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DOWNSTREAM FISH MIGRATION ALONG THE LOW MEUSE RIVER

Action C3

Installation of an advance remote-controlled hydropower management

Report on the construction of the downstream migration model and the turbine rules

Révision				
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I. Introduction

Action C3 of the Life4Fish program is dedicated to the implementation of specific turbines rules defined based on the eco-hydraulic migration models developed in action A4 both for eels and salmons. The present report focuses on the definition of these turbine rules starting for the proposed migration models.

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 migration dynamics for both species has been studied in the preparatory action A4 of the Life4Fish project (De Oliveira et al 2018).

II. Eco-hydraulic migration models

II.1 Salmon smolts

The model developed for salmon smolts enables to give the cumulative proportion of the stock migrating downstream since the beginning of the migration season. The formulation developed by De Oliveira et al. (2019) during action A4 is the following one :

$$PCum = \frac{\exp(P)}{1+\exp(P)}$$

with

$$P = -3.96419 + PTU_{7°C} \text{ x } 0.00245 + Q_{peak} \text{ x } 2.88322 - PTU_{7°C} \text{ x } Q_{peak} \text{ x } 0.00083$$

This model involved the photo-thermal units accumulated above 7°C ($PTU_{7°C}$) and the peak discharge (Q_{peak}) experienced after the spring equinox, as well as the interaction term between these two factors.

De Oliveira et al. (2019) also analyzed the transfer duration between the Ourthe River (Mery – where the above model was developed) and the Meuse River (Monsin – where the turbines rules should be applied). The travel time of smolts is estimated between 10.1 and 38.2 hours (mean: 15.6 hours) to reach the Monsin site. Accordingly, mitigation measures at the Monsin site should be conducted the day after when a migration run was predicted on the Méry site.

II.2 Silver eels

During action A4, Teichert et al. (2019) developed a model giving for each day the proportion of the silver eel stock that migrate downstream. This model is based on hydraulic conditions observed for last 5 days in the Meuse river in Amay and the predictive discharge conditions for the next 8 hours at the same site.

$$Prop = \frac{\exp(Pred\_lin)}{1+\exp(Pred\_lin)}$$

with

$$Pred_{lin} = \log Qobs_{24h} \times 1.6098 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 2.77051 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 2.05141 - 7.926$$

They also defined the proportion of the daily migrating stock that migrate during a given night time window.

$$Prop_{wind} = \frac{\exp(Pred\_lin\_wind)}{1+\exp(Pred\_lin\_wind)}$$

with

9pm to 3am:

$$Pred_{lin\_wind} = -\log Qobs_{24h} \times 0.9109 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 4.1659 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 0.9073 + 4{,}4909$$

8pm to 4am:

$$Pred_{lin\_wind} = -\log Qobs_{24h} \times 1.2788 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 4.1659 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 0.9073 + 7{,}0336$$

7pm to 5am:

$$Pred_{lin\_wind} = -\log Qobs_{24h} \times 1.6252 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 4.1659 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 0.9073 + 9.3618$$

6pm to 6am:

$$Pred_{lin\_wind} = -\log Qobs_{24h} \times 1.8087 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 4.1659 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 0.9073 + 10.8564$$

5pm to 7am:

$$Pred_{lin\_wind} = -\log Qobs_{24h} \times 1.9751 - \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 4.1659 + \log Qobs_{24h} \times \frac{Qpred_{+8h} - Qobs_{5d}}{Qobs_{5d}} \times 0.9073 + 12.1795$$

The proportion of the silver eel stock migrating in a given night time window is then the product of the daily migration proportion and the window proportion.

This model could be applied in the morning (when discharge predictions are available) to define turbine rules for the night after.

III. Turbine rules

III.1 Salmon smolts

Pilot site for salmon smolts migration model has been defined in Monsin. Even if the model proposed by De Oliveira et al. (2019) enables to refined the migration period definition, a full shutdown of the turbines during this large period (around 30 days) will create energy losses higher than the 5% goal of the project. The pilot test will then be conducted providing a minimum discharge on one gate of the dam to enable fish passage during the migration window defined by the model. The turbine discharge will then be mitigated accordingly to guarantee the dam discharge.

