DOWNSTREAM FISH MIGRATION ALONG THE LOW MEUSE RIVER

LIFE16 NAT/BE/000807

Action D2

Monitoring of the effectiveness of the pilot solutions

Part II : salmon smolts

Deliverable report

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I. Introduction

Among the different Actions covered under the LIFE4FISH project, different protection measures have been selected to be tested at the pilot scale on the different sites of Luminus production dams.

The selection varies between salmon smolts and silver eels. In the present reports, we will only focus on the pilot measures concerning salmon smolts, the report relative to silver eels has already been published (Sonny et al. 2020).

II. Material and Methods

II.1 Pilot mitigation measures tested

The selection of the different mitigation measures has been made through an official tender described in Actions C1&C2, the elements are available in the corresponding deliverable reports (Recordon 2019 a & b). The selected study sites to test pilot protection measures were (Figure 1) : the station of Grands-Malades (CHG) for the electrical barrier and the bypass, and the station of Ivoz-Ramet (CHR) for the adapted spillage. The station of Monsin (CHM) and Lixhe (CHL) were monitored since lot of tagged smolt were expected to pass through, and since these sites had particular operations possibly in favour of safe smolt passage during spring 2021.

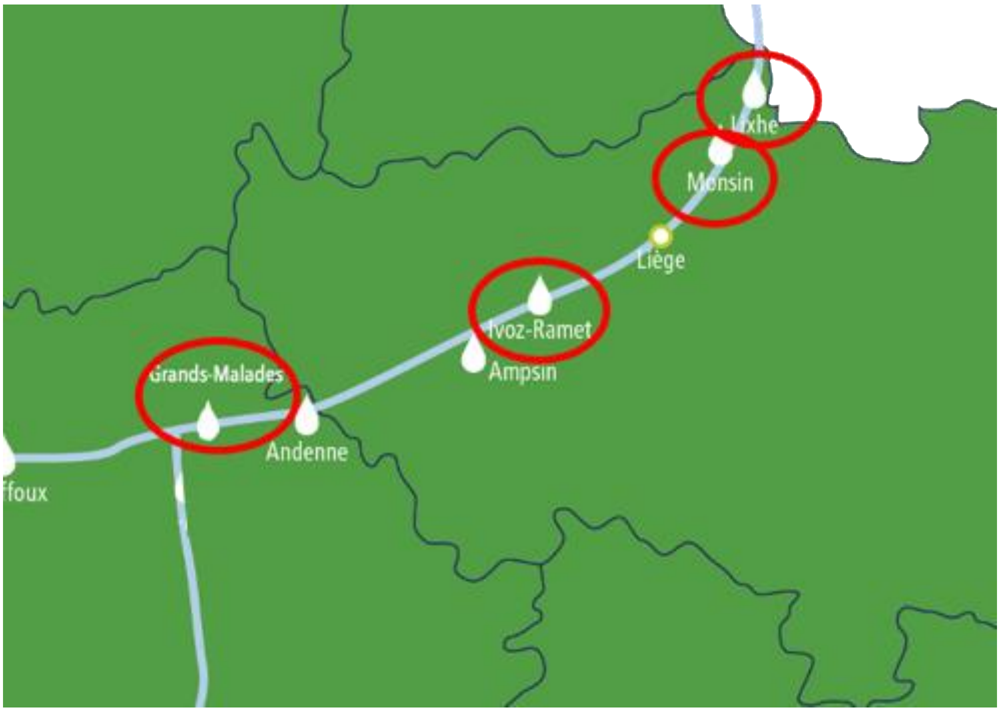

Figure 1 : view of the 4 pilot sites selected to test the smolts protection measures.

The technical details of each solution are described later in the report.

II.2 Assessment of the efficiency

The method for assessing the efficiency of the fish protection measures has been determined in the deliverable report of Action A1 (De Oliveira et al. 2018).

For the guidance devices, the efficiency measurement takes into account (Figure 2) :

- Number of fish arriving on site in the vicinity of the guidance device influence (N barrier in)
- Number of fish crossing the guidance device or going back upstream without crossing the dam (N barrier failure)
- Number of fish passing over the alternative passage solution (N barrier out)

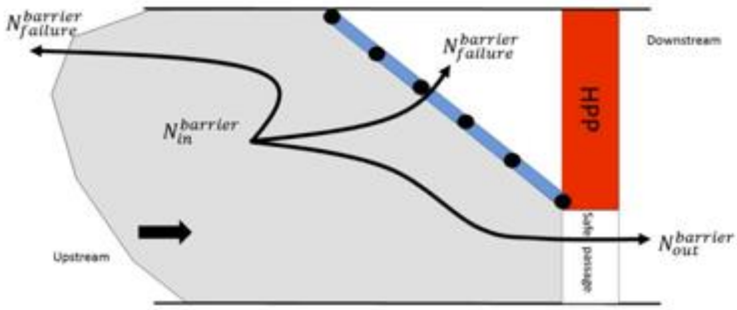

Figure 2 : Efficiency measurement of a behavioural guidance barrier (from De Oliveira et al. 2018)

The efficiency of the guiding device is the ratio between the number of fish successfully passing over the spillway or the bypass and the total number of fish entering the attraction area of the intake.

$$S^{barrier} = \frac{N_{out}^{barrier}}{N_{in}^{barrier}}$$

This concept implies to be able to determine with precision the position of the fish when they arrive upstream the sites. Therefore, a dense telemetry network has been installed at CHG.

II.3 Telemetry study

II.3.1 Telemetry network

We used the JSAT technology (LOTEK WHS 4250 receivers) to track salmon smolts passages, detecting coded pulsations transmitted by acoustic tags at a frequency of 416.7 kHz. This technology has been selected after several performance tests comparing the detection range of different acoustic telemetry technologies on the Luminus HPP (Roy et al 2017).
The network was composed by a first group of hydrophones covering the dam area (spillway length being 22-30 m long) and a second group of hydrophones covering the HPP intake area. When existing, one hydrophone was also installed in the boat sluice. Finally, 1 to 2 hydrophones were installed > 1000 m downstream each dam, to confirm fish passage. Hydrophones were anchored by either mechanical anchors in the concrete structure, or by the mean of steel anchors of 600 kg installed by divers. A detailed description can be found in the corresponding Milestone report (Lerquet et al. 2021).
Hydrophones were downloaded on a monthly basis, excepted when discharge conditions excluded the possibility to work close to dangerous area like spillways.

The details of the networks are presented later in this report since it is important to link the interpretation of the results to the map of the network.

II.3.2 Fish tagging procedure and release strategy

Atlantic salmon smolts used for this experiment have been gracefully delivered by the Mosan Salmon Conservatory of the Walloon Region in Erezée (Belgian Ardennes), where young salmon are raised until parr to smolts stages for restocking purposes. In spring 2021, a total of 237 smolts have been tagged, while 250 tags were available for this experiment. The tags were stocked since spring 2020 due to the postponing of the smolt telemetry survey because of the Covid-pandemia. Stocking tags for 1 year was obviously source of activating trouble for some of them, which reduced a bit our sample.

The tagging procedure was conducted under anaesthesia using a solution of Eugenol (0,5 ml/l of 10% Eugenol), following a strict surgical procedure conducted by an experienced fish surgeon (incision, insertion of the tags, closing stitches, disinfection). After wake-up, smolts have been transported from Erezée to the study sites where they have been stocked overnight in a tank poured with water from the River Meuse. The smolts where released the day after tagging in early afternoon for each experiment.

The release strategy of smolts is presented in Figure 3.

Figure 3 : tagged salmon smolts release locations along the 6 HPP operated by Luminus on the Meuse River 2019 (orange).

A total of 147 smolts, belonging to 3 different batches, has been released upstream CHG to evaluate the efficiency of the electrical barrier or the bypass. No test was scheduled in CH Andenne nor in CH Ampsin. 90 smolts have been released upstream CH Ramet to evaluate the effectiveness of the adapted spillage.

II.3.3 Data treatment

Several steps are crossed from the raw data set to the final interpreted passage data, all of them are detailed in the Milestone report (Lerquet et al. 2021). In simple, these steps are :

1° Hydrophones times resynchronisation
2° Erasure of the negative and false positive detections: using filters based on coded frequency of fish and pulse frequency
3° Passage identification: validated when > 80% of the detections of the last 30 s are detected on the hydrophones of the dam or of the forebay and that the ID has been detected on a downstream station.
4° Link with operational discharge data: some passages are re-considered when they are in opposition with the hydraulic conditions.
5° 2D treatment, data with a DOP < 2 (Dilution of Precision) are considered as valid (Roy et al. 2014), DOP value is given by the UMAP software for each position.

III. Results

III.1 Main migration patterns

As revealed by Figure 4, upstream CHG, a total of 147 smolts have been released, split into 3 batches spread during end of March to end of April 2021. Among these smolts, 112 have been detected upstream CHG. The two following sites, CHA and CHN were not equipped by a telemetry network consequently we don't know how many smolts passed through these sites. 29 smolts were detected upstream CHR, 5 get definitely lost in the Albert Canal and 18 were detected upstream CHM. 15 smolts were detected in CHL and finally 8 were detected downstream at the border with The Netherlands.
The total success of migration of the smolts through this stretch of the River Meuse was 5.4%. During the reference years in 2017, among 60 smolts released upstream CHG, 0% reached CHL, only one smolt succeeded to reach the upstream area of CHR.

