Date: 5-Mar-20	Deliverable	
Project: Life4Fish project	Arcadis	
Version: V2	Rue des Guillemins, 26 - B-4000 Liège (Belgique) ☎ + 32 (4) 349 56 00 - 🖷 + 32 (4) 349 56 10 olivier.machiels@arcadis.com - www.arcadis.com	Contact name: Olivier Machiels

DOWNSTREAM FISH MIGRATION ALONG THE LOW MEUSE RIVER

Action D1

Definition and evaluation of performance indicators

1st study report on estimation and biological status of resident stocks

Révision				
Ind.	**Date**	**Published by**	**Checked by**	**Remarks**
0	03/04/19	Olivier Machiels (Arcadis)		First version
1	12/07/19	Imen Ben Ammar (Unamur)		Including biological aspects
2	04/10/19	Olivier Machiels (Arcadis)		Consolidated version including biological aspects in global conclusions

TABLE OF CONTENTS

FIGURES

I. Introduction

Action D1 of the Life4Fish program is dedicated to the evaluation of the effectiveness of the protective solutions developed in order to help downstream passage of targeted fish species along the low Belgian Meuse river. The present report focuses on the initial status of both stocks along the study area in order to further catch the relative influence of the tested solutions.

The two species targeted in this program are the Atlantic salmon (*Salmo Salar*) at smolt stage and the European eel (*Anguilla Anguilla*) at silver stage. The biological status for both species is defined based on available literature on stock repartition (Vlietinck et al 2007), on site surveys ordered by EDF Luminus before to the start of the Life4Fish program (Profish 2017, Roy et al 2018, Sonny et al 2018 a and b), results of the preparative actions A (De Oliveira et al 2018, Ben Ammar et al 2018), and dedicated survey actions D of the Life4Fish program.

II. Study area and analysis scale

The study area extends to the entire Belgian lower Meuse from Namur to the border with the Netherlands downstream of Lixhe. The water intakes of the Tihange nuclear power plant and the Albert Canal are the exhaust limits of the study area. The confluence with the Mehaigne and the Ourthe are the entry limits of the study area. In particular, the 6 dams equipped with hydro-electric power plants present in this area will be investigated.

This document is based on the nomenclature developed in the framework of the Life4Fish program (De Oliveira et al 2018). On the global scale, 3 entries in the study area are considered at the level of the upstream Meuse (Namur), and the confluence with the Mehaigne (Huy) and the Ourthe (Liège). The production of a share of the stock within the 5 reaches located between the sites is also considered. Finally, 3 exits of the study area are considered at the level of the downstream Meuse (Lixhe), and the water intakes of the Tihange power plant (Huy) and the Albert Canal (Liège).

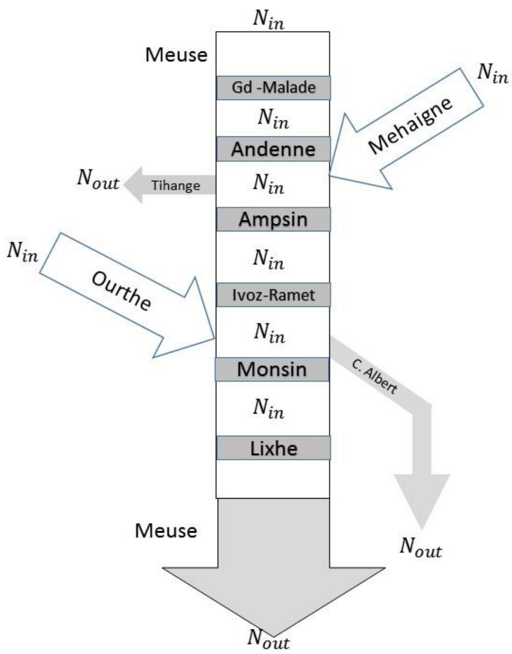


Figure 1. Schematic view of the study area (De Oliveira et al 2018)

In order to model the whole study area to allow calculation of the various outputs (N_{out}), the stocks repartition (N_{in}) and the influence of both sites and reaches need to be defined.

III. Stocks repartition

III.1 Residence places

III.1.1 Atlantic salmon (*Salmo Salar*)

The distribution of salmonid smolt stocks is carried out based on the Saumon 2000 program's reintroduction data. According to data transmitted by the SPW fishery service (X. Rollin – personal communication 2017), 48.288 wild smolt equivalents were reintroduced into the Ourthe-Amblève basin and 11.861 wild smolt equivalents were reintroduced to the tributaries of the Meuse upstream of Namur (mainly on the Lesse and the Samson).

Making the hypothesis of equivalent impacts from reintroduction places to entry in our system, this study therefore considers:

$N_{in\ upstream}$ = 20%

$N_{in\ Ourthe}$ = 80%

The other contributions are neglected.

