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DOWNSTREAM FISH MIGRATION ALONG THE LOW MEUSE RIVER

Action A4

Definition of hydropower management rules based on a downstream migration model

Deliverable – adaptation of an existing model to the Lower Meuse conditions

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I. Introduction

Given the linear nature of freshwater habitats, dams and weirs act as anthropogenic barriers that fragment the river. These barriers have frequently been implicated in the decline of anadromous and catadromous fish population because of their effect on upstream and downstream migration (Noonan, Grant, and Jackson 2012). Fish downstream migration is a major concern due to the presence of hydropower plants. Passages through turbine are source of immediate and/or delayed mortality for migrating species, such as salmon and eel. Several mitigation efforts have conducted (e.g. fish passes, operation of turbines shut down…) to restore connectivity and aid with both upstream and downstream fish migration (Clay 1995). Downstream fish passes have been deployed to divert fishes from passing via the turbine (Larinier 2001). They often consist of stopping fish at the intake screen with a sufficiently small bar spacing then guiding them towards a surface bypass (Larinier and Travade, 2002). Intakes with fine-spaced and low sloping racks, either inclined or angled have now proved to be successful (Nettles and Gloss, 1987; Tomanova et al., 2017; Tomanova et al., 2018) but they are dedicated to rather small or medium sized hydropower plants. Technical solutions for large plants are still lacking due to both technical and economical limitations.

The Life4Fish project deals with the ecological continuity and more specifically with the downstream migration of Atlantic salmon smolt (*Salmo salar*) and the European eel (*Anguilla anguilla*). The three major objectives of the project are:

- to increase the survival rate of downstream migrating silver eels and salmon smolts along the Lower Meuse River to 80% and 90%, respectively;
- to enhance operational management possibilities of hydropower plants with integration of fish migration intensity forecast;
- to maximize the renewable energy produced, designed as “green energy”.

The aim of the project is to facilitate the fish downstream migration in the Belgian Lower Meuse. Ambitious species restoration programs are in progress, targeting Atlantic salmon and European eel. The project includes a characterization of population stock and downstream migration routes along the study site. The project proposal includes installation, implementation and monitoring of innovative solutions designed to increase the migratory success of the targeted species. Specific and innovative technologies, such as fish guidance devices and fishways, and new hydropower control strategies will be applied and tested accounting for the downstream migrating process.

This report focuses on methods that will be used to investigate the downstream migration dynamic of the targets species, the Atlantic salmon and the European eel. Indeed, implementing a controlled hydropower management requires predicting downstream migration peaks in order to determine when the operation of turbines must be adjusted or stopped. For the lower Meuse basin, the models for predicting downstream migration peaks will be developed based on historic data, knowledge and the telemetry studies conducted in the project. The aim is to create models capable of being applied to different types of waterways. With such models, it will be possible to propose rules to manage plant turbines so as to optimize the survival rates for migrating individuals and turbine flow rates. Developed models will make it possible to run through a large number of scenarios, for instance, in terms of plant management methods or changes in turbine survival rates.

II. Predicting downstream migration of smolts

The smolt production potential in the Walloon Meuse basin is estimated at 393,000 individuals and is divided as follows: 1/3 from the Meuse River upstream of the confluence with the Ourthe and 2/3 coming from the Ourthe river basin (source). The main part of the smolt production currently comes from the restocking operations. Smolt stock assessment for each production area are necessary to taking account new areas. For the current project, the Ourthe Basin is the priority focus and will be the main production area of smolt. For the next step, the Samson, Lesse and Semois will be targeted as new potential production area of smolts.

The downstream migration model of smolts will be based on a temporal window of the migration related to the river discharge and temperature (Figure 1, step 1), associated with an average swimming capacity required to determine the transit duration in the different river sections (Step 2). The mortality at the hydropower plants will be evaluated based on the results of survival test conducted on the HPP of the Meuse River and on the formulas developed in previous studies (Step 3). Moreover, the data collected during the telemetry surveys will be used to determine the migration velocity and the proportion of fish passing the dams. Indeed, the telemetry experiments revealed that a significant proportion of smolts did not crossed the dams, especially during low flow conditions. This effect can be related to predation risk in the river sections or the loss of favorable environmental cues (temperature, flow condition…) for triggering fish migration. Despite the complexity to evaluate these effects, an estimation of non-passing fish will be provided for each river section using telemetry data.

