come with numerous limits: the cost of acquisition (several tens of thousands of euros per unit), the difficulty of identifying species except by using high frequencies, and the lack of software for post-processing the images (and therefore very high analysis costs). Technological advances are underway that should, in the long run, enable the utilisation of this type of camera to become more widespread in the framework of monitoring the fish passage capacity of transversal hydraulic structures.

CONTRIBUTION OF LANDSCAPE GENETICS

At the interface between landscape ecology and population genetics, landscape genetics is a recent discipline that aims to study the influence of eco-landscape structures on the spatial structuration of the genetic variability of populations. It is based on the analysis of multi-locus genotypes (microsatellites, SNP arrays) for different groups of individuals sampled in a given area. From a theoretical point of view, each population is characterised by the collection and frequency of the genes it contains. When a population is not impacted by the presence of obstacles (dams, weirs, waterfalls …), the different groups of individuals analysed in an area tend to "resemble each other" due to the effect of inter-population genetic mixing (Figure 43). Conversely, the lack of gene flow inherent to ruptures in connectivity leads each population to evolve independently from a genetic point of view. Each group of individuals then accumulates specific genetic features: the presence of obstacles to fish mobility is thus revealed by the development of distinct genetic groups (Figure 43) (Raeymaekers *et al.* 2008; Neville, Dunham, and Peacock 2006; Torterotot *et al.* 2014).

By studying the existing populations in a given area, molecular tools therefore offer the possibility of assessing questions about migrations and gene flows, facilitating the identification of possible genetic discontinuities. Unlike traditional approaches, generally based on the *ad hoc* assessment of passages at the level of a hydraulic

Figure 38 : Examples of acoustic cameras used for monitoring migratory fish flows. From left to right, Oculus M1200d, Blue view M900-2250, Aris explorer 3000. Source: Soundmetrcs, Subsea.

