HYDRO POWER AND EEL (KRAFTTAG ÅL)

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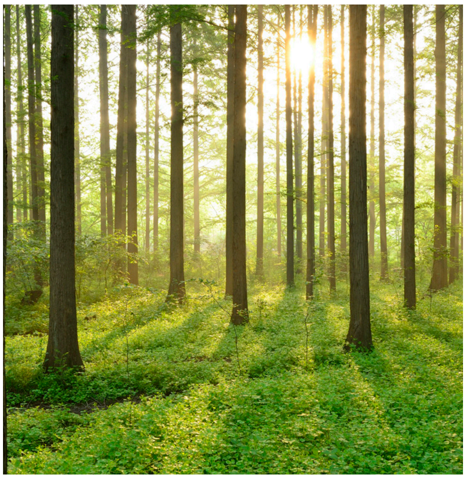

KRAFTTAG ÅL

Energiforsk

Hydro power and eel (Krafttag ål)

Measures and Research

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Foreword

The Krafttag ål programme was carried out through the cooperation of several hydro power companies and the Swedish Agency for Marine and Water. This final report gives an overview of the research, development and measures from 2015 to 2017.

In 2010 six hydro power companies and the Swedish Board of Fisheries agreed on the memorandum of understanding. The Swedish Agency for Marine and Water took over the role when the Swedish Board of Fisheries was decommissioned. The program Krafttag ål commenced in 2011 with the objective of transforming the memorandum of understanding into actions to positively effect eel stocks.

The stakeholders in the programme were Fortum Sverige AB, Holmen Energi AB, Karlstads Energi AB, Skellefteå Kraft AB, Sollefteåforsens AB, Statkraft Sverige AB, Sydkraft Hydropower AB, Tekniska Verken i Linköping AB, Umeå Energi AB, Vattenfall AB, Vattenfall Indalsäven AB and the Swedish Agency for Marine and Water.

Steering group of the programme:

Erik Sparrevik (chairman)	Vattenfall Vattenkraft AB
Niklas Egriell	Swedish Agency for Marine and Water
Johan Tielman	Sydkraft Hydropower AB
Marco Blixt	Fortum Sverige AB
Rikard Nilsson/Jan Lidström	Holmen Energi
Henrik Jatkola/Angela Odelberg	Statkraft Sverige AB
Ola Palmqvist/Katarina Ingvarsson	Tekniska Verken i Linköping AB
Sara Sandberg (adj.)	Energiforsk

Stockholm May 2018

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Sammanfattning

Programmets verksamhet var uppdelad i två delar: åtgärder samt forskning och utveckling. Två typer av åtgärder genomfördes inom programmet. Dessa var fångst och nedtransport av utvandringsfärdig ål samt utsättning av importerade ålyngel på västkusten. Sju utvecklingsprojekt bedrevs inom programmet.

En bärande tanke med avsiktsförklaringen är att åtgärder sätts in där de gör mest nytta. Enligt Ålförvaltningsplanen betraktas Sverige som ett enda ålavrinningsområde för att vidtagna åtgärder ska bli maximalt kostnadseffektiva med störst effekt i form av ökad blankålsutvandring.

Mellan 2015-2017 transporterades drygt 47 000 utvandringsfärdiga ålar förbi kraftverk i fyra vattendrag. Ålarna fångades, transporterades och släpptes nedströms det nedersta kraftverket. Åtgärden genomfördes i Göta älv, Motala ström, Lagan och Ätran. 1,2 miljoner importerade karantäniserade ålyngel sattes ut på västkusten. Målet för åtgärder som var knutet till åtgärder vid vattenkraftverken nåddes 2015 och 2016. Målet som inkluderar omräkning av ålyngel nåddes 2016 och 2017.

Forskning- och utvecklingsprojekten gav ny kunskap om ålars vandring, skonsam drift och låglutande fingrindar. Rapporter från utvecklingsprojekten finns att ladda ner från Energiforsks webbsida.

Summary

The Krafttag ål[1] programme comprised of two parts: measures and research. Two types of measures were conducted. The first was the trap and transport of silver eel. The second was the stocking of imported glass eel on the Swedish west coast. In total, seven R&D projects were carried out.