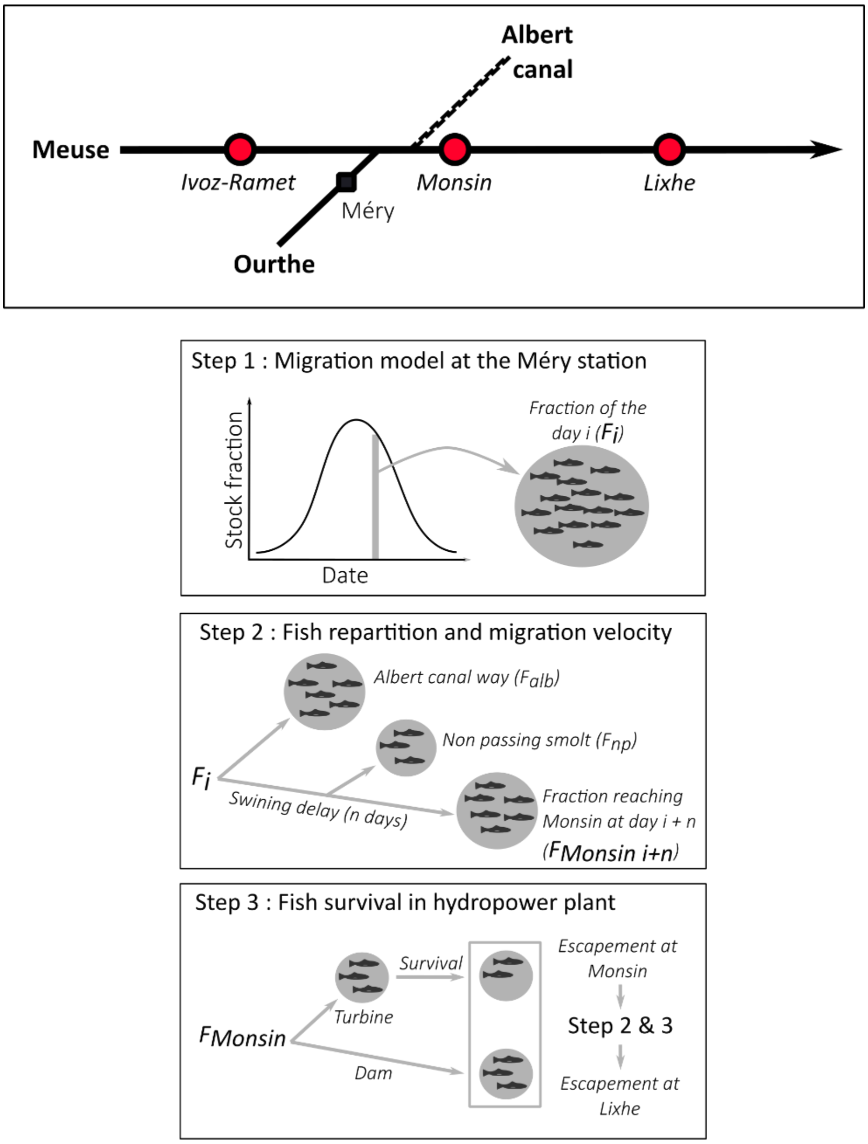

Figure 1 : Schematic view of the downstream migration model for predicting smolts survival at the hydropower plants of the lower Meuse River. The three main steps are presented.

II.1 Migration period of smolts

To evaluate the impact of hydropower plants on the smolt migration, the temporal dynamic of downstream migration should be modeled to predict the probability of passage in the hydropower plants. In European region, the downstream migration of smolts generally occurs during the spring season. Previous studies reported the influence of temperature to control the smolt migration (Jonsson & Ruud-Hansen 1985; Jonsson 1991). A temperature-related smolt window indicates that delays in migration will decrease smolt survival and these negative consequences will be greater in warmer condition (Mccormick et al. 1998). According to results of these authors, a parameter of 400 degree days can be applied as the maximum threshold of the window. Moreover, Antonsson and Sigurdur (2002) indicated that water temperature is the focal point for the onset of the smolt migration. They reported that the smolt downstream migration is triggered when the water temperature reached a minimum of 10°C for the fifth day (not necessarily consecutive) in Icelandic

Rivers. Such an estimate is likely site-specific, but reveals the possibility to adjust a downstream migration model based on temperature data.

To develop a predictive model adapted to the Meuse basin context, the data collected in a trapping station located in Ourthe River (Méry station) will be used to determine the local phenology of smolt migration and the influence of environmental conditions (e.g. Philipppart et al. 2010) The main part of the smolt production of the Meuse basin comes from the restocking operations upstream of Méry in the Ourthe River. Therefore, the Méry station provides direct information on the seasonal variation of smolt production reaching the Monsin and Lixhe hydropower plants. The Liège University conducted the monitoring of the Méry station from 2010 to 2016, providing daily records of the smolts trapped from March 15 to May 31 of each year. When data will become available the phenology of smolt migration will be modeled according to the water temperature and discharge recorded in the Ourthe River. This model will be used to predict the migration peaks and their daily occurrence in the Monsin and Lixhe hydropower plants. Because data from the upper sites are lacking, the same model will be used to determine the migration dynamic of smolts in the Meuse River upstream of the Ourthe confluence.