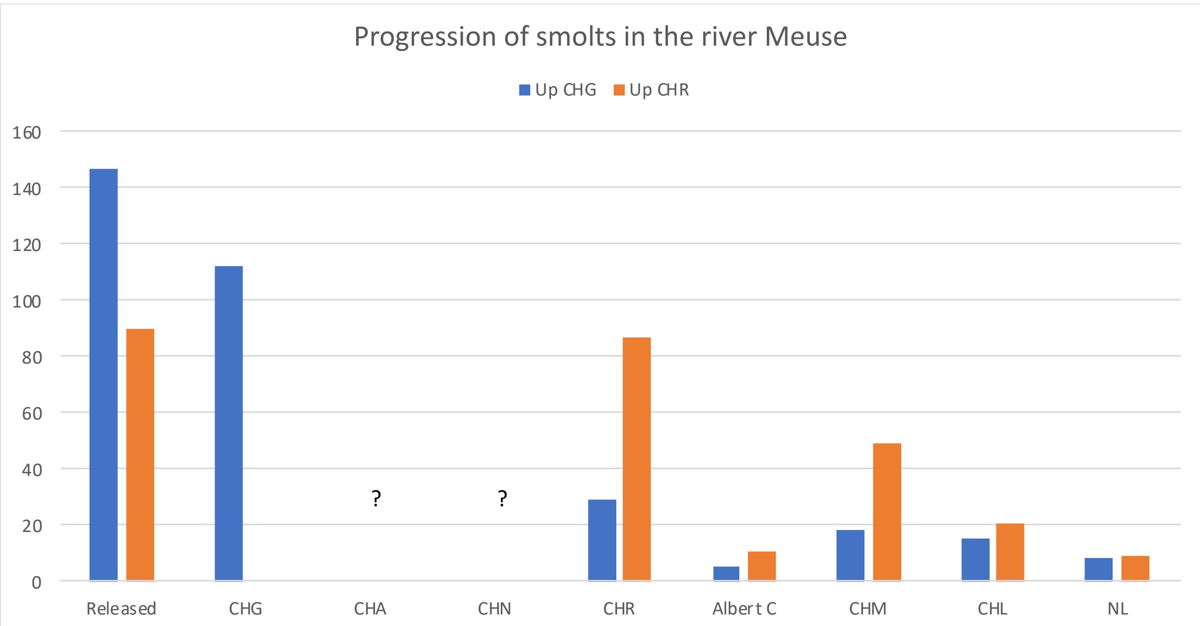

Figure 4 : Number of salmon smolts detected at each site equipped with a telemetry network during the 2021 survey. The smolts are split in two categories: the batches released upstream CHG (blue) and the batches released upstream CHR.

For the 90 smolts released upstream CHR, 87 have been detected on site, 11 were lost in the Albert Canal while 49 were detected at CHM. Finally, 21 were detected at CHL and 9 downstream the site in the Netherlands waters. The global success of migration at the entire study scale was 10%.

III.2 Neptun electrical barrier and bypass at CH Grands-Malades (CHG)

III.2.1 Description of the tested solutions

At CH Grands-Malades, two different pilot solutions have been deployed. First, an electrical barrier has been installed in the intake canal in an angled position aiming to guide salmon smolts towards the left corner of the water intake, where a bypass has been implemented. The electrodes are composed by stainless steel pipes, anchored to the bottom and kept in vertical position thanks to buoys (Figure 5). The dimensions and technical details are described in the C1 deliverable report (Leyssens 2020).

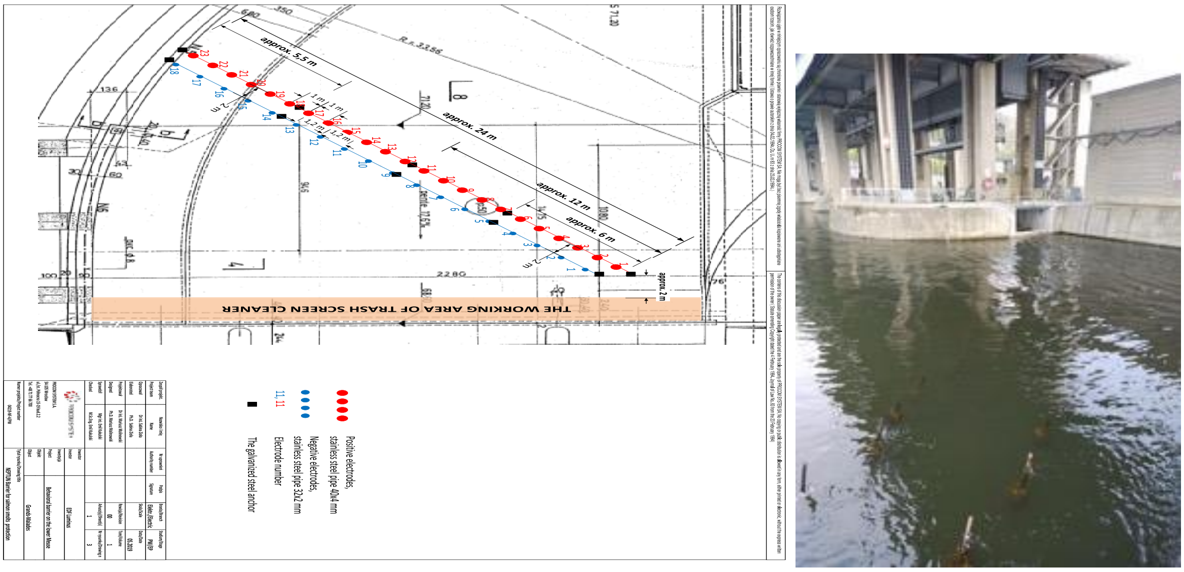

Figure 5 : Drawing and picture of the electrical barrier in the forebay of CHG.

When starting the turbine after the installation, the lines of electrodes started to incline with the current and the closest electrodes entered in contact with the screens of the turbines. Consequently, a total of 10 electrodes had to be reduced in height, reducing the electrical field near the surface in the last 10 m of the barrier close to the corner of the bypass.

The bypass has been designed in the A3 action (Erpicum et al. 2019) and after implemented with success as described in the CA deliverable report (Murillo Calvo & Leyssens 2021). Figure 6 presents the pictures of the bypass. The inlet section is 3 m wide x 2 m deep and has a nominal discharge capacity of 3.4 m^3/s.

Figure 6 : pictures of the entrance (left) and outlet (right) of the bypass designed in CH Grands-Malades.

III.2.2 Telemetry monitoring survey

To evaluate the efficiency of the pilot solutions at CH Grands-Malades, a total of 13 LOTEK WHS 4250 hydrophones have been deployed upstream the dam and the powerhouse, 1 hydrophone was covering the sluice and 2 hydrophones were installed 1500 m downstream to confirm fish passage. The global telemetry network is presented in Figure 7.

Figure 7 : 2D telemetry network installed at CHG (up) and CHR (down). Hydrophones 64, 65, 69 and 26 are covering the forebay.

The acoustic telemetry did not work properly in the bypass due to the high background noise generated by the turbulences of the flow. Consequently, detecting smolts in the bypass required 2 options :

1° Equip the bypass entrance and outlet with RFID antennas and double tag smolts with both acoustic telemetry and Pit-Tags 23 mm, but the size of the antenna do not guarantee a 100% operational detection.

2° Use a net in the outlet downstream the bypass to catch all the smolts passing through.

Since it was necessary for Action A2 to verify the good sanitary state of smolts after their passage through the bypass, we decided to install a large net at the bypass outlet, connected to a floating cage and a pontoon, where operators could easily catch the smolts (Figure 8).