The basic idea with the memorandum of understanding was to implement measures where they could be most effective. In order to create cost-effective measures and in accordance with the 2007 eel management plan, Sweden is considered as one single catchment basin for eel. Between 2015 and 2017 about 47 000 downstream migrating eels were transported past hydro power plants in four rivers. The eels were caught in lakes, transported and released downstream from the hydropower plants nearest the sea. This trap-and-transport was carried out in the Göta, Motala, Ätran and Lagan rivers. 1.2 million imported quarantined glass eels were released on the Swedish west coast. The programme's goal on hydro power related measures was achieved in 2015 and 2016. The goal included an estimate of the silver eel population as a result of glass eel stocking, and was reached by 2016 and 2017.

Seven R&D-projects resulted in new knowledge on eel migration, adaptive hydropower management and the use of low sloping intake racks. The full-text reports from the research projects can be downloaded from Energiforsk's website.

[1] "Kraft" is Swedish for power. "Ål" means eel. "Krafttag" is an expression that means taking action.

List of content

1 Background

The population of the European eel Anguilla anguilla (L.) is in severe decline (Dekker, W. 2015). The reasons for this decline are uncertain but may include overexploitation, pollution, non-native parasites, diseases, migratory barriers and other habitat loss, mortality during passage through turbines or pumps, and/or oceanic-factors affecting migrations. These factors will affect local production differently throughout the eel's range. (ICES 2017)

1.1 EUROPEAN EEL LIFE CYCLE

European eel life history is complex, being a long-lived and widely dispersed stock. The shared single stock is genetically panmictic and data indicate the spawning area is in the Sargasso Sea. The newly hatched leptocephalus larvae drift with the ocean currents to the continental shelf of Europe and North Africa where they metamorphose into glass eels. The growth stage, known as yellow eel, may last typically from two to 25 years (and could exceed 50 years) prior to metamorphosis to the "silver eel" stage and maturation. The amount of glass eel arriving in continental waters declined dramatically in the early 1980s, and has been very low in all years after 2000. (ICES 2017)

The eel stock in Sweden occurs from the Norwegian border in the Skagerrak on the west side, all along the coast to about Hälsingland (61°N) in the Baltic Sea, and in most lakes and rivers draining there. Further north, the density declines to very low levels. According to the Swedish Eel Management Plan, all of the Swedish national territory constitutes a single management unit. (Dekker, W. 2015).

1.2 EEL REGULATION

In 2007, the European Union decided on a Regulation (No 1100/2007) establishing measures for the recovery of the stock, which obliged Member States to implement a national Eel Management Plan by 2009. Sweden submitted its plan in 2008, (Jo2008/3901). The common limit for all these plans is an escapement of at least 40 % of the silver eel biomass relative to the escapement if no anthropogenic influences would have impacted the stock and recruitment would not have declined. (Dekker, W. 2015).

1.3 SWEDISH EEL MANAGEMENT PLAN

Based on the eel regulation, Sweden wrote an eel management plan. The initial phase is focused on measures that rapidly increase the migration of silver eel to their spawning areas. One of the goals is that 90 % of the silver eel that currently could be produced and sustained in Swedish waters will survive and contribute to ongoing reproduction. The plan focuses on four different measures: further reduction in the fisheries, reduced hydro power related mortality and increase in stocking of imported glass eel.

In addition to the downstream migration of silver eel, which is the subject of the EU regulation, the upstream migration of young eels in inland waters is an important issue in order to utilise all eel habitats. Such measures will be taken, but are not included in the present plan. (Anonymous 2008)

1.4 MEMORANDUM OF UNDERSTANDING

In 2010 a voluntary memorandum of understanding was signed by six hydro power companies and the Swedish Board of Fisheries. The purpose was to reach the goal of 40 percent survival on downstream migration within five years', of the implementation of the national eel management plan 2009. In order to achieve this, several methods were employed. The choice of method depended on local factors, with the options including:

- Establishing fish passage past the hydro power plant
- Adaptive hydro power management during periods of large silver eel migration
- Trap and transport past hydro power plants
- Compensatory measures (for example re-stocking)

The rivers chosen, were generally selected based on where measures would result in the widest positive effect on silver eel migration. If possible, measures that would achieve long term solutions for all types of fish migration should be chosen. Because the national eel management plan considers Sweden as one catchment basin for eel, this enables a cost-effective choice regarding which measures should be taken and where. Rivers which have a larger number of hydro power stations, but few eels, can generate unreasonable costs compared to their overall contribution to the sustainability of silver ell migration. From a biological point of view, there is little risk with this approach, as the European eel, contrary to most other species, consists of one single genetic population.