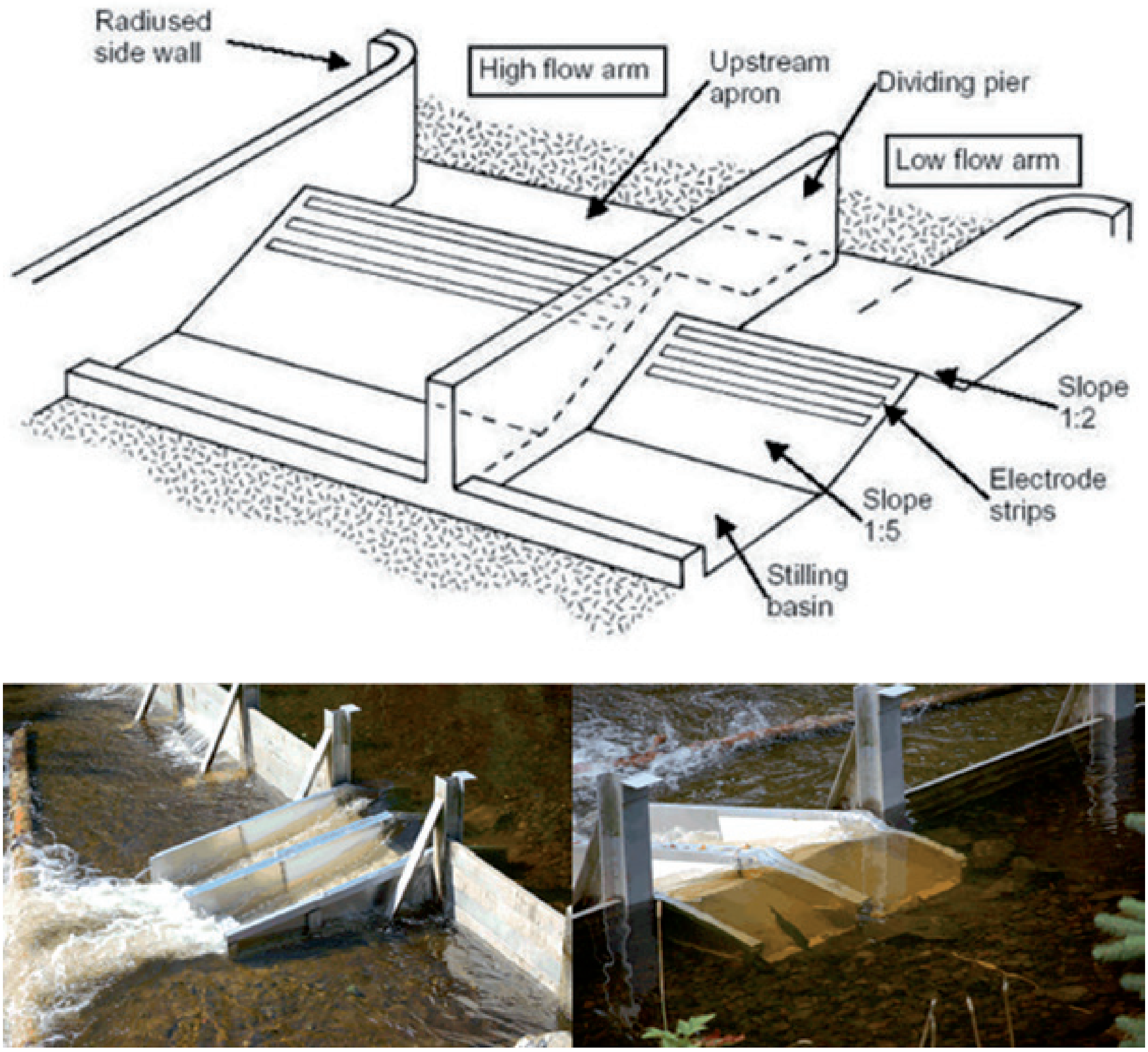


Figure 39 : Example of a resistivity counter used in a river (Diagram: Loughs Agency (2016); Photo: InStream Fisheries Research).

structure, genetic data have the advantage of evaluating the incidence of obstacles in the long term. They are therefore an integrative metric of population dynamics over time, reflecting the biological functioning of populations and enabling the precise identification of barriers to fish mobility.

UTILISATION OF ENVIRONMENTAL DNA

Environmental DNA (eDNA) can be defined as all the DNA that can be extracted from a sample taken in the environment (e.g., soil, water, sediment). Applied to aquatic habitats, this definition includes both the DNA of the microscopic organisms naturally living in the sampled habitat and the so-called "free" DNA released in various forms by the micro and macro-organisms in close contact with the habitat (e.g., dead cells, faeces or gametes). From a single environmental sample (Figure 44), eDNA therefore offers the possibility of non-invasive, large-scale investigation of a wide variety of biological groups that are sometimes little-known or difficult to observe using traditional approaches (e.g., bacteria, diatoms, macro-invertebrates, fish or small aquatic mammals).

Several molecular biology approaches can be used for the analysis of eDNA samples (Bruce *et al.* 2021), frequently including:

- Metabarcoding, which targets a short region of DNA (or "DNA barcode") characteristic of the community biological being studied. The DNA sequences associated with this region and present in the sample are sequenced and compared to a reference gene base, enabling the species to be identified and providing a diversity assessment.
- Species-specific monitoring targets a short fragment of DNA characteristic of a single species, thus precisely verifying its presence or absence in the sample studied.

Applied to issues of monitoring the ecological continuity of rivers, these approaches can be used in parallel to respond to management and conservation questions. DNA metabarcoding applied to fish communities can assess species richness in various sections of the river and measure the effect of the elimination of hydraulic structures on the communities (Muha *et al.* 2021). If the approach targets a bioindicator group such as diatoms (Vasselon *et al.* 2019), it is possible to assess the impact of a restoration action on the ecological status of the river. Species-specific monitoring by the eDNA of a species of community interest, such as the Twait Shad (*Alosa fallax L.*, a migratory fish) for example, provides information on the spatial and temporal extent of breeding migrations, as well as the passage capacity of hydraulic structures at the scale of a drainage basin (Antognazza *et al.* 2021).

Although very much under development, approaches based on eDNA already provide operational tools to support the management and conservation of aquatic habitats. Forthcoming technical advances together with method-transfer actions from science to management are set to facilitate their operationality and accessibility for managers in the near future..