III.1.2 European eel (*Anguilla Anguilla*)

The Eel Management Plan for Belgium (Vlietinck et al. 2007) gives assessment of the distribution by river basin of eels on the non-channeled streams of the watershed of the Belgian Meuse and an estimation of stocks on the channeled courses (Meuse, Sambre and Albert Canal).

Tabel 17. Répartition par bassins hydrographiques des effectifs numériques et de la biomasse de l'anguille dans les cours d'eau non canalisés du bassin de la Meuse en Wallonie pour la situation 1990-2007. Superficie colonisée: 1.566 ha (sauf Meuse, Sambre et Canal Albert).

Bassin	Superficie (ha)	Nombre	Biomasse (kg)
Ourthe-Amblève-Vesdre	-	10.637	4.124
Lesse-Lhomme	-	4.113	1.490
Semois	-	4.017	2.484
Méhaigne	-	2.264	753
Hermeton	-	1.167	188
Geule	-	748	217
Viroin	-	649	384
Berwinne	-	632	203
Ruisseau des Awirs	-	472	102
Houille	-	457	199
Affluents Sambre	-	358	188
Molignée	-	229	190
Bocq	-	214	70
Samson	-	121	32
Chiers	-	101	21
TOTAL		25.579	10.653

Tabel 18. Essai d'estimation de l'ordre de grandeur du stock d'anguille européenne dans la partie belge du bassin de la Meuse.

Milieu	Superficie (ha)	Nombre	Biomasse (t)
Meuse	1.600	113.700	22,0
Canal Albert	100	7.100	1,4
Sambre	300	1.200	0,2
Affluents en Wallonie	1.566	25.600	10,7
Grensmaas	-	-	-
Affluents Grensmaas	-	-	-
Total sauf Grensmaas	3.566	147.600	34,3

Figure 2. Evaluation of eel stocks in Wallonia (Vlietinck et al 2007)

Based on following two assumptions:

1. The annual silvering rate is similar across the entire watershed (spatial repartition of yellow eels and silver eels are equivalent)

2. The Meuse biomass is distributed homogeneously in proportion to the lengths of the reaches (conservative assumption because the stock is more important downstream (near the sea) than upstream).

Fishing activities within each reach of the Meuse river are planned in order to evaluate the eel density, the silvering rate and the sanitary status variations along the various reaches of the studied area.

This study will therefore consider:

$N_{In\ upstream}$ = 37%

$N_{In\ reach\ 1}$ = 9%

$N_{In\ reach\ 2}$ = 11%

$N_{In\ reach\ 3}$ = 9%

$N_{In\ reach\ 4}$ = 11%

$N_{In\ reach\ 5}$ = 8%

$N_{In\ Mehaigne}$ = 2%

$N_{In\ Ourthe}$ = 7%

Downstream of the study area:

$N_{in\ downstream}$ = 1% / 29,2%

$N_{in\ Albert\ Canal}$ = 5% / 3,6%

III.2 Biological status

In the first year of the project 48 eels were caught in 4 different stations: La Plante (upstream Grand-Malades HPP), Lives-Sur-Meuse, Andenne (between Grand-Malades and Andenne HPP) and Hermalles-sous-Argenteau (Between Monsin and Lixhe HPP). La Plante station was prospected twice: 21/03/18, water temperature 5.5°C, 0 eels caught and 25/05/18, water temperature 18°C, 5 eels caught). Andenne station was located right upstream the hydropower plant of Andenne and prospected 15 times from 05/09/18 to 18/12/18. More eels were caught in the downstream part than in the upstream part of the Meuse river sub-basin included in the area of study.

Station	Catch effort (CE)	Number of fyke-net used	Eel abundance	Number of eel/CE	Number of eel/fyke-net
La Plante	3	5	5	1.67	1
Lives-S-Meuse	2	7	12	6	1.6
Andenne	15	2 lines	15	1	0.5
Hermalle-s-Argenteau	2	7	16	8	2.1

Eels size varied between 406 and 1045 mm (mean 823.5mm). Their weight ranged from 94.9 to 2619.6g (mean 1182.3 g). Only three eels showed serious external damages (Head injury, loss of the right eye or loss of a part of the tail). The 93.7% other were externally healthy.

Station	water temperature	Mean size (mm)	mean weight (g)	Condition factor	Silvering stage
La Plante	18°C	864±30.5	1326.6±171.79	0.21±0.02	40% YFIII and 60% SFIV
Lives-S-Meuse	23°C	736.33±124.98	787.42±451.13	0.17±0.03	41.7% YFII, 41.7% YFIII and 16.6% SFIV
Andenne	from 18.8 to 9.5°C	882.5±122.61	1345.43±491.48	0.17±0.06	26.7% YFIII, 46.6% SFIV and 26.7% SFV
Hermalle-s-Argenteau	23.9°C	820.81±173.62	1290.57±735.12	0.20±0.02	6.2% YFI, 18.8% YFII, 18.8% YFIII and 56.2% SFIV

In the Meuse river stations, the eels were mostly in the beginning of the silvering process (SFIV 43.8%) followed by the yellow stage III and II (YFIII 29.2% and YFII 16.7) and only one yellow stage I eel. Some downstream migrating eels were also caught (SFV 8.3%). The most advanced stage eels were found during the downstream migration period near Andenne HPP. An important proportion of silver eel was also found in the downstream part of the Meuse river at Hermalle-sous-Argenteau.