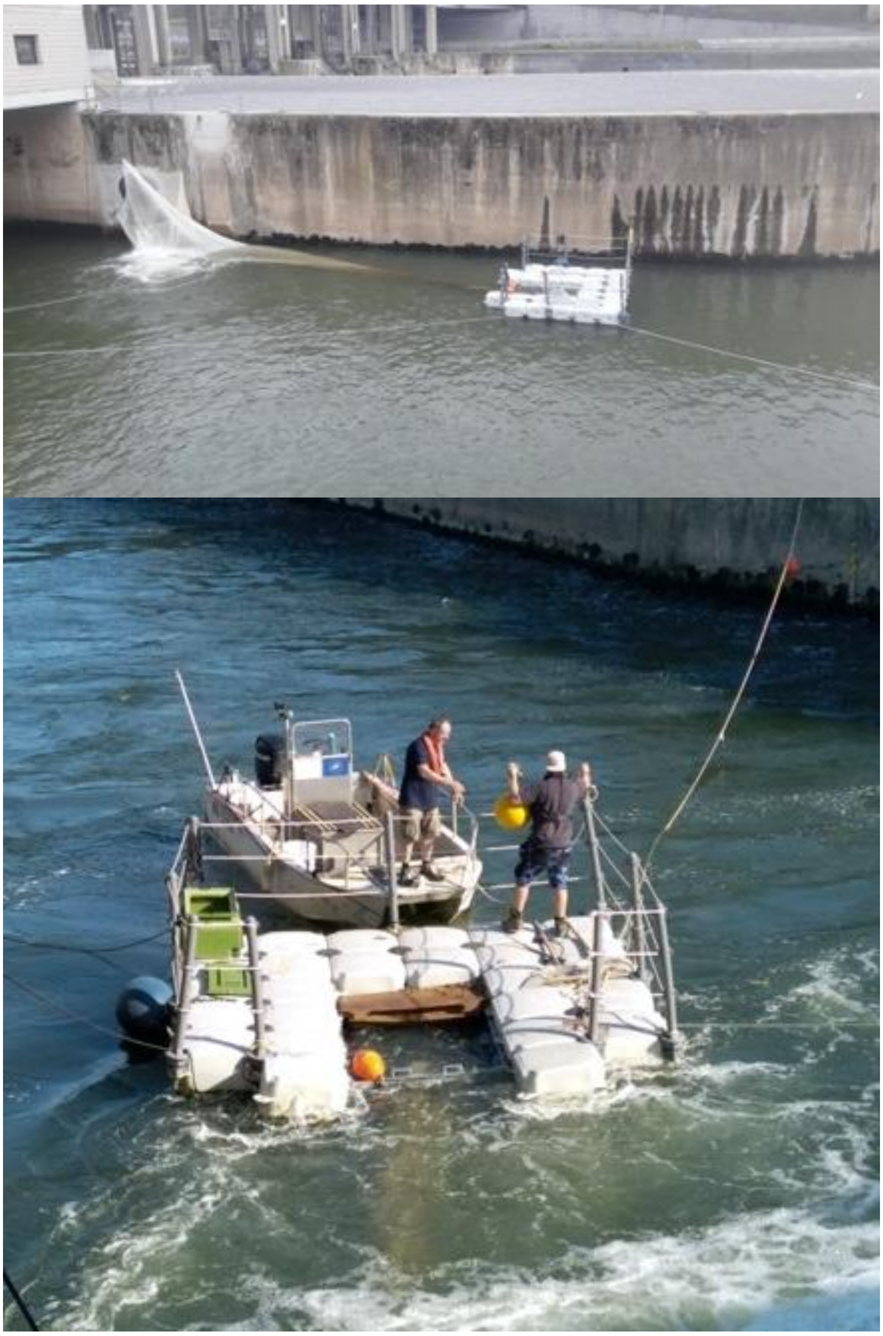

Figure 8 : view of the net and the pontoon in still water (up) and in bypass and turbine operation (down).

A first experiment has been scheduled on 31st March with the release of 51 tagged smolts at 13:30. During the afternoon and the beginning of the night, we stayed on site to control the catching system regularly. One tagged smolt was caught when the team left the site at 22h. The next morning, operators came back on site to control the cage and found no smolts. A large tear was observed in the net explaining that smolts caught after a passage in the bypass could easily escape from the net.
Consequently, for this first sample of tagged smolt release, the bypass passage can't be distinguished from a turbine passage by the acoustic telemetry dataset.

This conducted us to test in emergency RFID antennas at the upstream and downstream end. 2 loops of cable around a wooden frame installed by divers in the bypass inlet have been installed upstream, and around the bypass outlet downstream (Figure 9).

Figure 9 : view of the wooden frame in the upstream part of the bypass (left) and the cable around the outlet tube downstream (right).

After some tests using injection of some smolts, we observed that the detection rate was < 100 % for each antenna, but that all smolts injected seemed to be detected by at least one of the antennas. Without having time to better assess the antennas efficiency, we decided to release the next batch of smolts with double tagging.

A new batch of 40 smolts, doubled-tagged with Pit-Tags and acoustic tags was released on the 20/04 13h20. For this batch, the electrical barrier was under normal operation with a voltage of 100 V, pulse duration of 60 ms and repetition time of 100 ms (Sources : Procom System).

A last batch of 46 smolts have been released on the 27/04/21 at 11h40, after that the electrical barrier was turned OFF for one week.

During both weeks of study, our team went almost every day to clean the debris accumulated on the large screen of the bypass, inducing a variable but non quantifiable clogging of the bypass with a possible incidence on smolt passages.

III.2.3 Results of efficiency of the electrical barrier and the bypass

To evaluate the efficiency of the electrical barrier and the bypass, we distinguished the number of smolts passing on each possible route during the present study in comparison with the reference year in 2017.

Table 1 : repartition of the smolt passage routes observed during the reference year study in 2017 and the present study with batch 4 with the electrical barrier ON and batch 5 with the electrical barrier OFF.

	2017 Ref situation	Batch 4 – Barrier ON	Batch 5 – Barrier OFF
N released		40	46
N in	55	36	33
N barrier in	NA	33	31
N dam	8	3	2

N turbine	20	19	8
N bypass In	NA	9	21
N bypass Out	NA	4	13
N bypass Out < 24h	NA	3	12
N undetermined	17	9	6
N sluice		0	1
Locked upstream	10	1	3

During the reference year in 2017, a total of 18% of the smolts detected stayed locked upstream and did not cross the site by any possible route. For the two batches observed in 2021, this proportion decreased to 3% and 9% (Figure 11).

Due to the morphology of the CHG and the detection range of the hydrophones, it is impossible on this site to avoid signal recovery between the left side of the dam and the forebay. Consequently, based on telemetry signals only, it is sometimes impossible to determine the passage route between these routes. In that case, the environmental factors are used if possible to confirm/infirm the route (dam closed or open, …). Unless this interpretation, the passage route remained undetermined for an important proportion of smolts, while the discharge repartition between the dam and the turbine was in favor of a majority of turbine passage for all observations in CHG.

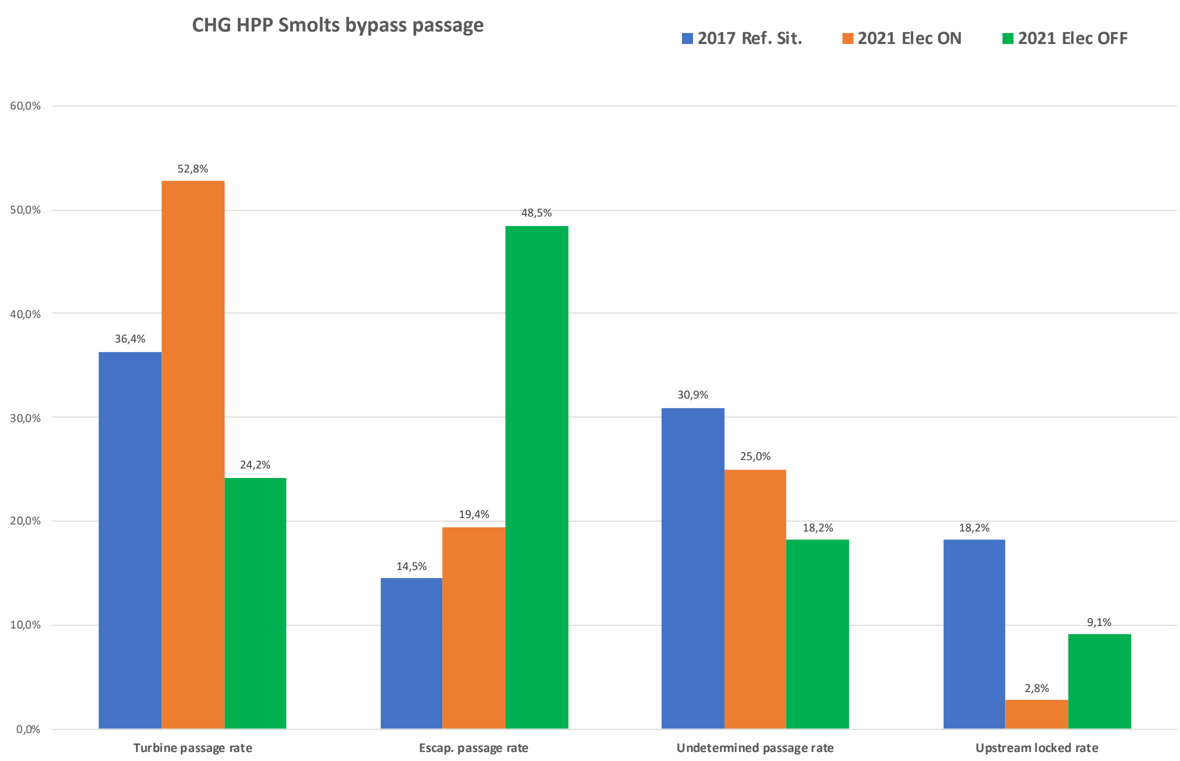

Figure 10 : smolt passage repartition (%) in 2017 (reference year in blue) and 2021 with electrical barrier ON (orange) and electrical barrier OFF (green). Escapement passage considers only dam and/or bypass passage. Sluice passages are not considered in this analysis.

Turbine passage in 2021 with the electrical barrier ON was higher than in 2017, but lower when the electrical barrier was turned OFF (Figure 10). These observations are strangely linked with the increase of escapement passage observed during both batches in 2021 compared with 2017 but can be better explained by the undetermined passage rate that decreases with an opposite trend than the escapement rate.