CONCLUSION AND PERSPECTIVES

There is a multitude of existing systems and technologies that can be used to assess ecological continuity, whether terrestrial or aquatic, and whether animal or mineral. Currently, technical and scientific (R&D) advances are miniaturising, optimising, simplifying and improving the reliability of tools that until recently were reserved for specialised users.It is up to the manager, or end-user, to choose the system that is most appropriate for the scientific questions posed, and also regarding the constraints of the sites/ habitats that favour one or other of the systems described in this chapter.

In order to better assist the reader in considering how best to monitor ecological continuity, below we provide a summary table (Table 2) describing the advantages/disadvantages, and also operating limits, of the systems described in this document.

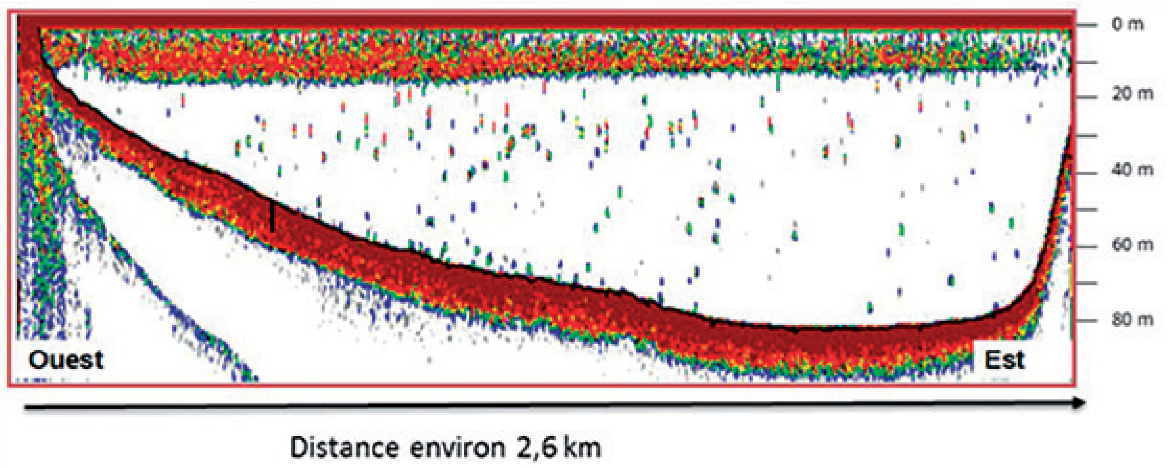


Figure 40: Example of an echo sounding transect on Annecy Lake produced using a multibeam sonar. The very high densities of echoes in the upper layers correspond to juvenile perch (Guillard 2016).

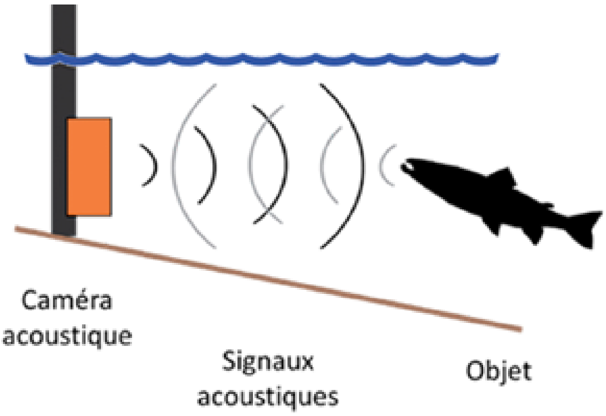


Figure 41 : Operation and theoretical positioning of an acoustic camera in a river (Abdallah, Robert and Rimbert 2020).

