ATTRACTION AND REPULSION MEASURES FOR SAFE BYPASS OF ATLANTIC SALMON SMOLTS

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While fine mesh trash racks constitute a safe barrier for downstream migrating smolts, such racks can be expensive and technically difficult to retrofit at hydropower intakes. Alternatively, a combination of attraction and repulsion measures can successfully pass fish by the intake and into safe corridors. At the Laudal hydropower plant in the river Mandalselva in Norway, Atlantic salmon smolts were tagged with conventional radio tags during the migration period in four different years. Based on recordings of the migration route, a statistical model could be developed to predict how flow diversion could attract fish into a bypass channel. Additionally strobe lights in front of the intake had repulsing effect during night. In order to create favorable flow diversion at the intake, manipulation of mountainous reservoirs were modeled and the economic cost related to flood spill and flow changes were calculated. Finally, 20 receiving stations were used to collect accurate 3D recordings from 100 smolts with surgically implanted acoustic tags during one migration season. An advanced computational fluid dynamics model was calibrated and applied at the intake to describe the hydraulics at different flow conditions and relate the physical variables to fish movement recordings. The results can be used to generate general rules for safe bypassing of salmon smolts at intakes.

1 INTRODUCTION

Most of Norway's electricity is based on hydro power. Reservoirs provide water during winter, when runoff is small and the demand is large. Power production may also have a diurnal variation since less energy is consumed during the night hours. Hydro power is well suited for rapid load changes, as start-up and shut-down procedures are technically simple and do not involve considerable costs. However, hydropower infrastructure and discharge schemes have caused the reduction and even extinction of numerous Atlantic salmon populations in Europe and along the east coast of North America.

Seaward migration of Atlantic salmon smolts remains a challenge in many regulated rivers as smolts appear to follow the main discharge [1] ,[2] Accordingly, they enter hydropower intakes and eventually go through the turbines. Migration through turbines can cause significant mortality as a result of direct blade strike [3] and delayed mortality due to various sub-lethal effects (Ferguson *et al.*, 2006).

This paper summarizes main findings from Norway's largest Atlantic salmon smolt study, started in 2003, with a main focus on models and measures developed to increase smolt survival past a hydropower intake, by guiding the fish into the old river course.

2 MATERIALS AND METHODS

By use of a rotary screw smolt trap and recordings of a number of physical variables, such as temperature and river discharge, a statistical model was developed to predict when the salmon smolts were expected to arrive at the intake Figure 1). This was a key tool to use for any further measures. Next, fish were radio tagged to identify their choice of route under different hydraulic situations. As part of this, the hydropower company provided flow situations as designed for the experiments, also including economic calculations of revenue loss because of water spill for bypassing of fish.

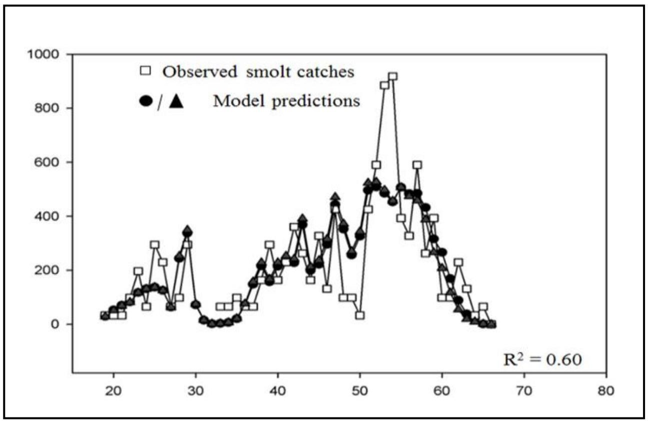

Figure 1. Model predictions for timing of smolt run and observed smolt migration from trap catches upstream of the intake

Strobe lights were mounted at the intake frame to show if tagged fish were scared off from the intake area when the lights were switched on. From recordings of radio tagged fish, it was possible to show if fish migrated into the intake or in the safe bypass and when fish chose to migrate. Based on these data, a statistical model was developed to describe the likelihood for fish to migrate into the safe bypass as function of total river flow and flow partition between intake and the bypass system. This model was used by the hydropower company to maximize smolt bypass rates combined with optimized electricity production.

In the last two years of the study, salmon smolts were tagged with 3D high frequency acoustic tags. In addition, a detailed hydrodynamic model was calibrated for the intake area. A combined eccosounder/RTK GPS/velocity profiler (Sontek M9) was used to collect accurate data of bathymetry and water velocities for model calibration. Preliminary results were used to link fish positions and behavior to flow conditions and migration route.

3 RESULTS

A statistical model was developed to describe the likelihood for smolt to migrate into the safe bypass [5] (Figure 2).