1.5 FROM MEMO TO ACTIONS

The Krafttag ål programme started in 2011 with the role of transforming the memorandum of understanding into action. During the first phase of the program, eight research and development projects were carried out. The projects increased knowledge on eel survival when passing hydro power plants and offered suggestions for technical solutions for downstream passage. A modelling tool was developed calculating the survival on eel passage at a specific plant. Prior to that, a standard figure was used for all types of hydro power plants. Some R&D projects were theoretical, some involved field studies.

The continuous phase of the program, was motivated by an identified need for further studies and measures in this field. In 2014 the measures were evaluated by two eel experts from the Swedish University of Agricultural Sciences (SLU). One of the recommendations was to expand trap and transport.

The steering group arranged a workshop where R&D topics were discussed. Conclusions and results from R&D projects were an important input in the planning of the next phase. The steering group identified eight prioritised areas of development and sent a request to potential project leaders. A number of the proposed project descriptions resulted in R&D projects.

The collaboration between hydro power companies and the Swedish Agency for Marine and Water (SWaM) continued during the phase that ran from 2015 to 2017. The Swedish Energy Research Centre (Energiforsk) managed the program. The projects included measures as well as research and development. The measures were funded by hydro power companies. The R&D part of the program was equally financed by the hydro power industry and SWaM. The programme description gives an overview of the program, including aims etc.

1.6 AIMS FOR THE PROGRAMME PERIOD 2015-2017

The program had three comprehensive goals:

- Increase knowledge of hydro power and eel
- Reduce the hydro power related impact on eel stocks
- Increase the silver eel downstream migration in Swedish waters

2 Measures

According to the memorandum of understanding, measures should be taken where they have the largest impact. From 2015-2017 glass eel stocking as well as trap and transport of silver eels were carried out. Initially testing the adaptive management of power plants during periods with large silver eel migration was carried out to discover if R&D studies showed any potential for being a cost-effective measure. A study on adaptive management was done and reported at the end of 2017. Hence, adaptive management was not carried out as a measure during this phase of the programme.

2.1 AIM

The specific aim for measures during this programme period was that measures taken should be equivalent to 100 000 silver eel per year, that migrates from Swedish waters. Whereof at least 15 000 derives from measures by the hydro power plants. A yearly follow up should take place.

2.2 RESULTS

The measures were followed up at least once a year. The table below shows the outcome of the measures. The calculation from glass eel to silver eel assumes that approximately 20 % of the glass eel mature to silver eel. This assumption makes it possible to compare the measures taken, to the above-mentioned aim.

Outcome (eels)	2015	2016	2017	Total
Glass eel	333 050	423 035	459 574	1 215 659
Estimated silver eel equivalents from glass eel stocking	66 610	84 607	91 915	243 132
Trap and transport	16 328	15 950	15 278	47 556
Total	**82 938**	**100 557**	**107 193**	

Table 1 About 1.2 million imported quarantined glass eels were released during 2015-2017. The aim related to hydro power plants was achieved in all three years. The overall goal was achieved 2016 and 2017, including the recalculation from glass eel to silver eel.

2.3 GLASS EEL RESTOCKING

Restocking of glass eel is a well-known, measurable and cost-effective method. Although, the impact on the silver eel stock comes about 15 years after the release of the young eels.

Restocking of young eels has been going on since the 1970ies, primarily to create and maintain a basis for a professional fishery. Lately, the motive for restocking is to build a larger population in order to increase the migration of silver eel. (translated from SLU Akvatiska resurser 2018). Eel migration has been studied for many years. Recently, researchers found evidence of the migratory routes that Nordic eels follow on their journey back to the spawning grounds in the Sargasso Sea. The study also showed that eels stocked in western Sweden followed the same migration route as ordinary migrating eels and that they displayed natural behaviour in many other respects as well. Many eels could be tracked for over 2,000 kilometers, which is the furthest anyone has ever managed to track migrating eels. (SLU 2017)

2.4 TRAP AND TRANSPORT

Trap and transport of silver eels passing hydro power plants was an important measure in the Krafttag ål programme. This method has an immediate positive effect on eel populations. The measures were carried out in the catchment areas of the Göta, Motala, Ätran och Lagan rivers. Those river systems are assumed to hold relatively large populations of eels and/or an infrastructure allowing an effective trap and transport.