Station	water temperature	Peroxidase activity (U/ml)	Lysozyme activity (U/ml)	Glucose levels (mg/ml)
La Plante	18°C	116.15±103.44	1555.54±217.72	0.24±0.06
Lives-S-Meuse	23°C	161.26±54.02	2179.92±443.73	0.30±0.08
Andenne	from 18.8 to 9.5°C	185.77±91.66	1039.40±352.88	0.24±0.07
Hermalle-s-Argenteau	23.9°C	208.54±78.54	1984.30±491.47	0.40±0.08

For both lysozyme activity and glucose levels, eels caught at temperatures of 23°C and more showed higher values than those caught at temperatures less or about 18°C. In fact, temperature can induce an increase in the metabolism and thus in glucose levels and can affect the immune system. For peroxidase activity (related to the immune function), eels from La Plante seems to have less levels and higher variability than the other individuals. The observed variability in terms of weight, condition factor, silvering stage, peroxidase and lysozyme activity and glucose levels did not allow us to have referential values from resident populations to be compared to the fish used for the assessment of the impact of the passage through the turbine. More sampling must be done to improve the knowledge about the immune and physiological status of the resident populations.

For salmonid smolts, special attention should be paid to the period of descent. The migration window for salmonid smolts is estimated to be approximately 400 °C x days (McCormick et al. in Wood and McDonald, 1997). If we consider the water temperature of 10 °C in the tributaries as a trigger of the migration, it means a window of 40 days (without taking into account here a warmer water in the Meuse and as we get closer to the sea).

In the framework of the Life4fish project, a complementary experiment was held in order to understand the variation of the physiological status of the salmon smolts when they reach the confluence between the Ourthe (principal source of salmon smolts) and the Meuse river. An observed shift of temperature of 3.4°C (mean value) due to the human activities (Tihange nuclear plant) exists between the Méry trap (in the Ourthe) and Monsin HPP (in the Meuse). This shift of temperature can, as we hypothesize, causes a chronic stress in the salmon smolts originated from the restocking activities at the Ourthe river and thus, affect negatively their survival and ability to migrate. It can also affect negatively the smoltification process by decreasing the $N^{+}K^{+}$ATPase activity and hypo-osmoregulatory capacities which may indicate that fish are undergoing desmoltification (Bernard et al., 2019).

In our experiment, the fish were kept one week at Méry and Monsin and sampled (the experiment duration was shortened because an entire tank of fish was stolen at Monsin). Our results showed that fish survival was not affected by the shift of temperature of from 2 to 4.3°C depending of the days. However, a week after the temperature shift, all the fish stocked at Monsin (water temperature range from 15 to 20°C, mean temperature 17.25°C) were already smoltified (robe changes as silver color and red points) while Méry group (water temperature range from 11 to 17°C, mean temperature 14°C) were not smoltified. A week after the temperature shift was already sufficient to induce significant differences between the two groups for complement activity ACH50 and maximum speed with higher values in Monsin group than in Méry group (table 3). No significant difference was observed in peroxidase activity and cortisol levels.

Group	ACH50	Cortisol (ng/ml)	Peroxidase activity (U/ml)	Maximum speed (BL/s)	Maximum speed (m/s)
Méry	59.56±21.01	287.49±138.81	222.51±141.15	4.7±0.71	0.78±0.11
Monsin	90.03±30.58	386.21±241.27	206.12±65.30	5.8±0.78	0.94±0.73

Both our and Bernard et al., (2019) results showed that the shift of temperature strongly affects the smoltification process resulting to a shortening of the downstream migration period. The fact that a week later the osmoregulation capacities and the $N^{+}K^{+}$ATPase activity strongly decreased, and the ACH50 activity is increased show that not only fish can undergo desmoltification process (loss of the ability to migrate) but are also potentially vulnerable to the pathogens after experiencing such a temperature shift. The maximum speed increase may help fish to reach their destination (the sea) more quickly but the presence of obstacles can attenuate this beneficial effect.

Generally, the delays in crossing the Meuse reaches by the smolts appear to be intimately linked to the flow rates. The total distance to be travelled between Lixhe and the main tributaries that can be used as habitat for salmonids is about 21km for the Ourthe upstream of the Grosses-Battes dam, about 110km for the Lesse at Anseremme and about 220km for the Semois at the French-Belgian border. To this is added about 310km of course between Lixhe and the arrival at sea via the Dutch Meuse. The active swimming speed of smolts appears to be 0,1 m/s in addition to the observed flow rate (Roy et al 2018).