Proportion of total discharge in bypass (%)	Total discharge ($m^3 s^{-1}$) 20	30	40	50	60	70	80	90	100	110	120	130
10	70	63	55	47	39	31	25	19	14	11	8	6
20	76	70	63	55	46	38	31	24	19	14	11	8
30	82	76	70	62	54	46	38	31	24	19	14	11
40	86	81	76	69	62	54	46	38	30	24	18	14
50	89	86	81	76	69	62	54	45	37	30	24	18
60	92	89	86	81	75	69	61	53	45	37	30	23
70	94	92	89	85	81	75	68	61	53	45	37	29
80	96	94	92	89	85	81	75	68	61	53	44	36

Figure 2. Table showing likelihood (%) for smolt to migrate into the safe bypass as function of total river flow at intake and proportion of water in the bypass system. Red line indicate limit (90 %) for desired amount of fish in the bypass.

Tagged fish could be monitored to verify if they migrated into the intake or safely into a bypass over the dam (Figure 3). Further analyses will show the movements of each individual fish, with the objective to better understand the behavior in front of the hydropower intake under various conditions.

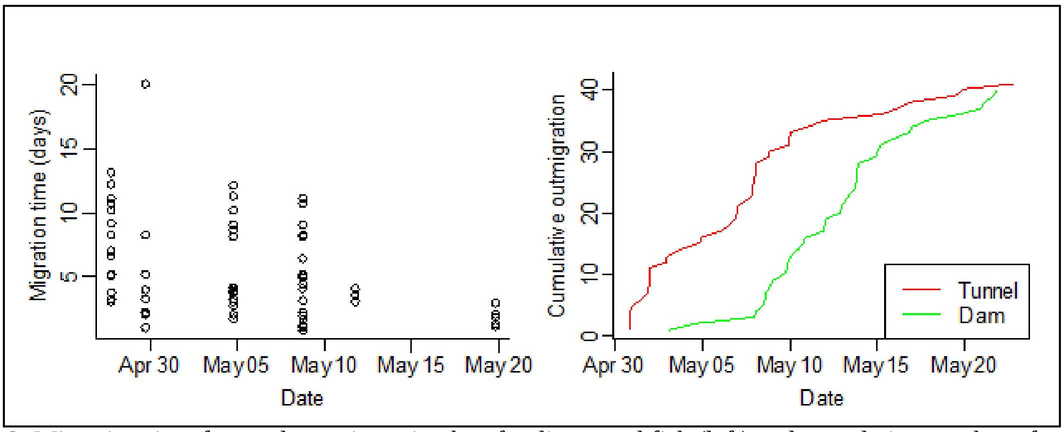

Figure 3. Migration time from release site to intake of radio tagged fish (left) and cumulative number of tagged smolts migrating either into the hydropower tunnel or into the safe bypass over the dam (right).

A CFD model was used to describe the topography and hydraulics in the proximity of the intake (Figure 4). Based on accurate 3D fish position data, calculations from the model could be used to describe the hydraulic variables where fish were observed and also to describe the route of the fish in the forebay area. Further analyses will be conducted in order to give a better understanding of the fish behavior on the study reach, and hopefully contribute to general understanding of Atlantic salmon smolt behavior at intakes.

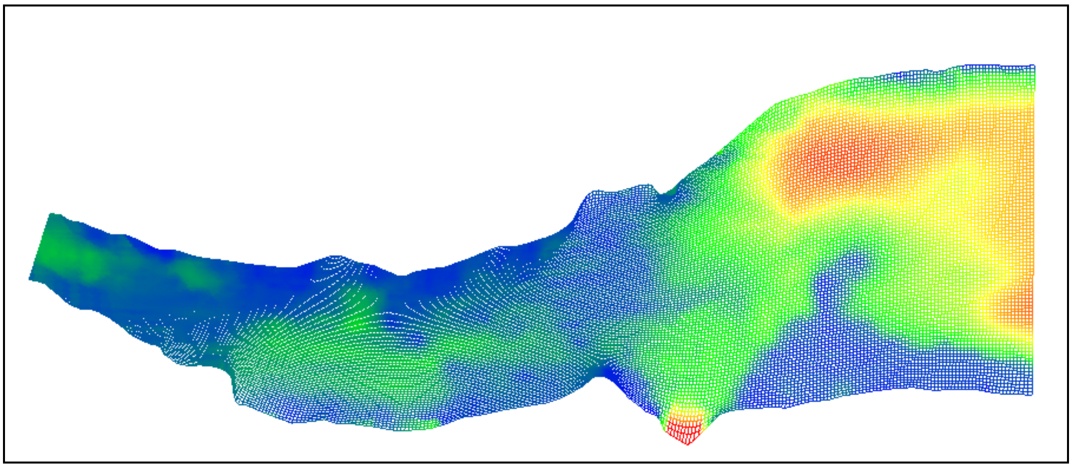

Figure 4. Topographic model of the study reach. The hydropower intake is located in the lower part of the figure, red in color.

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