Initially, it was stated that inspections of the transported eels would take place. This was eventually re-defined as site visits by an eel expert. Recommendations and conclusions from the site visits were reported to the steering group.

As part of the follow-up on the measures, journals were filled in by those who were responsible for carrying out the measure. The steering group did a thorough review of 2015’s journals and in some cases journals from 2016. One purpose of the review was to give feedback to the people who filled in the journals and discuss whether there were any specific observations. Another purpose was to exchange experiences in the steering group, of the measures in the different rivers.

3 Research and development

3.1 THEME

The R&D had three overall themes: Adaptive management, Fish passages and Eel migration.

Adaptive management during periods with large downstream migration of eel is a relatively untested method. Hence, the steering group identified a need for research and development to study opportunities and challenges for this measure. Regarding **fish passages**, two issues were pointed out: How can low sloping racks and other downstream passage facilities be designed in an appropriate way? What technical challenges and uncertainties arise when upscaling the technical solutions and implementing them at large hydro power plants? The third theme was eel migration. The purpose was to increase knowledge of the behaviour and migration adjacent to the hydro power plant and how that knowledge can be used in practice. This theme was related to adaptive management.

The R&D projects were carried out during 2015 and 2017 resulted in eight reports. In the following chapters, the English summaries from the reports are presented. Full-text reports (in Swedish) can be downloaded from energiforsk.se.

3.2 ADAPTIVE HYDROPOWER MANAGEMENT

Project managers: Henrik Jeuthe, Swedish University of Agricultural Sciences, Department of Aquatic Resources and Kjell Leonardsson, Swedish University of Agricultural Sciences, Department of Wildlife, Fish, and Environmental Studies

The current report aims to summarize the state of knowledge concerning adaptive hydropower management in connection to eel migration, and to evaluate the potential for such mitigating measures to be applied at hydropower facilities in the eel producing river systems of Göta älv and Motala ström in Sweden. The investigation comprised primarily a literature review based on internet search as well as inquires through collaborative networks within research, environmental management and power companies. Visits to hydropower facilities and interviews with technicians and management on site were also included to determine the practical potential of implementation at the specific facilities.

The authors' interpretation of the concept "skonsam drift" is that it includes measures where adaptive hydropower management is implemented during fish migration season (in this case downstream silver eel migration) to facilitate safe passage. The measures include three types of adaptations:

- Adjusted flow, and passage, through the turbines
- Turbine shutdown (complete or partial) and passage via substantial spill
- Implementation of temporary intake barriers and passage via moderate spill

The prerequisites of the facility in question determine which measure should be applied. There is no universal solution that works for all types of facilities. In general, adjusted flow through the turbines comes with the lowest cost, but has a limited mitigating effect as some mortality will remain even at optimal turbine operation. Complete turbine shutdowns will eliminate all turbine induced mortality, but the extent of such measures will of course affect the cost in lost production. The implementation of temporary, adaptable, barriers at the turbine intake will, in additions to running costs, entail investment costs unless most of the infrastructure is already in place.

One of the most important prerequisites for implementation of adaptive hydropower management is the ability to predict eel migration. There are a number of potential early warning systems available for this purpose. They can be based on changes in the environment that trigger eel migration, indicators of theactual migration or direct observations of migrating eels. Different types of early warning systems, existing and potential, are described within this report. An optimal warning system should be able to tell when and how many eels are heading for the hydropower plant, and preferably also when the eels have passed, and normal operation may resume. The literature review in this report indicates that no early warning system meets these criteria today. In some cases, systems have been shown to work with more or less acceptable accuracy, but these results are limited to application at specific sites.