II.2 Migration velocity and repartition of smolts

The migration velocity should also be estimated to model the fraction of the smolt stock reaching every day the Meuse hydropower plants. The results of the telemetry study conducted by Profish in 2017 (Roy et al. 2017) were used to estimate the fish migration velocity and the maximal velocity (subtracting the river water velocity) for three river sections located in the upstream part of the study area (between Grand-Malade and Ivoz-Ramet). The results revealed that the median velocities ranged from 0.031 m/s to 0.124 m/s, with a large inter-individual variability (from 0.005 to 0.296). As a first approach, a migration velocity of 0.08 m/s (average of the median velocities for the three sections) will be used to model the progression of smolts along the study area. In a second approach, the swimming capacities of smolts will be analyzed in relation to the local hydrological conditions in order to test the possibility of modelling migration velocity according to the river discharge. Such a model could be used to determine more accurately the timing of fish arrival in the hydropower plants.

Once the daily stock fractions reaching the hydropower plants are predicted, the survival can be estimated by evaluating the proportion of fish crossing the turbines using formulas developed in previous studies and *in situ* estimations (telemetry studies on the Meuse River). The mortality caused by the turbines will be estimated based on measurements conducted at each HPP and on the formulas proposed by Larinier and Travade (2002), that account for fish size and dimension of turbines. When available, the data collected during the telemetry surveys (Roy et al. 2017) will be used to estimated local parameters for survival and repartition in the different ways.

The repartition of smolts in the Albert canal and in the ways of the hydropower plants (dam vs. turbines) will be estimated using the formulas developed by Croze et Larinier (2001), which take into account the proportion of diverted flow and the configuration of the water intake. Similarly, the mortality caused by the turbines will be estimated based on the formulas proposed by Larinier and Travade (2002), that account for fish size and dimension of turbines. When available, the data collected during the telemetry surveys (Roy et al. 2017) will be used to estimated local parameters for survival and repartition in the different ways. Finally, the combined model will produce estimate of daily survival for the two hydropower plants located downstream of the Ourthe River (i.e. Monsin and Lixhe).

III. Predicting downstream migration of silver eels

The development of model for predicting downstream migration of silver eels requires determining several parameters, including favorable calendar period and environmental cues triggering the eel migration. In the project, we will apply an existing model developed for forecasting eel migration in the Dordogne river basin, and then we will improved this baseline using data collected on the Meuse based on telemetry monitoring conducted in 2017-2018 (Sonny et al. 2018). Similarly, previous monitoring data collected in the water intake of the Thiange nuclear power plant (from 2006 to 2009) will be used to improve the migration model (Sonny, 2009).

III.1 Migration period of silver eels

The choice of migration period is an important issue because of its influence on the potential number of day for which the operation of turbines must be adjusted or stopped. This migration period can be defined based on historical monitoring data available at proximity of study site. Acou et al. (2019) conducted a bibliographic review suggesting that downstream migration mainly occurs between October and January, but migration events are possible from the end of summer to spring. Specifically, the authors reported a study in the Netherlands (Deelder 1954) where events of early downstream migration occurred in July and August. Similarly, data collected on the intake of the Nuclear power plant of Tihange (Sonny, 2009) demonstrated that the migration period of silver eels occurs from august to February in the Meuse basin (i.e. from 20 august to 28 February).

This temporal window was thereafter used in the project to determine the calendar period during which silver eel downstream migration can take place. A similar migration period was previously proposed for modeling occurrence of eel in the Monsin hydropower plant. Currently, the available data are not sufficient to consider possibility of shifts in the migration period between years. Future investigations could consider the possibility of modelling changes of the onset and the end of migration period, notably as function of environmental conditions encountered during the spring or summer months (e.g. hydrological drought, temperature…).

III.2 Environmental cues

Within the migration period, the downstream migration of eel can be influenced by several environmental factors, including water level, river discharge, turbidity, rainfall, lunar phase, temperature… (e.g. Winter et al. 2006 ; Bultel et al., 2014 ; Durif & Elie, 2008). Nevertheless, the main environmental triggers of eel migration are generally inter-correlated and related to a sharp increase in river flow (Aarestrup et al., 2010). Indeed, the migration peaks essentially occur during increase of water discharge, which are associated with high values of water level, velocity and turbidity.