The calculation of the bypass efficiency is influenced by the detection patterns of the RFID antennas. Since we know that the detection rate is < 100% for each antennas, we defined the following categories:

- Bypass entrance rate: proportion of smolts detected at least 1 time by the upstream RFID antenna of the bypass, relative to the number of smolts detected in the forebay (N barrier in).
- Bypass efficiency < 24h : proportion of smolts detected by the downstream antenna of the RFID < 24h their first detection upstream the site, relative to the number of smolts detected in the forebay (N barrier in).
- Bypass max efficiency <24h : proportion of smolts detected by the downstream antenna and the upstream antenna, as last detection upstream, in a delay < 24h, relative to the number of smolts detected in the forebay (N barrier in).
- Bypass max efficiency : proportion of smolts detected by the downstream antenna and the upstream antenna, as last detection upstream, no matter the delay, relative to the number of smolts detected in the forebay (N barrier in).

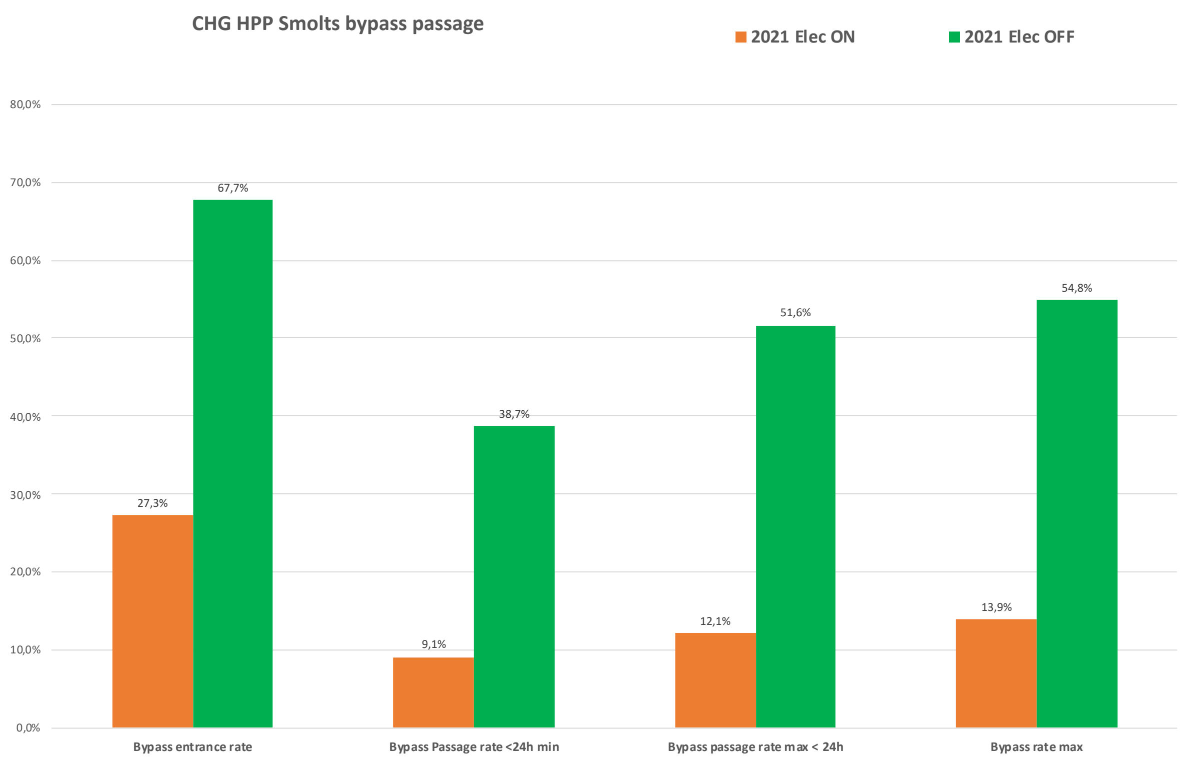

Figure 11 : Bypass entrance rate and passage rate observed in CHG in 2021. Bypass passage rate max is obtained including all smolt only detected by the upstream RFID antenna as last detection on the site, but not confirmed by a detection by the downstream RFID antenna.

The variables used to calculate the bypass efficiency were much higher when the electrical barrier was OFF than with the electrical barrier ON (Figure 11), suggesting a negative effect of the electrical barrier on the bypass efficiency.
The maximum observed performance of the bypass is 55%, associated to the electrical barrier OFF, but considering only passages within 24h of their first detection upstream the site, the efficiency of the bypass is ranging from 39% to 52%.
When the barrier was ON, the maximum bypass passage rate was 2 times lower than the entrance rate, while only 20% lower when the barrier was OFF.

III.2.4 Behavioural analysis of the electrical barrier

To better understand the difference in bypass efficiency for both batches and the possible effect of the electrical barrier on smolt behaviour we compared different variables.
First, we compared the delay between the first detection upstream the site and the last detection before the passage (Figure 12).

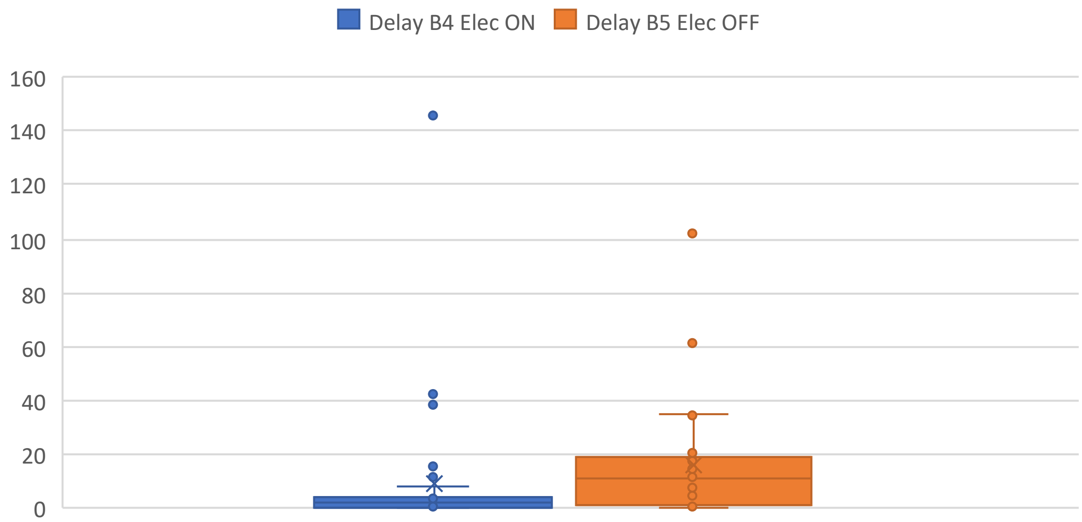

Figure 12 : blox-plot of the delay (Y, hour) between fish first and last detection upstream the site for the batch 4 with the electrical barrier ON (N = 36, blue) and the batch 5 with electrical barrier OFF (N = 33, orange).

The delay of passage for batch 4 with the electrical barrier ON was significantly lower (Wilcoxon Test, P = 0.0012, median value Batch 4 = 1.76 h; median value for Batch 5 = 11.08h). This comparison suggests that the electrical barrier in operation induced a faster transit towards downstream than when turned off.

Since a behavioural barrier can induce avoidance reaction, the electrical barrier in operation could induce more trials of passages, or more approaches than with the barrier OFF. To verify this hypothesis, we first selected the hydrophones located into the forebay (Cf. Figure 8 for hydrophones position). Within this network, we considered that a lack of detection > 5 min constituted a new approach. We obtained for each ID a number of approaches.

The number of approaches was not significantly different between the 2 batches (Wilcoxon test, P = 0.06254, median value for Batch 4 = 1, median value for batch 5 = 2), but 2 ID of Batch 4 exhibited a very high number of approaches (ID 7FC9, N= 60 and ID B570, N =55) which suggest they might have stay for a long period at the same position in the forebay. ID 7FC9 finally disappeared in a turbine passage pattern and was never detected downstream, while ID B570 was detected downstream CHG but with regular movement between the downstream station and the sluice that does not correspond to a normal smolt behaviour and might be associated with a possible predation. We removed these 2 ID from the analysis, revealing a significant difference between the number of approaches (Wilcoxon test, $P = 0.0159$), confirming that the smolts exposed to the electrical barrier with power ON exhibited less hesitation in the forebay than the smolts of the next batch with the electrical barrier OFF (Figure 13).

