ENVIRONMENTAL IMPACTS OF HYDRO PEAKING - WITH EMPHASIS ON RIVER NIDELVA IN TRONDHEIM, NORWAY

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INTRODUCTION

It is well known that rapid fluctuations in river flow lead to a dramatic change in the habitat for the freshwater biota. Previous studies in American rivers have documented numerous biological impacts of hydropower induced flow fluctuations, and some mitigation requirements are suggested by Hunter (1992). Further, scientific studies of biological impacts of hydro peaking are also documented from Norway. Hvidsten (1985) reported large losses of 0+ Atlantic salmon and brown trout in river Nidelva in Mid-Norway, and suggest that the poor recruitment of trout in the anadromous part of the river was due to hydro peaking. Arnekleiv et al. (1994) documented significant cross section zonation of macroinvertebrates linked to the dewatering zones of river Nidelva after a period of hydro peaking. This river has a rich bottom fauna, but the fauna in the shallow zone is very sparse. They linked the reduced diversity to frequent water fluctuations caused by hydro peaking of the river.

The recent deregulation of the Norwegian energy market will most probably lead to increased use of hydro peaking production, utilising the full potential of the hydropower system for daytime power production and running a low production or power import at night time. The effects of such a strategy on the aquatic ecosystem are not well understood, and the Norwegian research council and several power producers have initiated a research program to investigate the impacts on the ecosystem from hydro peaking and to provide tools for analysing the impacts of future hydro peaking projects

A multidisciplinary project lead by SINTEF Civil and Environmental Engineering has been initiated to study the effects of hydro peaking on aquatic ecosystems, called the EFFEKT-project. The project was started in 1997 and will be completed by 2001 to reach the following main objectives:

(a) to quantify the ecological consequences of rapid changes in fluvial water levels on fish, benthos and water vegetation,

(b) to develop management tools and guidelines to decrease the harmful effects of hydro peaking.

To reach these goals, the following subprojects are defined:

1. Field experimental studies carried out in two Norwegian rivers to quantify stranding of juvenile fish (Atlantic salmon and Brown trout) under various climatic and hydraulic conditions.
2. Short-term temporal variation in composition and distribution of available **physical habitats** for juvenile salmonids and benthos analysed at study sites downstream peaking hydropower plants. Both habitat- and bioenergetic modelling for fish will be carried out.

3. **Fish behaviour** and shelter type selection during rapid water level variation investigated in laboratory (Vehanen et al, 1999) and subsequently studied in natural situations using high precision telemetry.

4. **Water vegetation** (moss and algae) and **river benthos** monitored and linked to modelled hydraulic conditions in hydro peaking rivers. Time series analysis to show the impact from the variable hydraulic conditions on the composition and distribution of water vegetation.

5. **Energy consumption and growth** for juvenile fish will be studied to quantify the energetic costs for fish due to rapid and frequent changes in water levels.

All the subprojects will be integrated and results will be analysed together, leading to an overall development of new methods and simulation models to assess environmental impacts of hydro peaking. More information about the project is available at: [http://www.sintef.no/units/civil/water/effekt/hydpeak.htm](http://www.sintef.no/units/civil/water/effekt/hydpeak.htm)

In this paper we will focus on the preliminary results achieved sub project no 1 and 2, namely from the experimental field stranding studies of juvenile salmonids, the habitat use of the drawdown zone and physical habitat modelling at a study sites in the river Nidelva in Trondheim.

**STUDY AREA**

Two hydro peaking operated rivers in Norway were selected for field experimental stranding studies, and habitat analysis under peaking flow. These are river Nidelva in Trondheim and the River Dale close to Bergen, western Norway. This presentation will, however, be concentrated on River Nidelva, which is currently operated as a hydro peaking system, with discharges varying from 30 m$^3$/s to 110 m$^3$/s. The river is 31 km long, with a mean annual flow of 102 m$^3$/s. The river has an anadromous stretch of 5 km, from the sea to the lowermost power plant at Nedre Leirfoss. The study site is located about 1.3 km downstream from the power plant. Dominant fish species are Atlantic salmon (**Salmo salar**) and brown trout (**Salmo trutta**), which also are the target species for this study.