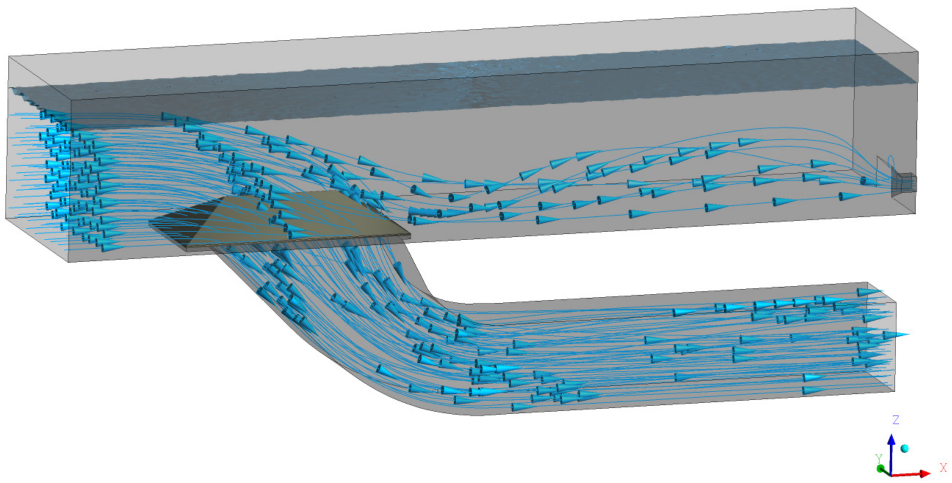
The authors' assessment of the potential for implementation of adaptive hydropower management suggests that measures that involve complete turbine shutdown is not suitable for the facilities in Göta älv. Passage via spillways at the facilities in question is likely to cause extensive injury and mortality to the eels. This assessment is based on visual examination of said spillways. However, this needs to be investigated further if implementation is considered. A more suitable action (according to the authors) would be to completely divert the discharge from the Francis-turbines of the Olidan station to the more eel-friendly large Kaplan-turbines at the Hojum station, during eel migration (generally August - October). In connection to this measure, discharge through the facilities at Vargön and Lilla Edet should be adjusted to minimize mortality during turbine passage.

For Motala ström, the authors assess that complete turbine shutdown is both a possible and suitable mitigating measure during silver eel migration. The extent of the shutdown period can be limited with application of a suitable early warning system. As an alternative, the cost of extensive turbine shutdown periods could perhaps be lowered by re-examination of the current regulations concerning spill through Norrköping city.

The development of adaptive hydropower management as an efficient mitigating measure will be a challenge. At the current state of knowledge it is not possible to resolve the issue of hydropower induced mortality quickly. An alternative would be to use the knowledge we have to efficiently capture as many as possible of the silver eels upstream of the uppermost hydropower plants, and transport them for release downstream of the last obstruction. This should not be meant as a final solution, but is justified in short term by the alarming situation of the eel population.

3.3 EVALUATION OF NEW DESIGN FOR INTAKE RACK

Projekt managers: Anders Andersson, Gunnar Hellström, Staffan Lundström, Luleå University of Technology, Fluid Mechanics, Fluid and Experimental Mechanics and Kjell Leonardsson, Swedish University of Agricultural Sciences.



Figur 1 Proposed design for eel passage.

Computational fluid dynamics simulations have been used to evaluate the potential for eel migration at a small scale hydropower plant. A suggestion for a new 'eel-friendly' intake rack was developed and investigated. The general flow in the intake chamber was evaluated and two possible problem areas were identified as the turbine intake and the spillways.

For small scale hydropower plants with flush mounted, horizontal intake racks there is a large risk for impingement of fish on the intake rack. Earlier studies have shown that racks with low angles relative to the bottom are effective at minimizing this risk. Therefore, a new design for intake rack is designed here to prevent eels from migrating through the turbine and at the same time keep them from impinging on the rack. The simulations show that the velocity at the rack rarely exceeds the velocity recommendation for impingement prevention and never exceeds the maximum velocity that impinged eels can escape from.

Earlier studies have shown that eels prefer spillways at the bottom of the channel and therefore several different configurations of spillways are simulated at the end of the intake channel. The difference of having two small spillways compared with one larger is evaluated regarding flow field and spill flow. All simulated cases show that the maximum velocity near the spillway gates is close to 10 m/s and that the maximum velocity gradient is 50 m/s per meter for one spillway and 85 m/s per meter for two small spillways. An alternative design of spillways with a contraction is simulated to reduce these gradients.

The contraction reduces the maximum velocity gradient that an eel would encounter with about 50% and spreads it out over a longer area but increases the amount of spill flow (with ~14%). The simulations show that the different configurations of spillways result in very similar velocities at the outlets but that a larger spillway has lower velocity gradients compared with a smaller one.