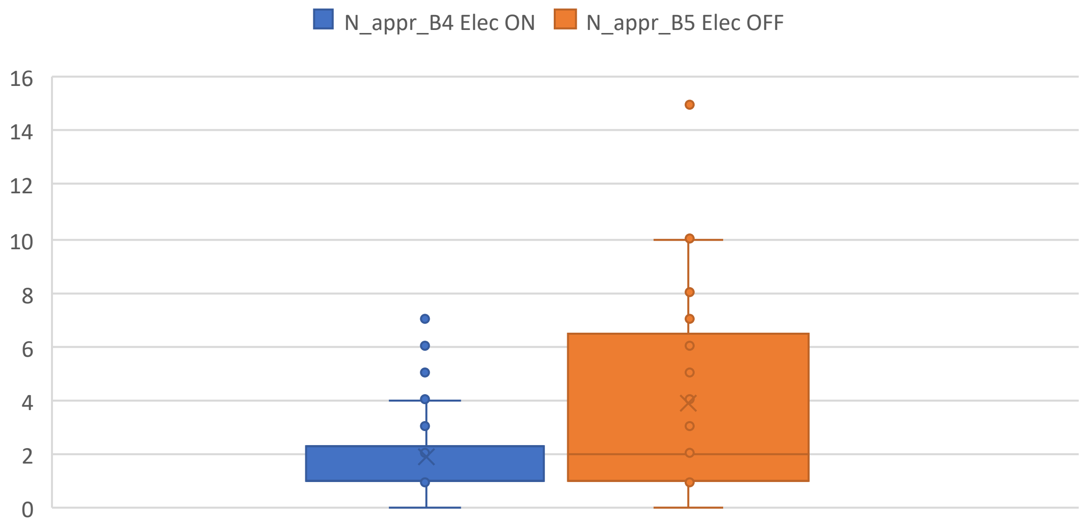

Figure 13 : Blox-Plot of the number of approaches in the forebay (Y, number) for smolts from batch 4 with electrical barrier ON (blue) and batch 5 with electrical barrier OFF (orange), after exclusion of 2 extreme values.

While the releases of the batch 4 and 5 have been done during two successive weeks, the river discharge condition during that period was slightly decreasing. Consequently, both weeks, the turbine discharge was abstracting most of the river flow, but the turbine discharge for batch 4 was significantly higher than for batch 5 (Anova test, $P < 0.0001$, mean turbine discharge batch 4 = 126 m^3/s; mean turbine discharge for batch 5 = 93 m^3/s). Also, the bypass passages were associated with a significantly (Anova test, $P = 0.005$) lower turbine discharge (mean = 91 m^3/s) than the turbine passages (mean = 118 m^3/s). Consequently, the hydrological conditions were different for both batches (Figure 14).

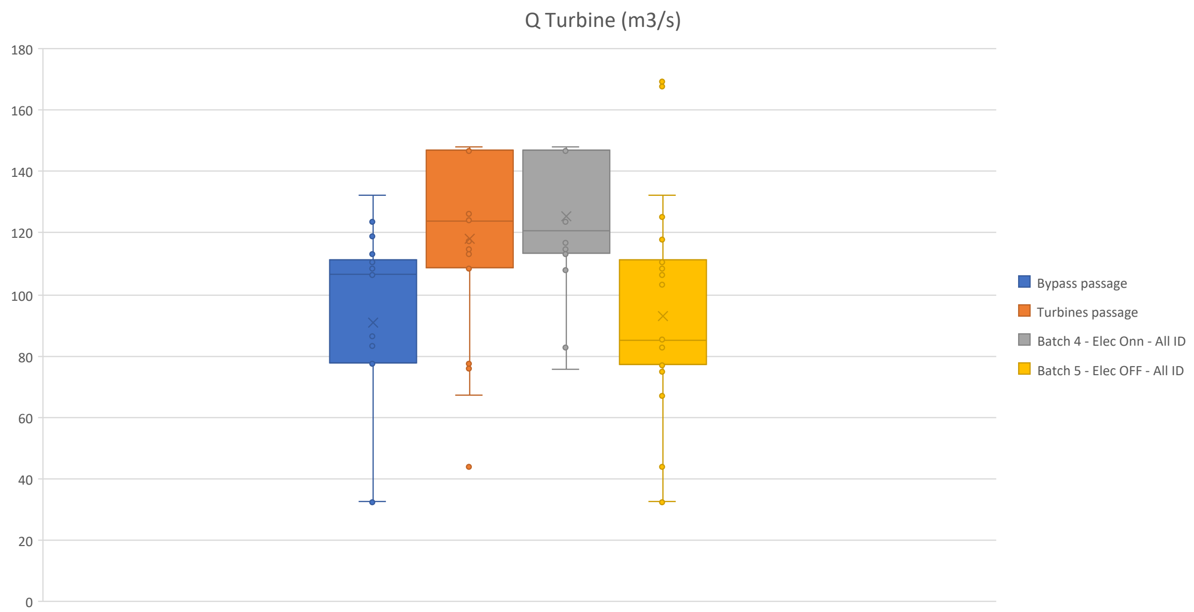

Figure 14 : blox plot of the turbine discharge (Y, m^3/s) for the smolts using the bypass (N = 21, blue) or the turbines (N = 31, orange) for both batches pooled together; and for all passages of smolts from batch 4 (N = 36, grey) and batch 5 (N = 33, yellow).

A lower discharge for Batch 5 means that some turbine group was more often stopped than for Batch 4. In particular, Group 4, close to the bypass entrance, is likely the most influent for bypass attractivity since its nominal operation induces a vortex in front of the entrance of the bypass. Moreover, this Group has very poor regulation capacity, meaning that it can be considered as an OFF/ON Group, the regulation being applied mostly on Group 3 on this site. As revealed on Figure 15, group 4 was most of the time turned OFF during the period of passage of smolts belonging to Batch 5.

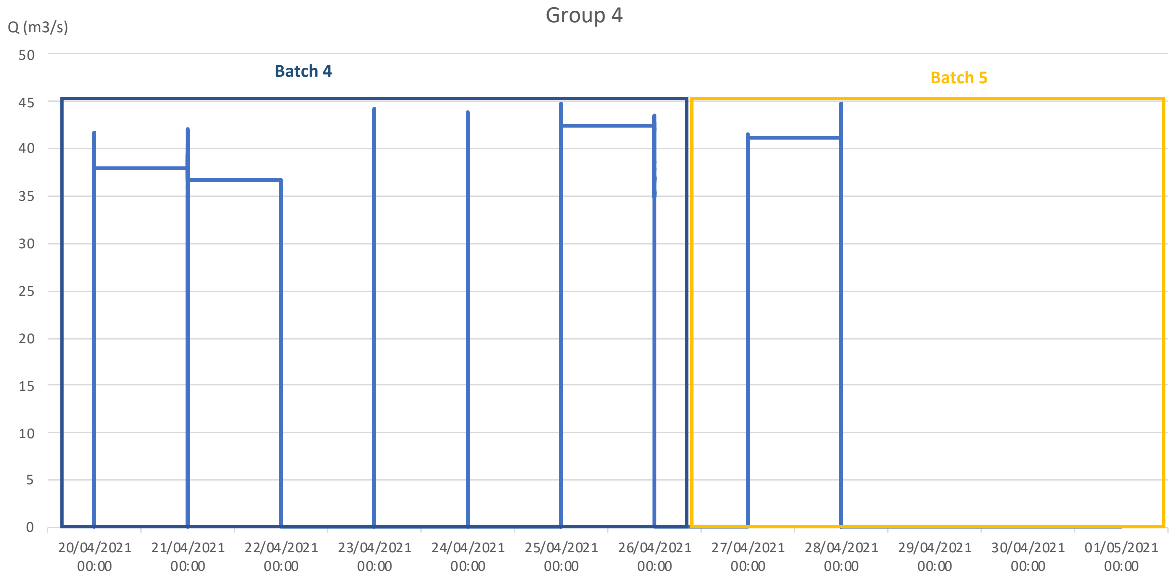

Figure 15 : Evolution of the Group 4 discharge at CHG for batch 4 and batch 5 during the period of smolt passage.

Figure 16 compares the passage repartition between situation with Group 4 OFF or ON for all smolts from both batches.

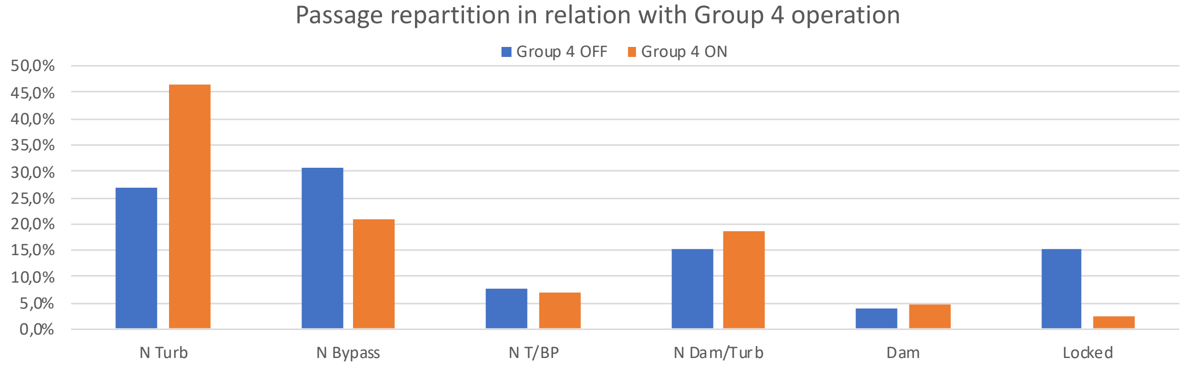

Figure 16 : smolt passage repartition (Y = N) for Batch 4 and Batch 5 when Group 4 was turned OFF (N = 26) or ON (N = 43) during the study period. Turb = turbine passage, Bypass = bypass passage, T/BP = turbine or bypass passage (last detection at the entrance of the bypass); Dam/Turb = undetermined passage between dam and turbine, Dam = dam passage, Locked = fish locked upstream.