For the average flow rate of Meuse (217 m^3/s at Amay), the flow velocity within the reaches would vary between 0,24 m/s and 0,36 m/s. Then these smolts would cross an average daily distance of 26 km without considering the time required to cross the various obstacles. They would need about 12 days to cross the Dutch Meuse, 1 extra day to come from the Ourthe (13 days), 4 days to come from the Lesse (16 days) and 8 days to come from the Semois (20 days). This would leave 27 days for the smolts of the Ourthe to cross the 10 obstacles separating them from the sea (3 days per obstacle), 24 days to the smolts of the Lesse to cross the 19 obstacles that separate them from the sea (1 day per obstacle), and 20 days to the smolts of the Semois to cross the 30 obstacles that separate them from the sea (16h per obstacle).

IV. Site influence

IV.1 Ways of passage

Parallel to the start of the Life4Fish program, EDF Luminus ordered downstream migration surveys of both species along the 6 sites of the study area.

For salmon smolts, this survey (Roy et al 2018) shows the following sites last detection schemes:

Site	Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Upstream presence	55	38	15	14	7	12
Downstream presence	35	23	3	12	0	3
Last detection before passing downstream						
Dam	*8*	*4*	*0*	*1*	*0*	*2*
Hydropower Plant	*15*	*12*	*0*	*9*	*0*	*0*
Sluice	*0*	*0*	*2*	*2*	-	-
Undefined	*12*	*7*	*1*	*0*	*0*	*1*
Last detection without downstream detection						
Dam	*16*	*2*	*7*	*1*	*4*	*3*
Hydropower Plant	*3*	*7*	*5*	*0*	*0*	*0*
Undefined	*1*	*1*	*0*	*0*	*0*	*1*
Upstream site	-	*5*	*0*	*1*	*3*	*5*

These last detection profiles have than been former studied regarding the works opening and the capacity of detection of the probes at the passage time. This enable to clarify some of the undefined last detections and some of the inconsistent patterns observed. For the remaining undefined passages, there have been divided in between the opened works at the passage time. According to these assumptions, the ways of passage on each site are the following:

Site	Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Upstream presence	55	38	15	14	7	12
Dam	17,5	0,5	0,33	0	0	6
Hydropower Plant	26	28,5	9,33	9,5	0	1
Sluice	1,5	3	2,33	2,5	-	-
Non crossing	10	6	3	2	7	5

For salmonid smolts, crossing rates vary greatly from one site to another. The same applies to the distribution between the crossing areas. However, we can distinguish three site classes.

The sites of Grands-Malades, Andenne, Ampsin-Neuville and Ivoz-Ramet have a similar operation with a large number of crossings by the plant and some passages isolated by the other works. For these sites, the crossing rates are above 80%. The plant allows the passage of the site to the downstream.

The site of Lixhe shows a different operation with a lower rate of crossings of the plant for the benefit of the dam. This element is linked to the presence of a permanent waterleaf of minimum 10cm on the site of Lixhe. This training of fish to the dam decreases on these sites the direct impact of the plant but also increases the rate of non-crossing (probably due to the too weak water slides generated). The crossing rate falls under 60%. The plant no longer provides a preferential route, and downstream migration is therefore partially interrupted at the site level.

Finally, on the site of Monsin, only 1 individual ventured into the water intake of the plant before going back to the Albert Canal. The remaining individuals stuck in front of the dam in closed position most of the time. The crossing rate for this site is zero creating a major obstacle to the descent of the species. However, low water discharge and low number of fishes observed on that site during the survey may influence these results.

The behaviour difference of the smolts upstream of the plants must be looked for in the approach conditions specific to each of the sites. At this stage of the study, we can only compare the conditions in the horizontal and vertical planes at the level of the water intake.

In the horizontal plane, we note the presence of plunge beams (1 m below the surface) at the entrance of the inlet channel at the sites of Ivoz-Ramet and Monsin. 2D behavioural follow-up along the Ivoz-Ramet plunge beam showed that it was acting as a crossing delay to the plant but that all the fish crossed it after a period of research. It therefore does not seem at this stage to be able to explain the non-crossing of the Monsin plant.

The position of the inlet channel of the plant at the upstream of the dam can also play a role. The distance between the entrance of the inlet and the dam is 30 m on the site of Ampsin-Neuville, 20 m on the site of Ivoz-Ramet and 110 m at Monsin. Monitoring of salmonid smolts has shown that, under observed monitoring conditions (low discharge), the fish first show up at the dam. The entry into the inlet channel of the plant would therefore require a movement of the fish more or less important upstream. On the site of Monsin, this phenomenon seems to play an important role because only 1 fish has been detected within the water intake of the plant. This phenomenon is not present on other sites where fish are observed several times upstream of the plant.