III.2.1 Methods: influence of environmental cues

An analysis was conducted to determine the main environmental factors influencing the eel downstream migration in the Meuse River, based on the telemetry data collected during the LIFE4FISH project in 2017-2018 (Sonny et al. 2018). In this study, 150 silver eels were tagged with acoustic tags and released at different sites along the study section and 144 fish were thereafter detected by the hydrophone network. A total of 415 attempts of passage were recorded on the six hydropower plants (see Sonny et al. 2018 for details of the passages). To investigate the influence of environmental cues on eel migration, a selection procedure was conducted to remove attempts with incomplete information or resulting from exploratory behavior or delayed migration. Therefore, 80 attempts were excluded from the analysis according to the following conditions: 1) attempt was recorded within eight days following the release; 2) attempt was not detected by hydrophones on the hydropower plant; 3) the fish passage times on the hydropower plant was over than one day; and 4) the passage was not confirmed by downstream hydrophones, with the exception of Lixhe hydropower plant due to the poor detection capacities of the downstream hydrophone. The remaining 335 passages were used to adjust a boosted regression trees model (BRT) to investigate the relative importance of several environmental variables and their marginal effects on the eel downstream migration. BRT provides a flexible approach to model a response variable according to mixed types of predictors (continuous and categorical). Interactions between explanatory variables are automatically considered, as well as complex nonlinear relationships (Elith et al. 2008). According to Trancart et al. (2018), the downstream migration steps were classified as daily presence/absence data, where presence/absence corresponded to daily records upstream of the dam (p = 0) until the first detection downstream of the dam (p = 1). The BRT model was fitted with a logit link function to model the probabilities of passage on the six hydropower plans together depending on the environmental conditions recorded the previous day (d-1).

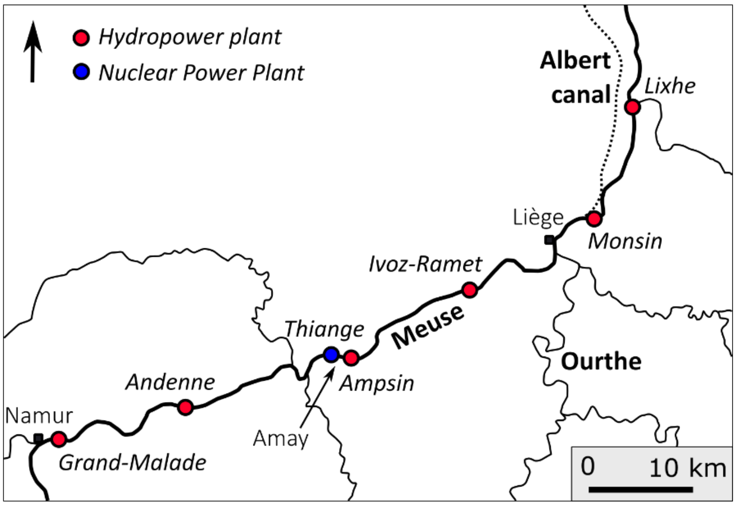

Figure 2 : Locations of the hydropower plants in the lower Meuse basin.

Environmental variables were provided by the Public Service of Wallonia (Direction générale opérationnelle de la Mobilité et des Voies hydrauliques, Département des Etudes et de l'Appui à la Gestion, Direction de la Gestion hydrologique intégrée, Boulevard du Nord 8 – 5000 Namur) and by the Department of Environment and Water (Direction des Eaux de Surface). The water discharge (m3/s) was recorded during the study period on the Amay station. Water temperature (°C), pH, conductivity (K20), oxygen concentration (mg/L), and the turbidity (NTU) were measured continuously on the Lihxe station and the rainfall (mm) at the Landenne station (Figure 2). These measures were considered representative of the conditions encountered over the whole river section where the six hydropower plants are implanted. For each parameter, daily averages were calculated in a format 12h/12h. Based on daily water discharge, delta values were also calculated to identify periods of flow increase within the time series. We calculated delta_1d corresponding to absolute difference of water discharge between the day d and d-1, and the delta_5d corresponding to the difference between day d and a reference period of 5-days. Finally, the lunar phase and the daily duration of sunshine were determined on a calendar basis to evaluate their influence on silver eel migration.

The statistical analyses were performed using R software. The BRT model was fitted following the standard procedure proposed by Elith et al. (2008), using gbm and Dismo packages. The relative importance of the 10 environmental variables was evaluated using the measure proposed by Friedman and Meulman (2003), implemented in the gbm package. Partial dependence plots were produced for the main environmental factors influencing the eel downstream migration (relative importance > 5%). This procedure provides a visualization of the fitted functions in the BRT, by showing the effect of a variable after accounting for the average effects of all others (Elith et al., 2008). A visual exploration of partial dependence plots was performed for interpreting the influence of environmental variables on the probability of eel migration. A deviation of fitted function values from 0 to 1 indicates positive or negative influence of the environmental condition on eel downstream migration.