**STRANDING OF JUVENILE SALMONIDS**

For the experimental field stranding studies, large enclosures were built in the drawdown zone of these two regulated rivers. In the River Nidelva the enclosure limited an area of 75 m$^2$ (see figure 1). The enclosure covered the area left dry, and fish leaving the area during flow reduction were trapped in a net bag, which remain under water at minimum flow. The enclosures were stocked with a known number of fish, varying from 50 to 100, depending on year class used ie. appr. 1 to 2 per m$^2$. Fish used were electrofished, and then acclimated for more than 24 hours in perforated cages in the river before they were gently transferred into the enclosure. Here they were given time to hide and establish territories in 6 - 120 hours before the stranding experiment started.

The number of stranded fish was estimated from counting the surviving fish collected in the net bag when leaving the enclosures. In addition, two persons searched for stranded fish in the substrate for ca 30 minutes in each experiment. The experiments were conducted with different
age groups and densities of Atlantic salmon (0+ and 1+) and brown trout (0+), as well as under
day/night situations, at different temperature conditions (winter/summer), substrate coverage,
peaking frequencies and drawdown speed. The results are analysed in a $2^4$ factor design and the
statistical program Minitab is used to estimate the effects of various factors. In this paper, we
only present results as the box plot comparisons.

Figure 1. The 75 m$^2$ enclosure in the drawdown zone of Nidelva, where stranding studies of
juvenile Atlantic salmon and brown trout are carried out during hydro peaking operation of the
river. The location is selected, because it previously is found to be a vulnerable site for
stranding of juvenile fish in the river, and the set up is chosen to study the relative differences of
stranding between various drawdown episodes.

The results so far are only preliminary, and further experiments are planned during 1999. In our
experiments it was difficult to find all stranded fish in the substrate. This finding indicate that
estimating mortality by observing for dead fish in the substrate at natural riverbanks outside
experimental enclosures highly underestimate the mortality and the consequences of hydro
peaking. However, stranded fish were able to survive for several hours within the substrate, but
the survival rate was depended on time of year, most likely because of the temperature.
Figure 2. Diurnal and seasonal responses to stranding frequencies of brown trout and Atlantic salmon from the field experiments carried out in river Nidelva in 1998. The results are presented as box plot comparisons of the stranding index (SI), where SI = 1 represents the worst stranding episode. See figure 3 for examples of flow reduction speed during the experiments at cold water.

In general a far higher stranding of fish was found at low water temperatures during winter conditions (< 4.5° C) compared to high temperatures during late summer/early autumn (Figure 2). These results are in accordance with the findings of Bradford (1997) on chinook salmon (Oncorhynchus tshwytshcha). We assume this is mainly due to lower fish activity during the cold season and that fish to a greater extend hide in the substrate. However, during the cold season the stranding rates of both 1+ Atlantic salmon and 0+ brown trout were lower during night, probably due to a dominating night activity of the species in winter (Heggenes et al. 1993). The tendency was opposite for both species when temperatures were > 9° C, i.e. higher stranding rate during night. Atlantic salmon has the most striking diurnal and seasonal respond to rapid flow decrease, compared to experiments with brown trout.