The depth of the water intake can finally play a significant role. Indeed, salmonid smolts are surface fishes usually moving within the upper 2 meters of the water column. The passage within the water intake of the plant therefore requires diving more or less deeply. At the sites of Monsin and Ivoz-Ramet, the Kaplan turbine technology with vertical axis makes the water intake close to the upstream surface level. The depth of water intake is low, and the fish should practically not dive to pass within the plant. This behavior is confirmed in Ivoz-Ramet where there is very little research movement directly upstream of the turbines. For other sites, horizontal-axis turbine technologies make the water intake close to the downstream surface level. The depth of water intake is then even more important as the fall is important (4,85 m to Grands-Malades, 3,45 m to Andenne, 4,65m to Ampsin-Neuville and 5,65m to Lixhe). On these sites, the creation of a surface water flow at the dam can locally alter surface courantology in comparison to the main background courantology. This phenomenon allows to attract and maintain more smolts from the Lixhe and the Grands-Malades dams. However, it is therefore appropriate to provide these fish with an effective way of crossing in order to avoid attracting them to a no-escape route that would increase the rate of non-crossing.

For silver eels, the survey (Sonny et al 2018b) shows the following sites last detection schemes:

Site	Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Upstream presence	45	47	54	94	89	83
Downstream presence	45	47	50	88	78	8
Last detection before passing downstream						
Dam	*19*	*29*	*38*	*54*	*47*	*7*
Hydropower Plant	*12*	*4*	*4*	*23*	*25*	*1*
Sluice	*1*	*0*	*0*	*1*	-	-
Undefined	*13*	*14*	*8*	*10*	*6*	*0*
Last detection without downstream detection						
Dam	-	-	*1*	*0*	*5*	*71*
Hydropower Plant	-	-	*3*	*4*	*6*	*0*
Undefined	-	-	*0*	*2*	*0*	*1*
Upstream site	-	-	*0*	*0*	*0*	*0*

Regarding the works opening and the capacity of detection of the probes at the passage time enables to clarify some of the undefined last detections and some of the inconsistent patterns observed. For the remaining undefined passages, there have been divided in between the opened works at the passage time. According to these assumptions the ways of passage on each site are the following:

Site	Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Upstream presence	45	47	54	94	89	83
Dam	24,5	38	42,5	59,33	58	81,5
Hydropower Plant	19,5	7	11,5	32,83	31	1,5
Sluice	1	2	0	1,83	-	-
Non crossing	0	0	0	0	0	0

For silver eels, the distribution between the crossing zones is fairly constant from one site to another. On the site of Grands-Malades, however, there is a greater presence at the plant compared to the other sites. Here we feel the influence of a drop zone close to the site during the survey. It is observed that 15% of the crossings take place before the first peak of migration, at lower discharges than the installed discharge (closed dam). On the other sites, less than 5% of the crossings are observed over the same period.

At the Lixhe site, there is a very low rate of crossing by the plant. This can come from the operation with a permanent water slide of about 20 centimeters on the dam. Especially when the Meuse discharge is lower than the installed discharge of the plant. This can also be the result of site-specific hydrodynamic conditions. On this site we observe an important vortex upstream of the turbines.

IV.2 Turbine influence

The impact rate of the plants is deducted from field studies (Sonny et al. 2018a). For the sites of Grands-Malades and Andenne, the rates measured in these studies will be considered directly.

For the sites of Ampsin-Neuville and Lixhe which have configurations close to the other two sites with safer turbine characteristics, it will be considered conservatively the most important impact measured on each species on the two tested sites.

Finally, in the absence of results on the sites of Monsin and Ivoz-Ramet characterizing the impact of the large vertical Kaplan turbines, the rates of impact on each of the two species will be arbitrarily determined. According to the larger size of the machines and the lower rotational speeds, the turbines can reasonably be expected to have smaller impacts than for the other groups. The proposed values therefore appear to be largely conservatives. These values will be adapted when in situ tests have been conducted (planned in December 2019 and January 2020).

Plant		Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Salmon smolts	Direct impact	**2,0%**	**6,7%**	6,7%	10%	10%	6,7%
	Moreover impact after 72h	**0,5%**	**0,6%**	0,6%	0%	0%	0,6%
Silver eels	Direct impact	**2,0%**	**0,7%**	2,0%	0%	0%	2,0%
	Moreover impact after 72h	**19,1%**	**10,6%**	19,1%	20%	20%	19,1%

Our experiment at Grand-Malades HPP (2018) showed that healthy salmon at smolt stage seems to be unaffected in terms of stress and immune parameters three and fifteen days after the passage through the turbine. No significant differences were found in plasma cortisol levels (acute stress indicator), in ACH50, and in peroxidase activity. The recovery of the fish seems to be fast, as they did not show significant differences from the control group after three days. Our conclusion is that there is no chronic stress effect due to the passage through the turbine in healthy individuals. However, caution must be taken as the salmon smolts in the wild show often parasitism (presence of leech) and Saprolegnia infection (fungi infection) at very high proportions (100% of fish sampled at Méry trap presented both in 2018) and can be vulnerable to the stress of the passage through the turbine more than healthy fish. Although we did not have an effect due to the passage through the turbine, there was a significant difference in cortisol levels between day 3 and day 15 with higher levels at the end of the experiment. Those levels can be explained either by the chronic stress due to the containment of the fish and the beginning of the smoltification process with the temperature and photoperiod increase (Bernard et al. 2018).