III.2.2 Results: influence of environmental cues

The BRT model integrating the 10 variables as predictors was fitted with an optimal number of 2 650 trees and explained 47.6% of the total deviance. The model showed high capacity of discrimination with an AUC value of 0.94 ± 0.007, estimated on the basis of cross-validation data. Three environmental variables showed a relative importance above 5% (Figure 3). Delta values reflecting the absolute differences in water discharge were the most influential factors on eel migration, followed by the water turbidity. The contribution of the other environmental variables was below 3.2%.

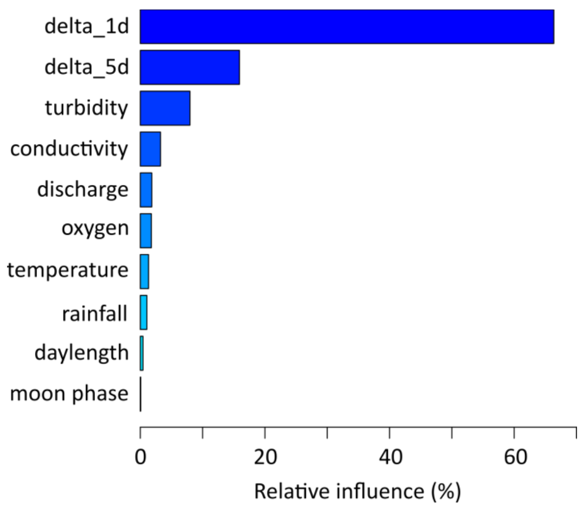

Figure 3: Relative influence of the 10 environmental variables on the probability of silver eel migration on the six hydropower plants of the Meuse River for the migration period 2017-2018.

As previously reported in other studies (e.g. Trancart et al. 2018 ; Acou et al. 2009), delta values of water discharge were more important than only discharge for triggering eel downstream migration. This indicates that events of eel migration can occur in response to sharp change in flow conditions, whatever the current discharge. Moreover, the partial responses for the delta values revealed clear threshold effects (Figure 4) suggesting than probability of eel movement promptly increases when a delta threshold is reached. For delta_1d and delta_5d, the threshold occurred for an absolute difference in river discharge ranging from 25 to 50 m3/s. The partial response for turbidity was more gradual indicating increasing probability of eel migration for higher turbidity values (Figure 4).

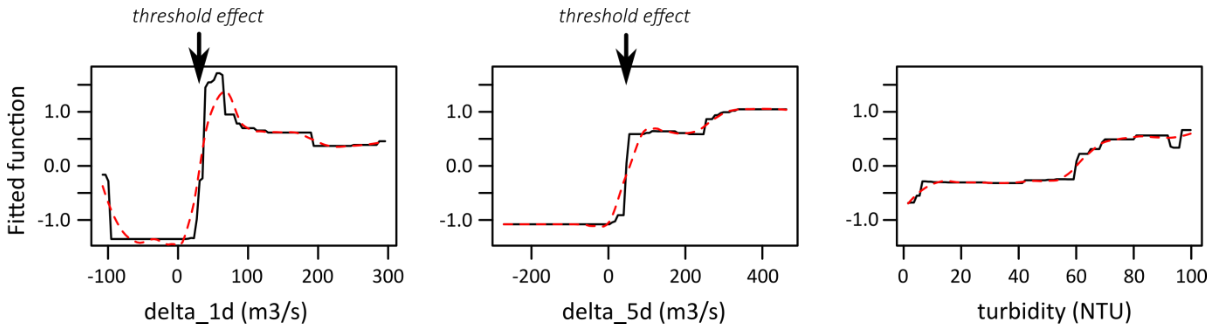

Figure 4: Partial dependence plots of the tree most important variables influencing the probability of silver eel migration on the six hydropower plants of the Meuse River for the migration period 2017-2018.

In summary, environmental cues triggering the downstream migration of tagged eel in the Meuse River during the season 2017-2018 were essentially related to abrupt changes in river discharge. Therefore, using delta values of discharge can provide suitable and parsimonious indicators to forecast the eel downstream migration. Even with slight influence on the migration, the other environmental variables appeared less relevant within an operational context. Indeed, most of these variables are challenging to monitor because of the use of probes needing an important effort of maintenance, especially during high flow conditions when eels are migrating. Although the BRT model indicated that water turbidity should provide additional information, previous experiments on hydropower plant reported the complexity to obtain reliable real time information on this parameter (e.g. Tuilière hydropower plant, Dordogne). Therefore, the monitoring river discharge as trigger of silver eel migration appears a parsimonious and efficient option to develop operational model for hydropower plant management.

III.3 Historical data: the Dordogne model

The model developed for the Dordogne basin (thereafter called Dordogne model) is based on a calendar period of migration associated with thresholds in flow condition triggering the downstream migration. Therefore, this model appears suitable for the Meuse context where peaks of eel migration are highly related to change in the river discharge.