3.4 DOWNSTREAM PASSAGE FACILITIES

Project managers: Olle Calles, Karlstad university and Axel Emanuelsson, Norconsult AB. In the project group: Fredrik Mikaelsson, Marie Böjer, Frans Göransson, Johan Östberg, Urban Öhrfeldt, Ylva Hemfrid-Schwartz and Petter Norén, all from Norconsult. Peter Christensen, R2 Resource Consultants was engaged contributing with international expertise.

The most common way of improving downstream passage conditions at hydropower plants is to use low-sloping racks to guide fish to and through bypasses. There are examples in the literature with such downstream passage facilities with a documented high passage survival for silver eels, but the examples have until now been limited to plants with an intake capacity of < 88 m^3/s. It is not known to what extent the technique can be upscaled to plants with an intake capacity exceeding this. The experience from Sweden was mostly positive and there was no obvious connection between the size of the plant and the experiences of production and generation at plants with low-sloping racks. Applying the technique to plants in the rivers Motala ström and Göta älv, however, showed that site-specific challenges have a significant effect on the feasibility of implementing low-sloping racks at these plants. Still, the technique was considered applicable to the Älvås plant in the river Motala ström, whereas the high costs and uncertainties identified for the Vargön plant in the river Göta älv revealed an important knowledge gap. Before implementing a low-sloping rack at any plant with a high dam safety rating, there is a need for improved knowledge to avoid problems resulting in unexpected costs and failures.

Figure 2 Power plant in Göta älv. Photo Norconsult.

Previous projects within the ”Krafttag ål” research program concluded that, from an eel management perspective, there was a high priority for improving downstream passage conditions for silver eels at plants in the rivers Göta älv and Motala ström. Furthermore, stemming from the general knowledge gap on downstream passage solutions, a feasibility study on upscaling the technique from

small to large hydropower plants was recommended, emphasizing the need for a collaborative approach including both biologists and engineers. Consequently, the goal of the current project was to identify possibilities and challenges with implementing low-sloping racks to hydropower plants both with an intake capacity exceeding that of previous projects and highly prioritized in Swedish eel management.

To gather information on the experience from existing downstream passage facilities using low-sloping racks, a survey among representatives from owners of such facilities showed an overall positive experience of operating the existing facilities (n=7). The owners reported very limited, in some cases even a reduced, head-loss, and the racks did not have a negative effect on plant operation. Conventional automatic cleaners scored the best performance, but manual cleaning of the racks was required to solve the problem of gradual accumulation of debris on the racks, which typically is the case also for conventional racks. There was no clear relation between the size of the plant and the perceived effects on production and generation, but there was a tendency of increased capital expenditure with increased plant intake capacity.

The Älvås hydropower plant is the first obstacle encountered by silver eels migrating downstream from the Lake Roxen in the river Motala ström, and so the location has been highly prioritized for implementing a downstream collection facility. The three turbine intakes are equipped with 110 mm bar racks, the total capacity is 90 m^3/s and the dam has a low dam safety rating. There is no automatic cleaner, i.e. the racks are manually cleaned, and macrophytes occassionally block the racks causing periods without production. A low-sloping angled rack designed for the Älvås plant was 4 m deep with a total wet area of 180 m^2 and 18 mm bar spacing. During extreme floods the rack can be removed completely to minimize the risk of blockage. Silver eels approaching the facility would be guided to a bypass and onwards to a collection facility for a continued transport downstream past all the remaining obstacles situated downstream. The estimated capital expenditure was 24-28 MSEK and the corresponding annual operational expenditure was 0.5 MSEK. In spite of uncertainties resulting from site-specific challenges, the conclusion was that a low-sloping angled bar rack can be implemented and operated at the Älvås plant in the river Motala ström.

