

ESTABLISHING MITIGATION STRATEGIES FOR SALMONID GRAVEL STAGES IN HYDROPEAKING RIVERS: A FIELD-BASED MODELLING APPROACH

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Egg development in most salmonids occurs in the gravel during winter with hatching and alevin development in early spring. Mortality from redd dewatering caused by rapid fluctuations in water levels due to hydropeaking - short-term variation in flow below hydroelectric power stations - has been documented in a number of salmonid species. Salmonid eggs are found to have the ability to survive dewatered conditions if moist and no frost, but when larvae become dependent on gills for respiration, mortality increases significantly. This may have implications on the fate of larvae in the substrate that becomes dewatered. Located in the hyporheic zone, these early life stages are exposed to surface-groundwater interactions and are dependent on influx of oxygenic subsurface water during regulated low flows for survival. Newly hatched alevins are found more sensitive to surface dewatering than the eggs showing higher mortality rates when exposed to dry conditions. Based on data for discharge, surface and subsurface water elevations, water temperature and survival rates for Atlantic salmon (*Salmo salar*) eggs and embryo in three Norwegian rivers, we modelled the long-term effects of hydropeaking and seasonal regulation in salmonid populations. We compared our results to non-regulated conditions, with a particular focus on gravel stages. The three rivers chosen for this study were the River Gaula, unregulated, the River Suldalsågen, with a seasonal stable regulation, and the River Lundesokna, subject to hydropeaking with high variations in flows. Current mitigation measures in hydropower do not take into consideration all early stages, neither the extent of groundwater influx nor the potential for flexible operations. Modelling exercise are therefore carried out for establishing specific thresholds for egg and alevin survival and for potential mitigation measures such as the reduction of the flow before spawning and for the recommendation of hydropower production during extremely cold air temperatures.

1 INTRODUCTION

Most salmonids spawn and bury their eggs in river gravels in the autumn. The eggs hatch in spring, and the alevins stay in the gravel until they have absorbed their yolk-sac and then emerge from the substratum, for external feeding. Hydropeaking - short-term variation in flow from hydroelectric power stations - produces rapid fluctuations in water levels in the river below. These fluctuations can inundate areas and create temporary suitable habitats for spawning. However, depending on the timing, frequency, duration, and magnitude, these discharge fluctuations can result in periodic dewatering of spawning habitat used by salmonids, leaving salmon redds exposed to dry and even to freezing conditions during winter, potentially increasing mortality rates for eggs and alevins in the redds [1, 2].

The dewatering of salmonid redds is of great concern for water resource management [3]. However, because of complex interactions between physical and chemical intergravel processes, the consequences of dewatering are not always straightforward [3]. Even if the embryo and alevins stages of salmonids are well protected in the gravel, they have no capacity to evade malign abiotic factors such as reduced flow, and therefore also need to be considered when managing flow in regulated rivers. Mortality from redd dewatering has been documented in a number of different salmonid species, but also in redds from non-salmonid species [4]. Being moist and no frost, salmonid eggs have the ability to survive dewatered conditions for weeks or months. When the larvae become dependent on gills for respiration, mortality increases significantly [5, 6, 7, 8, 9, 10, 11]. Key factors are both the hydropower production regime and the influence of groundwater influx to the spawning area.

Primarily we address the influence of regulation type and groundwater influx for the hatching success of Atlantic salmon (*Salmo salar*) in two Norwegian rivers, and we compare it to a non-regulated river. We review

current mitigation strategies to mitigate potential impacts and assess their long-term efficiency given long-term hydrological scenarios with consequent differentiated hydropower production and water releases.

2 METHODS

2.1 Study sites

Three rivers were selected for the studies, Gaula, Lundesokna and Suldalslågen. Field experimental studies to assess egg survival, hatching dates, hatching success and alevin survival were carried out in autumn to spring 2011-2012 in the Rivers Lundesokna and Suldalslågen. The unregulated River Gaula was used for the modelling purposes.

The River Gaula is the largest unregulated river in central Norway and it is listed among the top five Atlantic salmon angling rivers in the country. It has a basin area of 3662 km², mean annual flow of 97 m³s⁻¹ and a total length of 151 km. Upper part is dominated by a gravel/block/rock river bed; lower part mainly gravel.