Within the normal limits of time spent for shutting down the turbines in the Bratsberg power plant, when water levels are reduced from 0.3 to 1.4 cm/min (figure 3), slow dewatering did not lead to reduced stranding rates. However, recent trials conducted spring 1999 with extraordinary long shut down procedures of the turbines during daytime, have shown tendencies towards a decreased stranding of Atlantic salmon. This seems to happen when the time spent for reducing the flow from 70 m³/sek to 30 m³/sek exceeds 2.5 hours at our study site at low water temperatures. Additional experiments are needed to verify this tendency. Reduced frequencies of stranding at slow rate of dewatering is also observed in experimental studies of coho salmon and rainbow trout in an artificial channel at winter water temperatures (Bradfords et al., 1995).
Figure 3. Examples of dewatering rates recorded at the enclosure site, 1.3 km downstream the outlet of Bratsberg power station, during the stranding experiments conducted in river Nidelva from 23 November to 16 December 1998.

PHYSICAL HABITATS FOR FISH AND BENTHOS DURING HYDRO PEAKING

An approximately 100 x 200 m reach of the river Nidelva surrounding the enclosure site has been surveyed in detail, and the hydraulic conditions have been modelled in two and three dimensions on several discharges using the SSIIM model (Olsen, 1996). A method based on fish preferences has been used in combination with a suite of spatial metrics describing the habitat composition in the study reach and the variability of spatial distribution of physical habitats during changing discharges (Borsanyi, 1998). Discharge time series from the peaking hydropower plant have been used to describe short-term temporal variation in both composition and distribution of available physical habitats for fish. A bioenergetic model developed at NTNU is also being tested at this reach.

The following discharges have been simulated in SSIIM: 30, 50, 70, 90, 110 m³/s. 30 m³/s is the minimum flow discharge, 70 m³/s is the water flow when one turbine is running in the Bratsberg power plant, and 110 m³/s represents full production with two turbines. The intermediate discharges are used in the habitat assessment process.
The depth distribution of the reach has been calculated based on the output from SSIIM for all discharges with a depth interval of 0.1 m, and the velocity distribution is found in intervals of 0.1 m/s. In a similar fashion the substrate distribution is grouped by using the Wentworth scale. The distributions show a strong reduction in available habitat with velocities in the 0.10 – 0.70 m/s range as the discharge increases from 30 to 110 m$^3$/s. Similarly a reduction in depths in the 0 – 0.8 m is found with the same discharge change. However, these habitat assessments are done at this specific reach as an example, and the tendencies should not be extrapolated to the entire river. The data shows that for the production discharge most of the habitat with depth and velocity in this range is found in the shallow areas that are dried out when the production is halted.

The hydraulic modelling done with SSIIM provides a reliable foundation for modelling the physical parameters needed in a habitat analysis. In this application of SSIIM the modelling system produced good results without the need to alter the roughness values in a calibration procedure. Still more field data is needed to further validate the model predictions, particularly on a micro scale level. For detailed studies of flow conditions in the drying and wetting zone, a more detailed grid may be necessary. At the moment this is too costly in SSIIM, but the new version of the program will support nested grids where a very detailed sub-grid can be inserted into a coarser grid of the entire reach.

**PRELIMINARY CONCLUSIONS AND FURTHER WORK**

The preliminary results of the physical habitat modelling at one selected reach in river Nidelva show that the habitat with the typical usable features are found in the areas affected by the drying and wetting process due to the hydro peaking operation. Further studies will include a subdivision of the reach to analyse changes in habitat in the different areas in the station. Similarly fish habitat will be categorised further when the preference curves are available. The next stage of this subproject is expected to yield more data regarding the available habitat and also methods to assess the effect of different ramping rate on the distribution and configuration of available habitat.

A preliminary conclusion of the experimental stranding studies in river Nidelva is that temperature, or season, and light conditions seem to have the most pronounced effect on stranding of juvenile salmonids affected by hydro peaking. However, the duration of the drawdown episodes is of importance for the stranding rates. The results so far show clear tendencies that ecologically adjusted operational procedures of hydro peaking power plants could lead to reduced stranding of salmonids.

All the subprojects of the "Effekt-project" will be integrated and results will be analysed together, leading to an overall development of new methods and simulation models to assess environmental impacts of hydro peaking.
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