III.3.1 Description of the Dordogne model

The Dordogne model (Courret et al. 2016) is based on daily flows calculated between 12h of the day d-1 and 12h of the day d in order to anticipate change in hydropower plant management the night of the day d when a migration event is predicted. Although the model is strongly site-specific, the proximity of hydrological characteristics between the Meuse basin and the Dordogne basin suggests transposition possibilities as part of a first approach. Indeed, the module of the Meuse River is 260 m3/s whereas that of the Dordogne is 280 m3/s. Similarly, the module of the main tributary of the Meuse (Ourthe River) is 55 m3/s against 58 m3/s for the main tributary of the Dordogne, the Vézère River.

According the last operational version of the Dordogne model (Courret et al. 2016), an event of eel migration is predicted when: 1) the calendar date is included between 1 October and 28 February, and 2a) the discharge gradient is over 35 m3/s in Dordogne compared to the previous 5 days (Q_{d-1} - $Q_{d-2\ to\ d-6}$) or 2b) the discharge gradient is over 15 m3/s in Vézère compared to the previous 7 days (Q_{d-1} - $Q_{d-2\ to\ d-8}$). Once an event of eel migration is predicted, the hydropower turbines are shutdown during the night of the day d from 18PM to 6AM.

As a preliminary approach, the Dordogne model was applied to the Meuse River context using similar flow thresholds, but with an extended migration period from 20 august to 28 February. Moreover, a minimal threshold of river discharge for triggering migration was fixed at 200m3/s. This supplementary parameter was used to constrain the possibility of downstream migration to high river flow condition.

Finally, the Dordogne model modified according the Meuse context based on historical data can be implemented as follow:

- calendar date included between 20 august to 28 February;
- river discharge over 200m3/s;
- discharge gradient over 35 m3/s in Meuse River compared to the previous 5 days or discharge gradient is over 15 m3/s in Ourthe River compared to the previous 7 days.

➔ Once an event of eel migration is predicted, the hydropower turbines should be shutdown during the night of the day d from 18PM to 6AM.

III.3.2 First application of the Dordogne model

The modified Dordogne model was applied to the Meuse hydrological conditions for the period extending between 1 September 2017 and 31 April 2018, corresponding to migration period when eel telemetry tracking was conducted (Sonny et al. 2018). During this period, several flow peaks were observed on the main course of the Meuse River, as well as on its main tributary, the Ourthe River (Figure 5).

According to the model, the flow conditions inducing silver eel migration where encountered for 36 days based on the Meuse discharge and 30 days based on the Ourthe discharge. This results in a total of 37 days of potential migration within the 244 days of the test period, which were essentially concentrated on the five periods of sharp increasing flow.

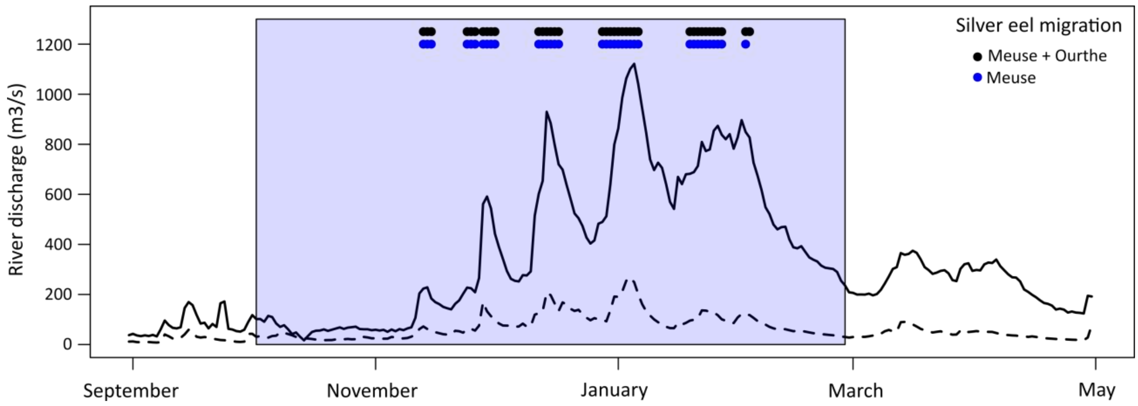

Figure 5 : Average daily discharge recorded on the Meuse River (Amay station, continuous line) and on the Ourthe River (Sauheid station, dotted line) between September 1, 2017 and April 31, 2018. The potential migration days predicted by the Dordogne model are identified for the Meuse (blue dots) and for the combination Meuse and Ourthe (black dots). The gray rectangle indicates the migration period (from August 20th to February 28th).