Group	Length (mm)	Weight (g)	ACH50	Cortisol (ng/ml)	Peroxidase activity (U/ml)
Control 0	15.52±0.47	33.15±3.18	69.54±18.20	37.54±19.11	124.53±20.23
Control at day 3	14.79±1.11	26.00±5.64	41.57±16.55	77.73±31.38	152.30±33.35
HPP at day 3	14.97±0.94	29.25±5.96	56.38±15.58	81.58±60.45	165.46±52.55
Control at day 15	15.42±0.83	29.42±5.74	84.51±21.72	180.68±107.41	166.17±62.91
HPP at day 15	15.40±1.19	30.59±4.97	84.90±43.31	186.90±119.06	187.25±56.82

For eels, the passage through the turbine of Grand-Malades did not affect the stress and immune parameters. Only a time effect was observed for cortisol levels and lysozyme activity. The passage through the turbine affected the glucose levels. In fact, after the passage through the hydropower plants, the individuals showed higher glucose levels in their blood at day 1 and 6 compared to the control group, which can be caused by an accelerated metabolism due to the stress and the effort made to swim through the turbine. These glucose levels are higher than the ones observed in wild individuals from the same area (Live-S-Meuse and Andenne station). However, the measured peroxidase and Lysozyme activity in this study were lower than in the resident stock.

Group	Length (mm)	Weight (g)	Cortisol (ng/ml)	ACH50	Peroxidase activity (U/ml)	Lysozyme activity U/ml	Glucose levels (mg/ml)
Control 0	719±31.75	790.29±83.96	216.61±141.06	2830.76±575.34	135.88±39.5	1194.13±676.8	0.33±0.04
Control at day 1	728.5±36.37	861.26±95.87	186.74±67.09	4378.57±650.08	79.3±35.35	1266.73±203.01	0.45±0.09
HPP at day 1	702.7±39.52	796.29±99.63	169.03±55.02	4173.9±786.68	80.92±39.79	1498.72±351.44	0.57±0.16
Control at day 6	713.5±21.25	776.94±71.7	65.38±18.39	3398.92±591.02	72.36±31.14	1159.1±352.22	0.3±0.08
HPP at day 6	712.3±19.32	790.8±67.33	71.71±27.04	3321.32±676.73	102.2±51.7	901.71±255.64	0.4±0.18

IV.3 Other ways influence

In a first approximation, the passages through the dam or the sluice are considered non-impacting for the downstream.

In fact, studies have shown that significant impact rates can be observed mainly in terms of flow conditions within the structure and energy dissipation downstream from it (Larinier and Travade 1999).

The determination of the specific impacts of each work requires a specific study of each of these which is outside the scope of the Life4Fish program.

IV.4 Considered sites influence

According to the assumptions developed here before, the influence of each site is divided between turbines influence and non-crossing. In the global view, we will thus consider the following influence rates:

Site		Grands-Malades	Andenne	Ampsin-Neuville	Ivoz-Ramet	Monsin	Lixhe
Salmon smolts	Non crossing	18%	16%	20%	14%	100%	42%
	Turbines	1%	5%	5%	7%	0%	1%
Silver eels	Non crossing	0%	0%	0%	0%	0%	0%
	Turbines	9%	2%	4%	7%	7%	0,4%

V. Reaches influence

V.1 Reaches impact

An individual is considered to have crossed the reach if he is present both upstream and downstream.

If the last detection of an individual is established at one of the water intakes (Tihange for reach 2 or Albert Canal for the reach 4), it will be categorized as non-crossing "water intake".

In the case of individuals who have crossed the upstream site but are not present at the downstream site or a water intake, the number of individuals concerned will be compared to the expected impact rate of the upstream turbine crossing. These individuals will not be taken into account in the calculations of the crossing and impact rates at the reach scale as already considered at the site scale.

Finally, fish present upstream and not falling into any of the above categories will be characterized from interrupted descent.

The causes of migration interruption for these individuals within the reach can be:

1. A decrease in swimming capacity after crossing the upstream site due to external and internal injuries
2. A degraded state of health status and stress with a potential depletion of the energetic reserves in eel due to the stress and the effort made to swim through the turbine.
3. Predation within the reach.
4. A physiological stop of migration within the reach espacially for salmon smolts if they face a shift of temperature that can accelerate the desmoltification process.

The following table shows the number of fish present upstream, downstream the reach and at the water intake as well as the number of fish expected to be impacted by the passage within the upstream turbines.