The River Lundesokna is a tributary to the River Gaula. The Lundesokna is 15 m wide at the study location c.750 meters below the power station. The study site is a 30m long and 20m wide lateral gravel bar with a stable armoured layer present. The lowermost power plant in the River Lundesokna, Sokna, operates according to daily and weekly market price vs. available water in the reservoirs. Hydropeaking therefore results in periodically abrupt flow fluctuations that can change from 20 to 0.45 m³s⁻¹ in less than 20 minutes, with a drop in water level > 0.6 m.

The River Suldalslågen, located in the south west Norway, known for its large sized salmon, is a seasonally regulated river. At the study area, a 100m long and 50 m wide side gravel bar on the southern side of the river c. 1 km below the dam the river is c.75 m wide. Its flow is reduced throughout the year, with an instream flow ranging between c. 12 and 65 m³s⁻¹, depending on time of the year and purpose (smolt migration, angling or flushing), but with a stable minimum flow of 12 m³s⁻¹ during winter (15 December to 1 May) released from the dam. The river discharge was stable during the study period, except for the two smolt migration floods in May.

2.2 Field data

Field experimental studies to assess egg survival, hatching dates, hatching success and alevin survival were carried out in autumn to spring 2011-2012 in the study sites at the river Lundesokna and Suldalslågen. A similar experimental set-up was established in both study sites, based on the main methods developed by [12, 13], and more thoroughly reviewed in [10, 11].

Several cylindrical boxes were placed both in the permanently wetted area (reference) and in the river bed in the drawdown zone of two rivers. Each box was composed by 8 stacking plastic compartments screwed together with an internal height and diameter of 3 and 6.2 cm respectively. Atlantic salmon eggs (acquired from local hatcheries) were introduced to the second and seventh compartments from the top. Several 0.032 m i.d. Durapipe® were inserted in the ground and used to set-up piezometers close to each pair of boxes. Water pressure transducers with integrated temperature loggers were inserted inside each piezometer and provided 1 to 10 min resolution data. Surface water temperature data was also acquired for each of the sites. A more detailed description of the results in both studies can be found in [10, 11].

Additional surface and subsurface water elevations and temperature data was acquired for each of the sites and five additional locations in the Lundesokna and Suldalslågen rivers for years 2012 and 2013. Data on egg survival, hatching success and alevin survival and hatching success from the unregulated river Gaula was obtained from The Norwegian Institute for Nature Research (NINA). Long-term air temperature and discharge data was obtained from the Norwegian Water Resources and Energy Directorate (NVE) for the River Gaula, and the Hydropower companies TronderEnergi (Lundesokna) and Statkraft (Suldalslågen).

2.3 Data analysis

Specific thresholds for egg survival were established in [14] based on the findings of [10], related to egg mortality being minimized when reducing the duration of hydropower production stops particularly during

extremely cold air temperatures. These thresholds will be used in the current project to estimate long-term (2000-2014) egg survival in the Lundesokna River according to water elevations and temperature and air temperature. Field and literature data will be used to establish similar egg survival thresholds for the Rivers Gaula and Suldalslågen [9, 11].

Function and field data of water temperatures is used to estimate egg development time and hatching date for each of the three rivers in the period 2000-2014 [15]. Thresholds on alevin survival will be then established based on available field data for the Lundesokna and Suldalslågen Rivers [16] and on literature and field observation in the Gaula River. They will be used in the current project to estimate long-term (2000-2014) alevin survival based on water elevations and air temperature at each of the rivers and sites. The above will result in a long-term modelling exercise for egg survival, hatching success and alevin survival based on actual hydrological conditions and hydropower operations in all the sites for the three rivers.

A second modelling exercise will be carried out taking into account potential mitigation measures such as the reduction of the flow before spawning in the river Lundesokna and Suldalslågen Rivers. The long-term outcomes of both models will be discussed in relation to the cost-effectiveness of the measures and their impact for salmonid populations.

3 EXPECTED RESULTS

This paper is currently at the analysis stage. Expected results are a long-term overview of egg development, hatching date, hatching success and alevin survival for two different types of hydropower regulation in comparison to a non-regulated river and also the comparison with the potential implementation of targeted mitigation measures. Results from this work will be used to discuss the extent of which current mitigation measures for hydropeaking practices have the potential to aid the survival and development of early-stages in salmonids, which are key bottlenecks in salmonid populations. The outcomes of this research will be particularly relevant for the future management of rivers with hydropeaking. Targeted alternative environmental flow releases to meet specific ecological objectives are often more effective than general operational rules to comply with legislation. The development of well-informed and targeted mitigation strategies is important for future environmental hydropower management [14, 16].

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