Focusing on the bypass and the turbine passage, it interesting to note that Group 4 ON is associated with a higher turbine passage rate and a lower bypass passage rate. This trend is influenced by the fact that Group 4 was OFF for 52% of the passages of Batch 5 against 25% of the passage for Batch 4 and can consequently be also affected by a potential negative effect of the electrical barrier in its attempt to guide smolts towards the bypass.

To avoid this influence, we compared the smolt repartition for Batch 5 only (electrical barrier OFF) during both situation where Group 4 was ON and OFF. Fortunately, the observations were well balanced between both situations (Figure 17).

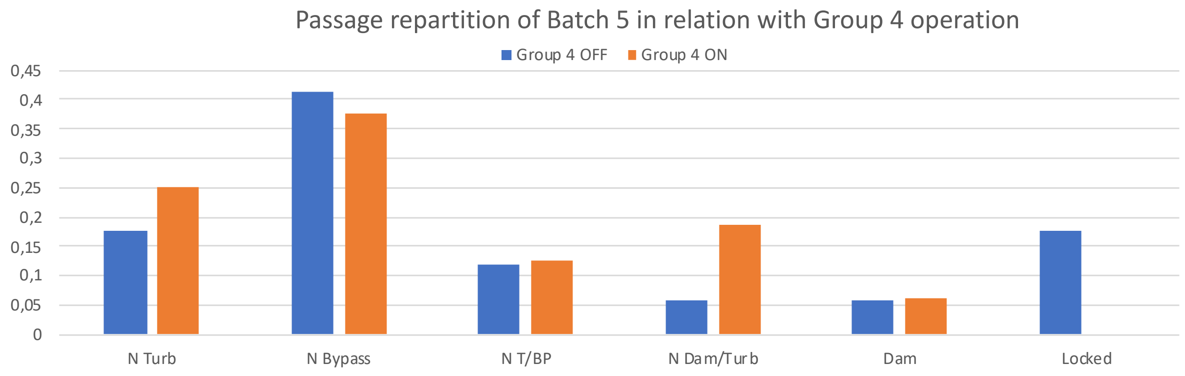

Figure 17 : smolt passage repartition (Y = %) for Batch 5 compared when Group 4 is OFF (N = 17) with Group 4 ON (N=16).

Without the influence of the electrical barrier, it seems that the operation of the Group 4 has not an obvious influence on the success of bypass passage.

III.2.5 Bypass behavioral analysis

To evaluate the performances of the bypass, we compared the number of detections for each ID at the entrance of the bypass by the RFID system (Figure 18). The number of entrances in the bypass was obviously higher for batch 5 than to batch 4 while the difference was not significant (Wilcoxon test, P = 0.064).

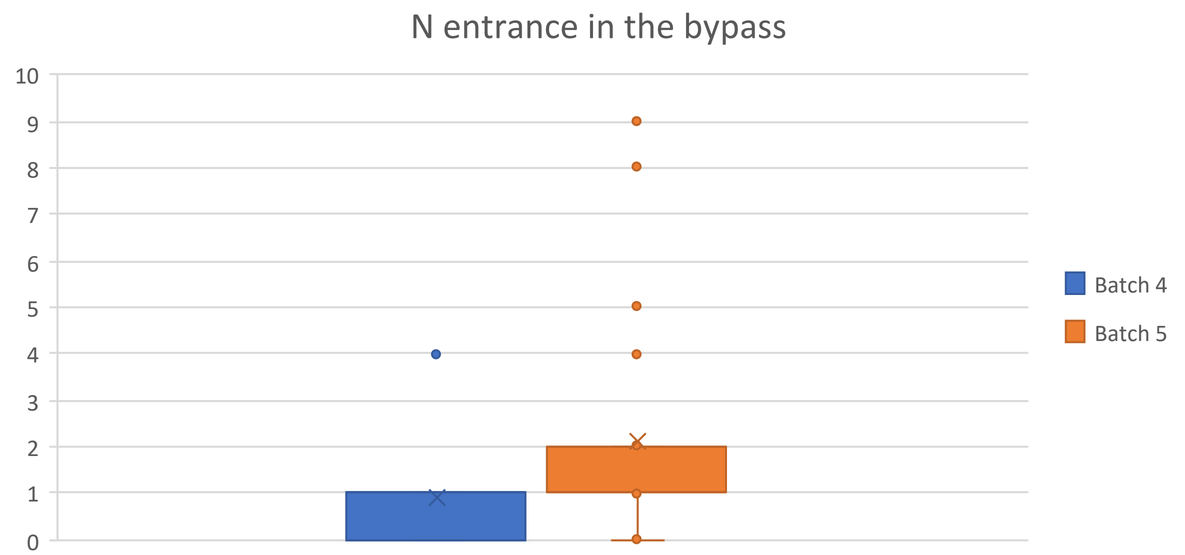

Figure 18 : Blox-Plot of the number of detections per ID by the entrance RFID antenna of the bypass for batch 4 (electrical barrier ON) and batch 5 (electrical barrier OFF).

Close to the entrance of the bypass, the electrical field of the barrier is not present, so the electrical barrier is probably not involved in this difference. The operation of Group 4, less important for Batch 5 is a potential influent factor. An important element that we observed on the field was the clogging rate of the large mesh screen upstream the bypass by large debris. While it was not possible to quantify that, our team went daily to clean the screen of the bypass during the first 3-4 days after the release for each batch. During the week of tracking batch 5, we found the bypass very clogged by debris quite every day, while the bypass remained reasonably clogged for the week of batch 4. We even observed smolts attempting to pass the bypass while we were cleaning it. While it is not possible to correlate it, we believe that clogging probably influenced bypass passage.

III.2.6 Discussion

During the monitoring of 2021 targeting to monitor the efficiency of the pilot solutions at CHG, we observed a reduction of the proportion of smolts locked upstream compared with the reference year in 2017.

The operation of the electrical barrier induced a strong difference of passage repartition compared to the batch of smolts released when the barrier was turned OFF. While we expected the electrical barrier to improve the efficiency of the bypass, it appears that the barrier induced a lower efficiency of the bypass, a higher turbine passage rate in a shorter delay and with less approach than for the batch with barrier OFF. All observed behavioural variables tend to suggest that the electrical barrier might have stunned the smolts bringing them unable to be guided towards the bypass. However, this hypothesis can't be verified.
In a past similar experience, salmon smolts have been exposed to an electrical Neptun barrier installed as a guidance device towards a surface bypass, in a similar design than in our experiment in CHG (Weibel & Wüst 2017). Radio-telemetry passage studies revealed that on 59 detected smolts, 88% successively used the bypass, 8,3% used the weir and 1,7% swam through the barrier towards the HPP canal. For this experiment, the electrical parameter used for the barrier were different than in the present experiment : shorter voltage, shorter pulse duration, shorter interval between group of pulses. Authors are not presenting data for the water velocity through the barrier during the experiment, neither the discharge repartition between the intake and the bypass, which can also influence the bypass attractivity. Finally, authors did not perform a control group study, so the bypass natural attractivity without the barrier is unknown. The only comparative element that can come from this study is that the barrier did not induce an electrical narcosis of smolts that would have swim through the barrier. The fact that all electrical parameters were lower during this past experiment can argue in favor of a too high electrical field exposition during the present study.

The water velocity through the electrical barrier at CHG was probably ranging between 0.7 m/s to close to 1m/s going from right to left bank, as suggested by the numerical model performed in A3 action (Figure 19).

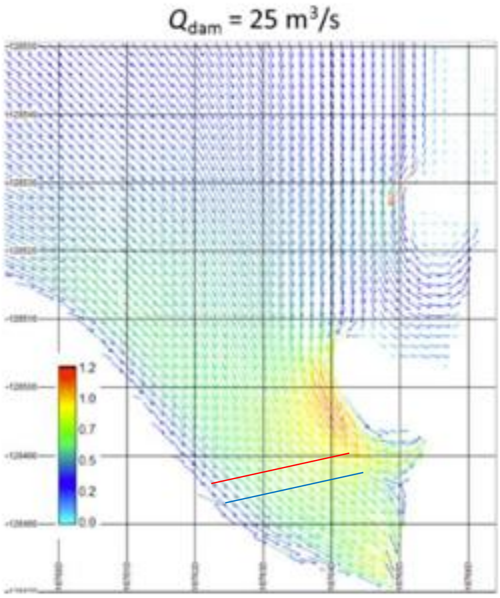

Figure 19 : Velocity fields in the forebay of CHG for a turbine discharge of 130 m³/s and a discharge of 25m³/s passing over the adjacent spillway. From A3 report (Erpicum et al. 2019).

The barrier expected efficiency could have been impaired by a combination of inadequate electrical parameter selection associated with high water velocities. While the present study gives not encouraging results for the electrical barrier, this conclusion must be restricted to the conditions of the present study. More studies in different conditions (electrical parameter, water velocity) are necessary to have a complete opinion about the potential of the electrical barrier to be used as an efficiency guiding solution for smolts.
Finally, the electrical barrier had to be modified before the experiment and the electrode design used in the field differed from the initial design on drawings.