Reach		**CHG-CHA**	**CHA-CHN**	**CHN-CHR**	**CHR-CHM**	**CHM-CHL**
Salmon smolts	Upstream	61	48	30	30	18
	Impacted by upstream site	0,65	2,08	0,68	0,95	0
	Water intake	-	7	-	11	-
	Downstream	38	15	14	4	12
Silver eels	Upstream	57	61	104	107	101
	Impacted by upstream site	4,11	0,79	2,43	6,57	6,2
	Water intake	-	5	-	8	-
	Downstream	47	53	94	89	83

V.2 Considered reaches influence

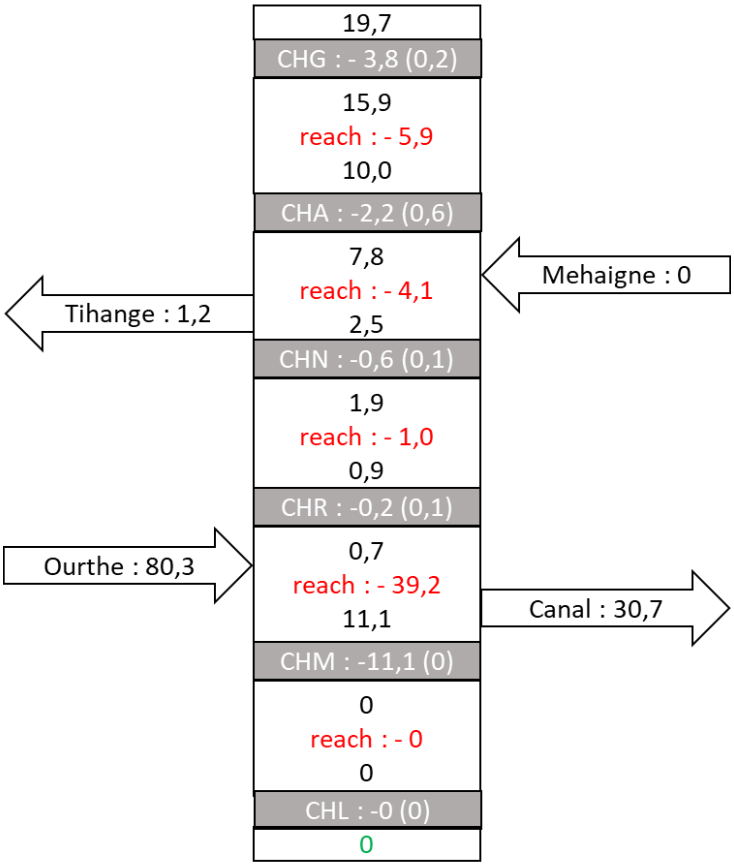
According to the assumptions developed here before, the influence of each site is divided between water intakes influence and non-crossing. In the global view, we will thus consider the following influence rates:

Reach		CHG-CHA	CHA-CHN	CHN-CHR	CHR-CHM	CHM-CHL
Salmon smolts	Water intake	-	15%	-	38%	-
	Non crossing	37%	52%	52%	48%	33%
Silver eels	Water intake	-	8%	-	8%	-
	Non crossing	11%	4%	7%	3%	12%

VI. Downstream migration capacity along the study area

VI.1 Salmon smolts

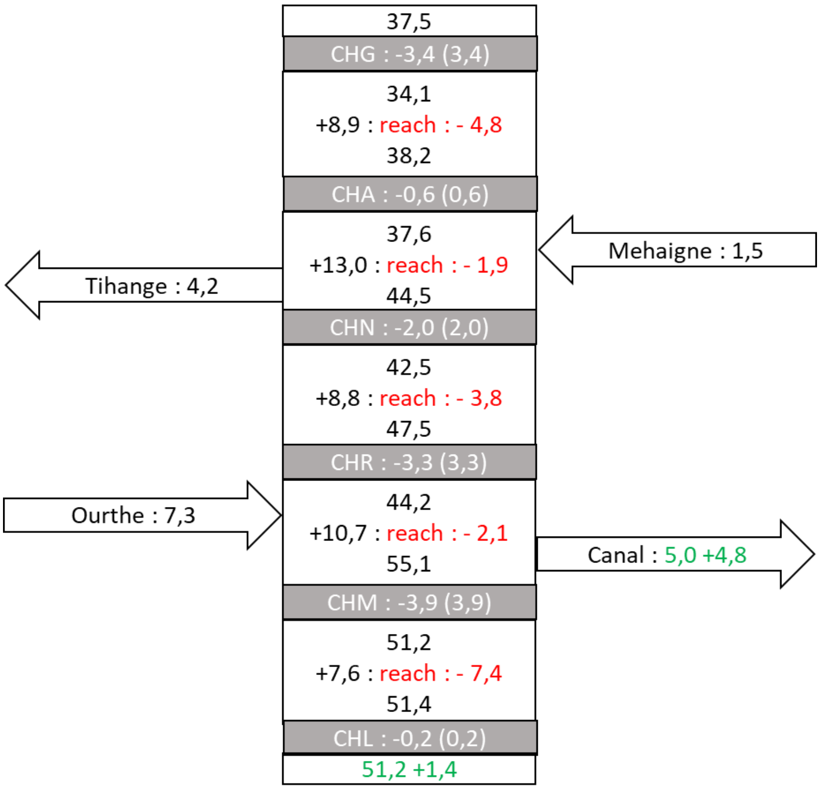
Based on the distribution of stocks and the successive influence of the different elements, the percentage of the stock ending its migration within each element is defined. Thus 1% of the stock would end up impacted by the turbines. 17% of the stock would end up upstream of the sites (non-crossing). 1% of the stock would end up in the water intake of Tihange. 31% of the stock would end up in the Albert Canal. 50% of the stock would end up within the reaches. Finally, 0% of the stock would arrive downstream of Lixhe.