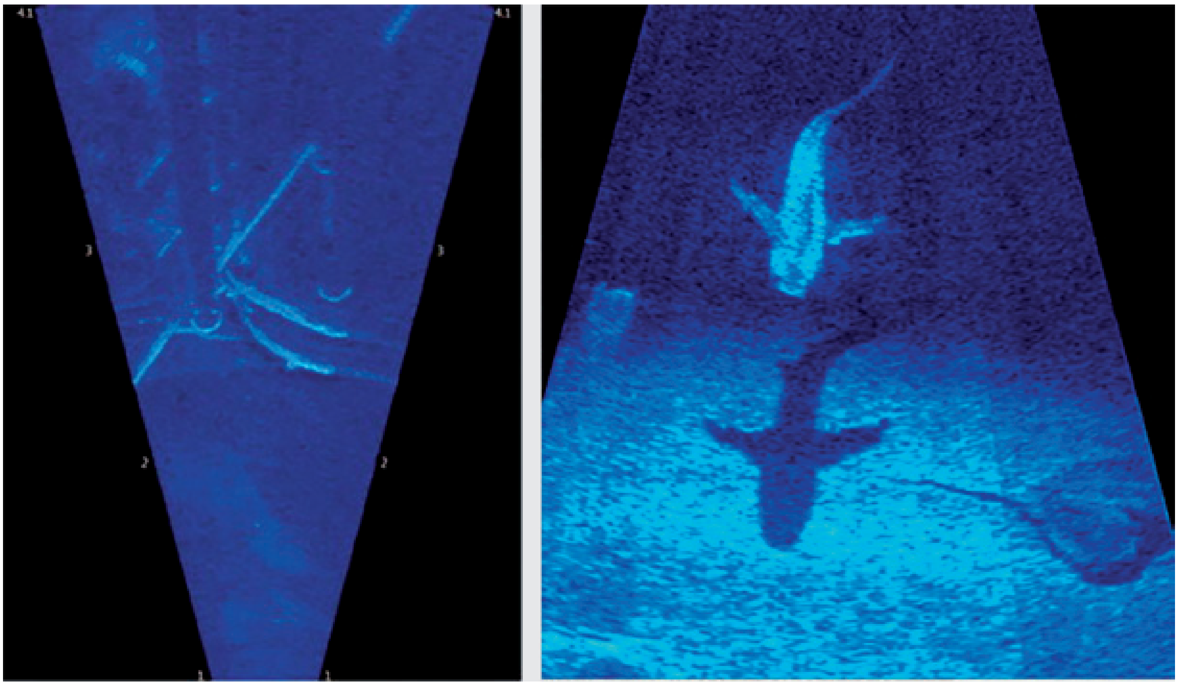


Figure 42 : Illustration of the quality of the images provided by an ARIS Explorer camera used at high frequency, 3.0 MHz (Source: Soundmetrics).

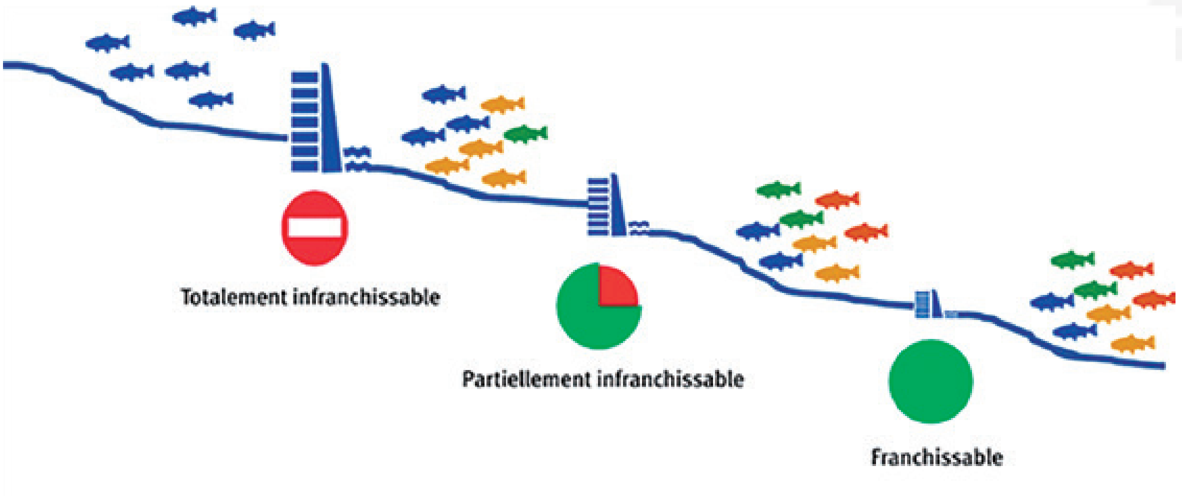


Figure 43 : Illustration of the genetic consequences of the fragmentation of habitats (source: Journal Science Eaux & Territoires, Trame verte et bleue 25, 2018) (Torterotot and Caudron 2018).