At this time of the project, the minimal discharge still to be defined according to :

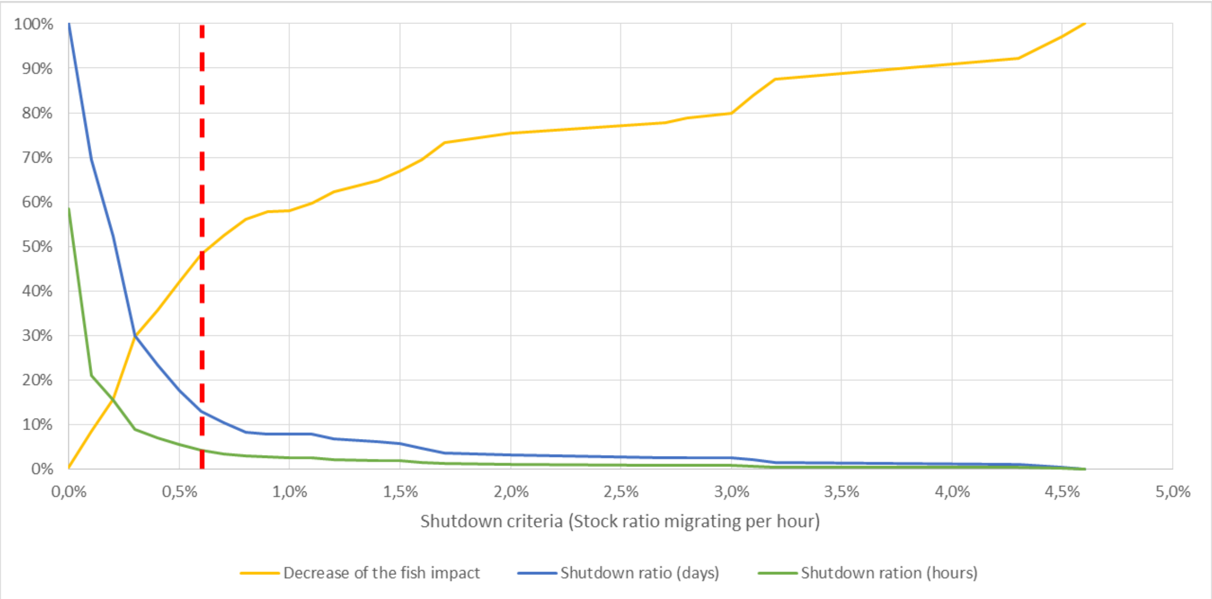
- the study led by University of Liège on dam discharge influence for fish passage,
- the dam capacity to be fixed by the Walloon Region function of the dam works schedule,
- and the project goals in terms of fish survival and green energy production.

III.2 Silver eels

Pilot site for silver eels migration model has been defined in Andenne. After a sensibility analyses, it seems easier and more relevant regarding the project goals (fish survival and green energy production) to perform complete shutdown of the turbines when the migration peaks occurs than discharge mitigation on a larger period.

In order to fix the shutdown criteria, we have to fix the minimal value of stock ratio migrating for which the turbines must be shutdown. In order to do that, we modelled for each day the stock ratio migrating for each night time window defined by Teichert et al. (2019) and calculated the equivalent hourly stock ratio migrating downstream. The turbines are then shut down for each period (each day and each night window) that presents hourly migrating ratios over the shutdown criteria.

The figure below shows the influence of the shutdown criteria on the effectiveness of the mitigation measure both on fish survival and green energy production for the 2017-18 migration period.



In order to guarantee the green energy production goal of the project (less than 5% of energy losses), we fixed the shutdown criteria for the pilot test at 0,6% of stock migrating per hour. This enable to limit the hours of shutdown to 4,1% of the period. The fish impact is then decrease to 48% of the initial impact of the site. According to the figure here over, this value seems to correspond to an inflection point of the curve showing that for an increase of fish protection, the energy losses will be more and more important.