The telemetry data collected during the LIFE4FISH project in 2017-2018 (Sonny et al. 2018) were used to test performances of the Dordogne model applied for the Meuse context. In this purpose, 371 eel passages (among the 415 attempts) were used after excluding: 1) attempts recorded within eight days following the release; 2) attempts not detected by hydrophones on the hydropower plant; and 3) the passages not confirmed by downstream hydrophones, with the exception of those of Lixhe hydropower plant.

Table 1: Comparison between the migration days predicted by the Dordogne model and the detection of tagged eels on the six hydropower plants on the Meuse River for the period 2017-2018.

	Number of days			Proportion of detection	
	Total	Eel detected	No detection	daily	18PM-6AM
Migration predicted	37	24	13	0.88	0.53
No migration predicted	207	21	186	0.12	0.47
Total	244	45	199	1	1

Among the 37 days for which downstream migration was predicted by the model (Meuse + Ourthe), the presence of eels was validated for 24 days (Table 1). No eel was detected for the other 13 days. These false positive predictions were essentially detected at the end of the migration season, when most of the tagged eels have already migrated downstream (Figure 6). Therefore, it could be expected that migration events occurred during this period if the stock of tagged eels was higher. On the other hand, eel passages were recorded on the hydropower plants for 21 days that were not predicted by the model. These false negative outcomes were generally observed at the beginning of the migration period and outside of the peaks of river discharge. Nevertheless, the proportion of eels crossing the hydropower plants during the 24 predicted days is relatively high, i.e. 88% of the tagged eels (Table 1). This is consistent with the fact that most of eels were migrating during periods of abrupt changes in river discharge.

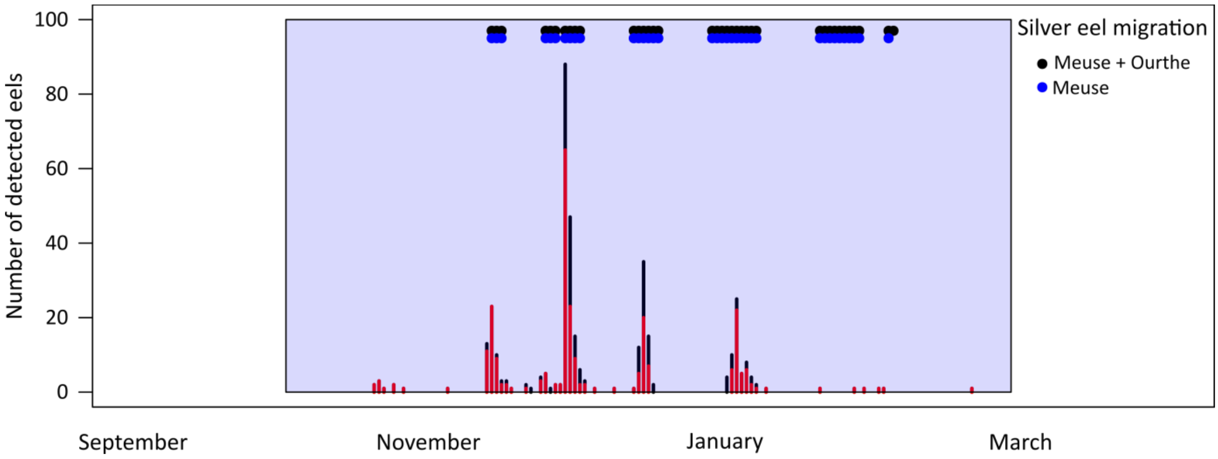

Figure 6: Number of eels detected on the six hydropower plants of the Meuse River between October 2017 and March 2018 (n = 371). The black bars represent all the records, while the red ones indicated the detections between 18PM and 6AM. The potential migration days predicted by the Dordogne model are identified for the Meuse (blue dots) and for the combination Meuse and Ourthe (black dots). The gray rectangle indicates the migration period (from August 20th to February 28th).

The Dordogne model also suggests that eel downstream migration essentially occurs during the night, as reported in numerous studies (e.g. Bultel et al. 2014). Therefore, a temporal window between 18PM and 8AM was fixed to operate changes in hydropower plant management. Using a similar temporal window for the Meuse River, the proportion of eel crossing the hydropower plants drops from 88% (daily records) to 53% (records between 18PM and 6AM) considering the days when migration is predicted (Table 1).

Based on the 371 eel passages, the percentage of detections on the six hydropower plants reveal a peak during the night and 63.6% of eel passages were recorded between 18PM and 6AM (Figure 7). This proportion reaches 78.4% for a time window extended from 17PM to 8AM.