The bypass has been successful to transit smolts downstream CHG powerhouse. The efficiency of the bypass has been higher for batch 5 than for batch 4. Between the two samples, beside the stop of the electrical barrier for batch 5, the turbine discharge was lower which was in favor of a higher attractivity of the bypass. The status of Group 4, located near the entrance of the bypass and inducing a vortex close to its entrance, did not seem to affect the bypass efficiency.

III.2.7 Conclusions

While the electrical barrier obviously failed to guide smolts towards the bypass in its present configuration, it appeared that the bypass solution can bring a passage efficiency of around 50% for salmon smolts. Considering the low loss of discharge induced by the bypass, this solution seems attractive to be used at other sites for the next step of the study. The electrical barrier needs further studies to verify if the limits of application have been overpassed in CHG compared to the past experiment mentioned in the literature. Unfortunately, no telemetry survey is dedicated to adjust the parameter of the electrical barrier. Consequently, it is likely that this solution will not be considered within the term of the LIFE4FISH project, but new electrical adjustment tests, if conducted, could bring more positive perspectives.

III.3 Adapted spillage

In the A3 action of the LIFE4FISH project, it was initially planned to develop a bypass passage facility for smolts at CHR. The bypass has been properly designed both at the numerical stage and on physical models (A3 Report, Erpicum et al. 2019).
For different administrative rand technical reasons, the implementation of bypass at CHR finally became impossible and other solutions had to be explored. Finally, different water level have been tested under the A3 action (results under publication) and finally two different water levels have been tested: 90 cm and 50 cm of opening, each monitored by the release and the telemetry survey of one batch of smolts.

The dam of Monsin is under refurbishment since a couple of years, and for this reason, only 2 spillways were available for the river discharge during spring 2021. Since a lot of tagged smolts was released upstream this site to study the performances of the solution deployed at CHG and CHR, it has been decided to equip this dam and the CHM intake with a telemetry network and also to ask to the SPW to open the spillway close to the opposite bank by 90 cm during the period of smolt migration as revealed by the operation of the prediction model developed in Action A4 (Teichert et al. 2019). The measure of the efficiency of the smolt migration prediction model was not scheduled in the D2. Despite that, we planned to tag wild smolts caught at the Mery trap to evaluate the performance of this model in 2021, but the catching rate per unit effort at Mery has been very low in spring 2021 and consequently this monitoring could not be performed. But the opening of the spillway on the opposite bank to the water intake at CHM was also considered as an opportunity for a direct comparison of the performance with the same measure in CHR, but on the opposite spillway, close to the water intake.

Finally, at CHL, an existing permit obligation requires an opening 20 cm of the adjacent spillway in order to let salmon smolts migrate. While this measure is not a target of the LIFE4FISH program, since lot of tagged smolts were expected to pass this site, a telemetry network has been deployed in order to estimate the efficiency of this measure compared to other water level (50 cm and 90 cm) left on the spillways at CHR and CHM.

III.3.1 Telemetry monitoring survey

At CH Ramet, the telemetry network was composed by 9 LOTEK WHS 4250 receivers located in the main river to distinguish several key areas (Figure 20) : arrival on site (80-82), detection along the intake and the dedicated spillway (74, 75, 77, 83, 84), sluice passage (36, 60). 2 ATS SR3017 receivers (32, 83) have been installed near the turbine screen to detect smolt passage through the HPP. Additionally, 2 LOTEK WHS 4250 have been installed 1.500 m further downstream to confirm passage.

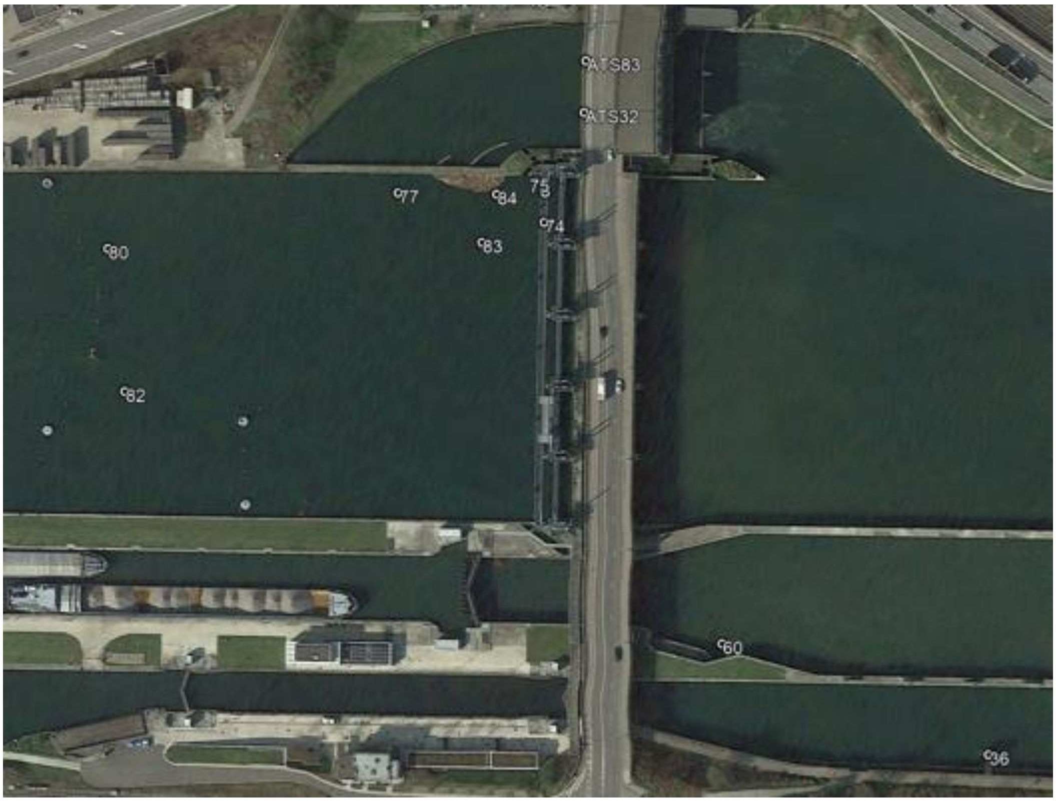

Figure 20 : view of the telemetric network installed at CH Ramet during the smolt 2021 survey.

On the 31st March 2021 at 12:00, Luminus required to the SPW the opening of the spillway n°5 with a water layer of 90 cm for 1 week. During this week, the mean river Meuse discharge was 142 m^3/s, and the mean HPP discharge was 69,5 m^3/s. All the remaining discharge was used by the HPP in priority without the need to open other spillways except under unplanned shutdown of the HPP.

On the 8th April 2021 at 12:00, the water level left on the spillway n°5 has been decreased to 50 cm for 1 week. During this week, the mean river discharge was 172 m^3/s and the mean turbine discharge was 132 m^3/s.

III.3.2 Calculation of the effectiveness of the spillage measure

Between 01/04/21 12:00 to 08/04/21 12:00, a total of 48 tagged smolts have been detected arriving upstream CHR. From these smolts, 77% used the open spillway to cross the site but 65% in a delay shorter than 24h, while 17% used the turbine. 6% stayed locked upstream (Table 2)

Table 2 : smolt passage repartition at CH Ramet with the different water level left on spillway n°5.

Measure 1 : 90 cm on Spill 5	**N**	**%**
N In	48	
N Spillway	37	77,08%
N Spillway < 24h	31	64,58%

N Turbine	8	16,67%
N Upstream Lock	3	6,25%
Measure 2 : 50 cm on Spill 5	**N**	%
N In	61	
N Spilway	33	54,10%
N Spilway < 24h	30	49,18%
N Turbine	25	40,98%
N Sluice	1	1,64%
N Upstream lock	2	3,28%

During the second study period from 08/04/21 12:00 to 15/04/21 12:00, a total of 61 smolts have been detected arriving upstream CHR. Among them, 54% used the open spillway to migrate downstream but 49% in a delay shorter than 24h, while 41 % used the turbines. 3% stayed locked upstream and 2% used the sluice.

After 15/04/21, the dam moved back in an automatic operation and no water was left on it. During this last period, a total of 9 smolts arrived upstream the site. 6 used the turbines (2 with a delay of passage > 24h) and 3 stayed locked upstream. This trend is also confirmed by a similar telemetry study conducted in 2017 in absence of any fish protection measure on the same site. The tagged smolt sample was low, N = 14 smolts arrived upstream and among them, none used the dam to pass downstream. 2 stayed locked upstream, 2 used the sluice to migrate downstream and the rest used the turbines. It is however important to mention that the reference situation in 2017 was weakened by a small data set and was conducted during a dry spring period in very low discharge with the turbines and the sluice as only available routes of migration for smolts. The combination of the 2017 dataset and the data from the present study after 15/04/21 gives the same trend: the sluice is the only alternative route to the turbine when the dam is closed. The sample is however too low to be able to establish the impact of sluice passage on smolt survival.