IV. THE OPERATING MODEL

The biological models developed by EDF R&D aim to determine the periods of fish migration. This section describes the implementation aspects of the operating model.

IV.1 THE HYDROELECTRIC DEVELOPMENT

A development on the Meuse consists of a hydroelectric power station, a dam and a lock. In Belgium, particularly in Wallonia, the management of a development is shared between two companies.

Luminus is the manager of 6 run-of-river hydroelectric power stations. On the other hand, Luminus is neither the manager nor the owner of the dam and lock. The owner and manager of its installations is the Service Publique de Wallonie (SPW). It is the regional authority that manages the infrastructure and regulates its use.

Today, the priority concerns navigation on the river. A constant water level must be maintained in order to maintain optimal navigation. The level of the Meuse is guaranteed by both the dam (SPW manager) and the hydroelectric power station (EDF Luminus manager). Close cooperation is therefore established between the two entities.

The priority is to guarantee a water level in line with the SPW's demand, always with the aim of facilitating navigation.

The current piloting of the power station is carried out by operators at the cockpit. On the basis of a level setpoint supplied by the SPW to EDF Luminus, the operators act via a Human Machine Interface on the opening and closing control of the wicket gate.

IV.2 IMPLEMENTATION

A first operational model was carried out on eels. This model is based on the measured flows and the provisional flow evaluated at 7:00 am for 3:00 pm. These data are provided by the manager of the Meuse, the SPW. The measured flows are retrieved from the official site of the SPW, which contains all the flow measurements of the Meuse river.

The forecast flow is sent every day by e-mail to the control center of the Meuse hydropower plants. This flow is calculated using an internal Hydromax software.

The data are entered into the operational model every day by the operators. It is an Excel file with 3 tabs. A tab " Piloting " indicating the history of the turbine’s stops as well as the eventual turbine’s stop of the day. A tab "Amay measurements" allowing the encoding of the measured flows. A tab " Forecast at 7h + 8h Amay " for the encoding of the forecast flow rate.

Luminus is aware that this operational model is not optimal for the control center as it implies a minimum time for the operator to encode the flow rate values. In the near future, the encoding will be done automatically to free up time for the operators.

The eel migration involves the shutdown of the Andenne power plant. The dam must therefore compensate for the flow turbined by the hydropower plant. The flow compensation system has been automated by the SPW to respond to the shutdown of the turbo generator.

On November 7, 2019, a conclusive test was carried out on the shutdown of the Andenne power plant with flow compensation by the dam. The aim of the test was to check the immediate response of the dam to compensate the turbine flow. This test was carried out in partnership between the Luminus teams and the SPW. Some modifications were made during this test. In particular the addition of a "migration mode" button on the control panel of the Seraing PC.

The procedure established jointly with the two companies during a probable migration is as follows:

1- After encoding the data, the model confirms the need for a shutdown and gives the shutdown period for the following night.

2- One hour before the indicated shutdown period, the shutdown sequence is launched.

3- The migration mode is activated at the Seraing control station by pressing the "migration mode" button. The barrier is thus automatically warned of a progressive stop of the machines. The flow will then be automatically compensated.

4- Depending on the flow rate, the machines in operation are stopped one by one, checking that the flow is resumed by the dam. About thirty minutes are necessary to stop all the units.

5- At the end of the downstream migration period, the machines are started one by one, making sure that the dam gates are closed. About thirty minutes are needed to restart all the groups.

6- As soon as there is no more flow on the dam or when the units are at nominal power, the "migration mode" button can be deactivated.

V. References

De Oliveira, E., Teichert, N. and Testard, S. (2019) *Downstream migration model for atlantic salmon smolts in the lower Meuse*, Life 4 Fish project, Downstream fish migration along the low Meuse river, action A4 : definition of hydropower management rules based on a downstream migration model.

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