The Vargön hydropower plant is the first obstacle encountered by silver eels migrating downstream from Lake Vänern in the river Göta älv, and so the location has been highly prioritized for implementing a downstream collection facility. Two of the turbine intakes lack racks, the total capacity is 930 m^3/s, and the dam has the highest dam safety rating. There is no automatic cleaner installed, i.e. the rack is manually cleaned, and frazil-ice and macrophytes occassionally block the rack causing periods without production. A low-sloping angled rack designed for the Vargön plant was 10 m deep with a total wet area of 1400 m^2 and 18 mm bar spacing. During periods of high risk of drifting ice the upper panels of the rack can be raised to minimize the risk of blockage. Silver eels approaching the facility would be guided to a bypass and onwards to a collection facility for a continued transport downstream past all the remaining obstacles situated downstream. The estimated capital expenditure was 280-350 MSEK and the corresponding annual

operational expenditure was 3-4 MSEK. In spite of uncertainties resulting from site-specific challenges, the conclusion was that a low-sloping angled bar rack can be implemented and operated at the Vargön plant in the river Göta älv. Taking the high costs, uncertainties and severe consequences of a potential failure into account, implementing a low-sloping angled rack at the Vargön plant can't be recommended at this time.

In conclusion, the fish passage solutions evaluated at plants with 72-88 m^3/s intake capacity can technically be designed for and implemented at the Älvås and Vargön plants. The estimated capital and operational expenditures would be high, and there are still problems to be solved, but nevertheless it was concluded that a low-sloping rack can be built and operated at the Älvås plant in the river Motala ström, whereas there is a need for improved knowledge before implementing a low-sloping rack at the Vargön plant in the river Göta älv. The current project did not include a socioeconomic evaluation of these projects, which was considered as the next important step to take as part of the process.

Figure 3 Aerial photo Motala ström. Photo: Norconsult.

3.5 HYDRAULIC CONDITIONS AND BEHAVIOUR OF THE EELS AT THE HYDROPOWER INTAKE

Project managers: Kjell Leonardsson and Gustav Hellström, Swedish University of Agricultural Sciences, Department of Wildlife, Fish, and Environmental Studies, Henrik Jeuthe, Arne Fjälling and Johan Östergren Swedish University of Agricultural Sciences, Department of Aquatic Resources, Johan Leander, Umeå university, Daniel Nyqvist and Olle Calles, Karlstad university.

In order to design and implement mitigation measures for successful downstream migration of silver eels a holistic approach is needed that accounts for many different aspects. Improved knowledge on what triggers the eel migration has been made possible in the project by the development of a new statistical method for analysis of behaviours triggered by changes in the environment. The use of high resolution acoustic telemetry allowed studies of the eels' swimming behaviour close to the hydropower inlet. The telemetry study also showed that direct and delayed mortalities for eels that passed through the turbines were comparable in magnitude. Difficulties in separating live from dead eels after turbine passage contributes to uncertainties in survival estimates from these types of studies.

The aim of the project was to investigate if it is possible to predict the downstream migration of silver eels, and to verify the predictions by catch data. The focus has been on initiation of migration, timing of arrival, behaviour and choice of migration route when arriving to hydropower stations, and survival after turbine passage. We also tested and evaluated sonars as a potential “early warning”-systems.

The investigations were performed in Motala ström, Norrköping. High-resolution acoustic telemetry was used to study the eels' swimming behaviour at the intake to Holmen's hydropower station. This method can provide a 2D positioning accuracy of decimetres. 60 eels were tagged with high-resolution tags and 34 of the eels were also tagged with depth sensors to allow the swimming depth of the eels to be registered. The tagging and the release of the eels were performed from the end of July to the end of August 2016.

The statistical method for what factors that initiate eel migration in freshwater identify significant environmental variables, quantifies the trigger response, as a function of these variables, and predicts the eel migration the following days given that the environmental variables are quantified on a daily basis. Applying the method on autumn data from the river Skärhultsån, 2011-2013, showed that the flow contributed most to the migration, but moon phase and day length also entered as significant variables. Water temperature improved the model slightly. With minor changes in the flow parameters the model could successfully predict the migration (catches) in Ätran (Ätrafors), and to some extent also in Mörrumsån, but not in Kävlingeån.

The eels with acoustic tags mainly followed the main stream, some distance above the bottom, during their downstream migration that took place during night-time. The behaviour of the eels at the hydropower intake and at the spill area varied between individuals despite similar hydraulic conditions. A majority of the eels displayed a search behaviour. The hydraulics or the characteristics at the hydropower station intake and at the spill gates frequently made the eels hesitate and turn away, resulting in 25 % passage probability per visit. The average survival was about the same, ca 36 %, for eels that passed the Holmen's hydropower station or for those that passed via spill gates. The eels that passed via spill gates also had to pass the hydropower station, Bergsbron/-Havet, further downstream before entering the sea. It was unclear what made the eels hesitate or pass. Five out of 19 eels that entered the spill area when most of the water was spilled (>20 m3/s) passed via the spill gates. Seven out of 16 individuals passed via 2 m3/s spill when the flow through the turbine was between 30 and 40 m3/s. In order for adaptive flow management of the hydropower plant to be a safe alternative for the eels, knowledge is needed on how the spill gates should be shaped in relation to the amount of spill flow to attract eels.