If it is considered that for smolt only the downstream of Lixhe is a potential route of migration, 0% of the stock of the Belgian lower Meuse would have an assured escapement. The major impacts are the disappearances upstream of the site of Monsin (reach, water intake of the Albert Canal and non-crossing site of Monsin). These elements are all related to the management and distribution of flows within this particularly complex node. The extremely low flow conditions during the survey period necessitated equally special management conditions, the impact of which is felt on the results presented.

VI.2 Silver eels

Based on the distribution of stocks and the successive influence of the different elements, the percentage of the stock ending its migration within each element is defined. Thus 13% of the stock would end up impacted by the turbines. 4% of the stock would end up in the water intake of Tihange. 10% of the stock would end up in the Albert Canal. 20% of the stock would end up within the reaches. Finally, 53% of the stock would arrive downstream of Lixhe.



If it is considered that for the eel, the downstream of Lixhe and the Albert Canal are potential routes of migration, 62% of the stock of the Belgian lower Meuse would have an assured escape to these routes of migration. The 20% of the stock remaining in the reaches may be partly made up of individuals still having the capacity to migrate during the next season. Only the overall impact of the plants and Tihange water intake allows to define a confirmed impact on the migration of 18% of the stock of silver eels.

VII. References

De Oliveira E, Tetard S, Benammar I, Erpicum S, Kestemont P, Machiels O, Mandiki R, Pirotton M, Sonny D and Theunissen P (2018). Action A1: Definitions and nomenclature. Life4fish. Downstream fish migration along the Meuse River. LIFE16 NAT/BE/000807. Project Delivrable product. 33p.

European Commission (2007). Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. Official Journal of the European Union, 22.9.2007 L248, 17–23.

Larinier M and Travade F (1999). La dévalaison des migrateurs : problèmes et dispositifs. Bulletin Français de la Pêche et de la Pisciculture, (353-354), 181-210.

Profish (2017). Tests de la télémétrie acoustique Vemco (69 & 180 kHz) et Lotek 416.7 kHz sur le site de Grands Malades. Rapport de synthèse. 06/02/2017. 35p.

Roy R, Beguin J, Watthez Q, Goffaux D and Sonny D (2018). Suivi des smolts de saumon en migration au niveau du tronçon de la Meuse exploité par 6 centrales hydroélectriques. Rapport de synthèse v2.3, 02/10/2018, 81p.

Sonny D, Watthez Q, Goffaux D, Beguin J and Roy R (2018a). Caractérisation des mortalités des turbines sur la Basse Meuse. Rapport final pour les centrales de Grands-Malades, Andenne et Monsin. 4 juillet 2018. 72p.

Sonny D, Watthez Q, Goffaux D, Beguin J and Roy R (2018b). Suivi des anguilles argentées en migration au niveau du tronçon de la Meuse exploité par 6 centrales hydroelectriques. Rapport de synthèse v1.1, 19/07/2018, 68p.

Vlietinck K, Stevens M, Coeck J, Van Vessem J, Philippart J-C, Gomez-da-Silva S and Thirion A (2007). Eel Management Plan for Belgium. Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. 198p.

Bernard, B., Sobandi, K. C., Darras, V., Rollin, X., Mandiki, S. N., & Kestemont, P. (2018). Influence of strain origin on osmoregulatory and endocrine parameters of two non-native strains of Atlantic salmon (Salmo salar L.). General and comparative endocrinology, 258, 205-212.

Bernard, B., Mandiki, S.N.M., Duchatel, V., Rollin, X., Kestemont, P., 2019. A temperature shift on the migratory route similarly impairs hypo-osmoregulatory capacities in two strains of Atlantic salmon (Salmo salar L.) smolts. Fish Physiol. Biochem. https://doi.org/10.1007/s10695-019-00666-x

Wood, C.M., McDonald, D.G., 1997. Global warming: implications for freshwater and marine fish, Society for Experimental Biology Seminar Series. Cambridge University Press, Cambridge.