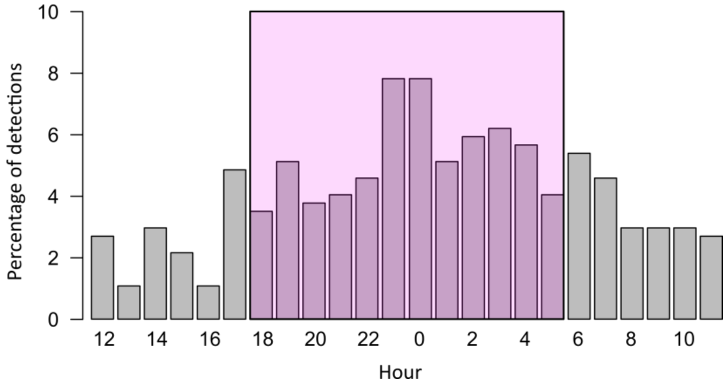

Figure 7: Hourly distribution of eel detections (%) on the six hydropower plants of the lower Meuse (n = 371) from October 2017 to March 2018. The colored rectangle indicates records between 18PM and 6AM.

In summary, the modified Dordogne model applied to the Meuse conditions was able to predict the main peaks of silver eel migration based on discharge data. The model structure based on a calendar migration period and thresholds on hydrological conditions appear suitable to forecast eel migration in the Meuse River. Using water discharge as main migration trigger provides a satisfactory trade-off between accuracy of predictions and acquisition possibility of real-time measurements. Nevertheless, the number of false negative (21 days) and false positive (13) predictions derived from the Dordogne model can certainly be optimized by determining thresholds of delta discharge relevant to the Meuse conditions. Similarly, the temporal window (18PM - 6AM) can be modified to determine the best compromise between silver eel escapement and duration of turbines shutdown.

III.4 Optimizing a threshold model for the Lower Meuse

A methodological framework will be developed within the project to determine the best decision rules based on threshold model (e.g. Dordogne model) for maximizing silver eel escapement and minimizing plant turbines shutdown. This method will be based on numeric simulations to estimate eel escapement and duration of turbines operation, associated with a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This method will make it possible to compare a large number of scenarios and outcomes will be used to determine the best of decision rules to apply given the data collected during the telemetry study. The generic methodological framework could then be used by all electrical operators for the implementation of solutions taking into account the peaks downstream migration of species.

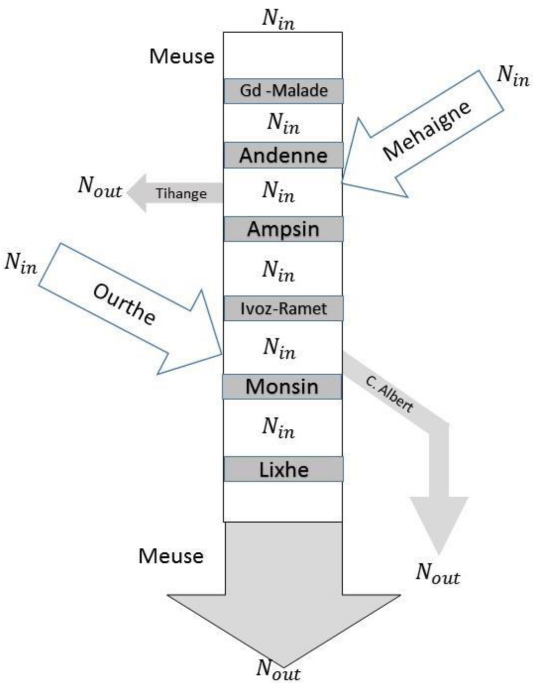

Figure 8: Schematic view of the study area and localization of the different sites considered in the project.

III.5 Developing a general model for eels in the lower Meuse

The distribution of silver stock is not known, the eels are thus considered distributed throughout the main Meuse channel and its tributary river basins. Therefore, downstream migration can occur from the main course of the Meuse as well as from its tributaries (up to the limit of upstream colonization). In the study area, three entering ways will be considered: 1) the upstream the first hydropower plant (Grand Malade), on the Meuse River; 2) the sections of the Meuse river in the study area; and 3) the two tributaries of the Meuse River, Ourthe and Mehaigne Rivers (Figure 8). Three leaving ways will be considered: 1) the downstream Lixhe HPP on the Meuse river; 2) the Albert canal; and 3) the intake of the Nuclear Power plant of Tihange.

To evaluate the migratory success of silver eel, the general model has to evaluate eel repartition and survival along the study area, comprising five river sections and the six hydropower plants. Different methods will be applied to estimate the distribution of eels between the three leaving ways and the ways of hydropower plants (dam versus turbine): 1) flow proportion, ii) logistic models proposed by Bau et al. (2013), and iii) models adjusted from telemetry data. For each hydropower plant, the mortality rate of silver eels will be estimated using the formulas developed by Gomes and Larinier (2008) for Kaplan type turbines. Direct estimates of turbine mortality at Meuse power plants will also be included when data become available. Finally, the combination of these parameters will be used to provide an estimate of the probability than individuals cross the hydropower plant n without damage and reach the upstream of the site n+1.

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