Technology	Information collected	Cost	Disadvantages
Passive telemetry	Presence / Absence Individual identification Behaviour Flight direction (if 2 antennae) Flight time (if 2 antennae)	-	Sensitivity of system Need for specific technical skills Need to capture animals to tag them
Active telemetry	Presence / Absence Individual identification Behaviour In-depth study of mobility	++	Cost of equipment, especially emitters Need for specific technical skills Need to capture animals to tag them
Video counting	Presence / Absence Speciation Counting of number of individuals Health status Individual identification (rarer)	++	Adaptability of system Need for very specific technical skills Time need to examine images
Flow analysis tools	Quantitative and semi-quantitative evaluation Speed, flightpath and direction data Individual identification (rare)	++	Need for very specific expertise Complex data analysis
Landscape genetics	Genetic proximity between groups of indivuals Assessment of genetic heritage	-	Invasive method (sampling of tissues) Complex data analysis
Environmental DNA	Speciation (species or group)	-- ++	Need for very specific expertise Complex data analysis Can quickly become expensive depending on the design

Table 2 : Technologies available for monitoring continuity: advantages/disadvantages and other details.

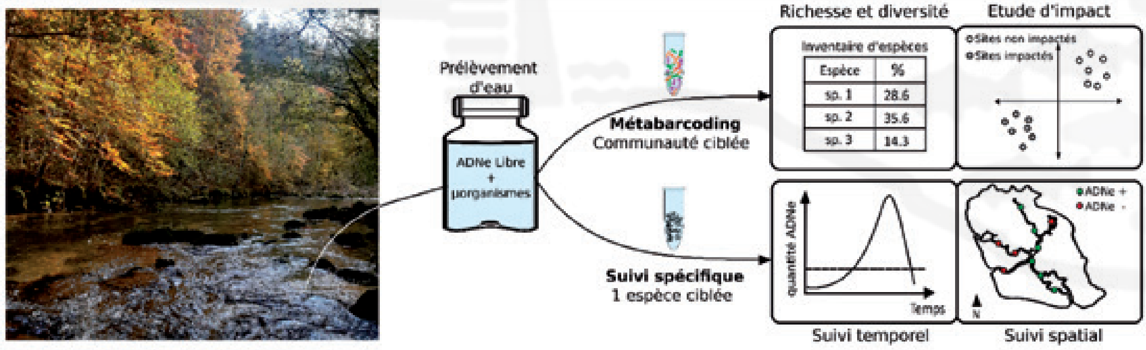


Figure 44 : Diagram of the principle of using eDNA as a tool for monitoring the restoration of ecological continuity.

Advantages	Recommandations	
	Ind. to tag or n sample	**Minimal monitoring period**
Adaptability of system Low cost of emitters Range of ecological questions covered	Min. 100 per study and per year	1 year (1 life cycle)
Adaptability of system Range of ecological questions covered Useable in all types of habitats	Min. 30 per study and per year	1 year (1 life cycle)
No need to capture the animals Quantification of passage flows: very difficult data to obtain Filming of animals	-	2 years (2 life cycles)
No need to capture the animals Adaptability of system Quantification of passage flows: very difficult data to obtain	-	2 years (2 life cycles)
High spatial and temporal resolution Identification of populations Identification of barriers to mobility	Min. 40/station	1 year
No need to capture the animals Adaptability of system Inventory of diversity easy to perform Precise detection of species of interest (invasive, rare …) Spatio-temporal monitoring accessible due to ease of sampling	Min. 1 sample/ station to be adjusted in function of the objective	1 year

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