Global efficiency of the adapted spillage in terms of smolt dam passage in less than 24h :

- **H = 90 cm : 65%**
- **H = 50 cm : 49 %**

III.3.3 Influence of the water level on the success of dam passage

While it has been asked to the SPW to open the spillway n°5 at 90 cm and 50 cm for one week to test the escapement rate of smolts, in practical, the water level left at the spillway n°5 oscillated around this value. Figure 21 shows the hourly water level recorded by the SPW on spillway n°5 of Ramet during the first half of April.

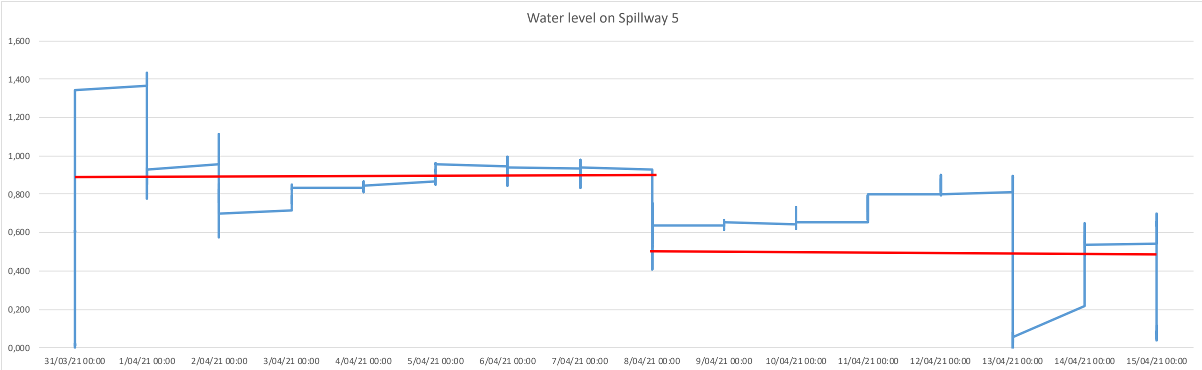

Figure 21 : hourly water level measured by the SPW on the spillway n°5 of Ramet dam. The red lines shows the order of management required: 90 cm from 31st March to 08th April and 50 cm from 08th to 15th April, Source SPW.

These water variations are due to the combined management of the water line for navigation purposes and the optimization of the turbine production.

In parallel to this operation in Ramet, a similar spillway management has been operated in CH Lixhe, where the HPP has a permit obligation to ask to the SPW to open the spillway adjacent to the powerhouse by 20 cm during the smolt migration. Consequently, the dataset of smolt passages combined from CH Ramet and CH Lixhe allows to study the relation between the escapement rate by the spillway and the water level on the spillway. Figure 22 presents these trends.

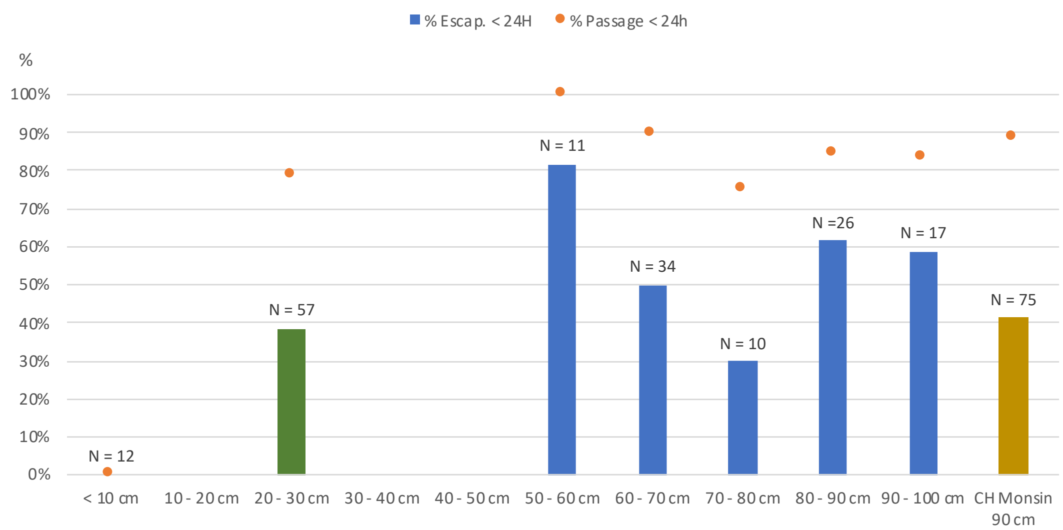

Figure 22 : Escapement rate by the open spillway (%) in less than 24h in relation with the water level measured by the SPW on the spillway adjacent to the powerhouse in Ramet and Lixhe and opposite to the powerhouse in Monsin. Only value with more than 10 smolts are used for the analysis. Green column is supplied by value obtained only in Lixhe, blue columns are related with Ramet data and orange column is for Monsin. The N presents the total number of observations used to calculate the escapement rate. Orange spot are showing the proportion of the smolts that passed the spillway within 24h of delay in relation with all spillway passage of smolts.

The figure shows a robust escapement rate of 39% for a water level of 20-30 cm within 24h after the arrival on site. This result being obtained 100% by data from CHL. The dam escapement rate varied between 30% and 82% for water level between 50 cm and 100 cm.

At any water level above 20 cm, it is observed that the majority of the smolt succeeded their migration within 24h.

From the total number of smolts that migrated over the spillway, the Figure 22 also shows that a large majority of them, ranging from 79% to 100%, migrated out within 24h of delay. There is no obvious link between the water level and this proportion, suggesting that this measure does not implies too much delay for smolts.

In Monsin, only the 2 spillways on the opposite bank to the CH Monsin were operational for maintenance reason, the 4 other spillways being under works. Luminus decided to ask to SPW to open the opposite spillway by 90 cm from 29/03/2021 in the morning to 12/05/2021. These dates have been selected by the prediction model developed for smolts (Teichert et al 2019a, Teichert et a. 2020b).
The efficiency of the prediction model of smolts has not been directly tested since it has not been possible to tag wild smolt caught directly in the Ourthe River during spring 2021. Consequently, only smolts tagged and released to tests the measures at CH Grands-Malades et CH Ramet could pass along the Monsin site during their migration.

A total of 75 tagged smolts have been detected arriving in Monsin, all within the timeframe of the defined by the model (*i.e.* 29/03 to 12/05/2021).
From these smolts, a total of 41% migrated out over the spillway within 24h, which represents 89% of the total smolts that used the spillway. Unfortunately, due to the work operation ongoing on the dam, no record of water level on the spillway is available from the SPW. Consequently, it is not possible to know how precisely this measure has been managed in its duration. This efficiency is lower than observed in the same range of water level for Ramet.

III.3.4 Discussion and conclusions

The order to open a water level of 90 cm and 50 cm in Ramet has been successfully performed while the precision of the measure is hard to respect due to the marge of error of the spillway elevation measure, and the regular and large river discharge fluctuations.

Dam escapement rate observed during this pilot test study revealed to be dramatically improved compared to the reference study performed in 2017, where the tagged smolt could hardly pass more than 2 or 3 successive HPP before to get lost by lack of water current. In the present study, the river flow was always sufficient to test the target water level on the spillway with still most of the flow going through the powerhouse.

Our study considered the efficiency following 2 approaches. The first approach considers the measure based on its order and do not consider the exact value of the water level measured on the spillway and its variation around the target measure. This consideration focusses on a real operational situation, since keeping an exact value on a spillway is not an easy task.
Considering only smolt that succeeded to migrate in less than 24h over the spillway, the 50 cm order induced an escapement rate of 49%, while the 90 cm order induced an escapement rate of 65%.

The same order of management asked on the opposite bank at CH Monsin induced an efficiency of escapement of 47%, which is lower than the same order in Ramet. The location of the spillway, opposite to the water intake could explain why less smolt succeeded to pass through this alternative passage. Since the exact water level over the spillway was not recorded, it is also possible that this efficiency is impaired by lower water level that had to be managed temporarily due to flow regulation.

The second level of analysis considered the water level measured on the spillway of Ramet and Lixhe stations and examine the escapement rate for smolts by steps of 10 cm of the spillway. At Lixhe, a water level comprised between 20 and 30 cm (order of 20 cm) on the spillway close to the powerhouse succeeded to offer an escapement rare of 39% within 24h. Above 50 cm of water level in Ramet, we observed a variable efficiency that is hard to link with external factors that could influence smolt behaviour.

IV. General conclusions

Among all tested pilot solutions for salmon smolts, only the electrical barrier gave disappointing results that could be explained by an inappropriate setting of the electrical parameter in combination with a high-water velocity in the forebay.
The efficiency of the bypass at CHG gave similar efficiency than the order to keep 50 cm on the adjacent spillway at CHR. It seems that the escapement over the spillway can increase with the water level.
Bypass presents the big advantages to use less water than the opening of the spillway for 50 cm and more. On the other hand, this last measure does not require any investment for the power company, neither any maintenance contrary to the debris management on the bypass that revealed to be needing to adapt a tool (dedicated trashrack system) to facilitate this operation.

The next step of the project concerns the selection of the solutions for smolts at all sites, depending on their priority in the project. Bypass design will be in competition with dedicated spillway, but only a technico-economic analysis will help to choose the final decision.

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