The eels spent just a few minutes in the area near the intake to the hydropower station or in the spill area independent if the eel passed or not. This means that a detection system for adaptive flow management of a hydropower plant needs to be implemented further upstream in the river since the swimming speed in the downstream migration often exceeded 0.5 m/s, which were faster than the highest water velocities in the area.

3.6 EVALUATION OF SONAR AS AN EARLY WARNING SYSTEM FOR DOWNSTREAM MIGRATION OF EEL

Project managers: Henrik Jeuthe and Arne Fjälling, Swedish University of Agricultural Sciences, Department of Aquatic Resources.

Results from the study show that the resolution of the DIDSON Long Range was insufficient for indisputable identification of eels at any distance. Hence, it cannot be considered suitable as a warning system in rivers the size of Göta älv. It would be difficult to say with certainty that the registered echoes come from migrating silver eels. The degree of uncertainty would be affected be the number of other fish species and object of similar size are present and likely to pass the sonar at the given location. Eels could be positively identified at up to 25 meters distance using the ARIS sonar. The standard DIDSON had a somewhat shorter range for positive identification. Hence, both ARIS and DIDSON could be used to monitor eel migration in smaller streams. However, this requires knowledge of the eels' swimming pattern at the given location, and that a representative portion of the eels pass through the sonars field of view. The project comprises studies on the European eel's downstream migration from onset, including its triggers, behaviour upon arrival at the hydropower station and finally passage. The project is reported in two parts. The current report (part two) is an evaluation of imaging sonars as potential technology for detecting downstream migrating silver eels. This technology is thought to provide an early warning on migrating eels in real time, which could be used to switch to eel friendly turbine management at the hydropower station. Three types of imaging sonars were included in the study, ARIS Explorer 1800, DIDSON 300 and DIDSON 300 Long Range (all from Sound Metrics Corp.). The potential of the sonars was evaluated through studies on migrating silver eels both in connection to the Holmen hydropower station in the river Motala ström, Norrköping, and during release of so called "trap & transport" eels downstream of the Lilla Edet hydropower station in the river Göta älv. Information on other's experiences on the use of imaging sonars for fish monitoring was gathered from collaborators and literature search were also included in the evaluation. This theoretical evaluation also covered the possibility to attain automated real time detection, which is a requirement for this technology to be used as an early warning system. According to the literature, ready developed software for automated detection of eels is available for DIDSON (Bothmann et al., 2016). The software can, supposedly, give warnings in near real time. Prior to implementation of imaging sonars as warning system for eel migration, existing automation software needs to be evaluated or new software developed. In addition, more knowledge on eel swimming patterns in different pristine environments is needed.

3.7 STUDIES ON THE EEL POPULATION AND EEL MIGRATION VIA FISH COUNTERS

Project managers: Mats Hebrand, Viktor Hebrand and Anders Eklöv, Fiskevårdsteknik.

Data from seven different control stations with fish counters in six rivers has been analyzed with the purpose of establishing a basis on how existing fish counters can function to record the migration of eels. The analysis shows that adult eels can be successfully registered in fish counters with a camera. For the registration of upstream migrating eel, fish counters installed in nature-like low gradient fishways worked best. For the registration of downstream migration, fish counters installed in fishways with a high relative flow and fishways located near fish diversion devices worked best. However, several of the counters were placed unsuitable for registration of eel.

Results from the study show that; The eel's migration began in spring (April - May) when the temperature rose above 5 - 7 ° C and ended in the fall (October - November) when the temperature went below 6 - 8 ° C. During the spring and autumn, the eel was mainly migrating downstream, but during the summer an upstream migration of adult eels also occurred. The size of the eel varied between 50 - 110 cm and the eels were most active during night. During spring, increased water temperature was the most important factor for the migration of eels, while in the autumn it was increased water flow.

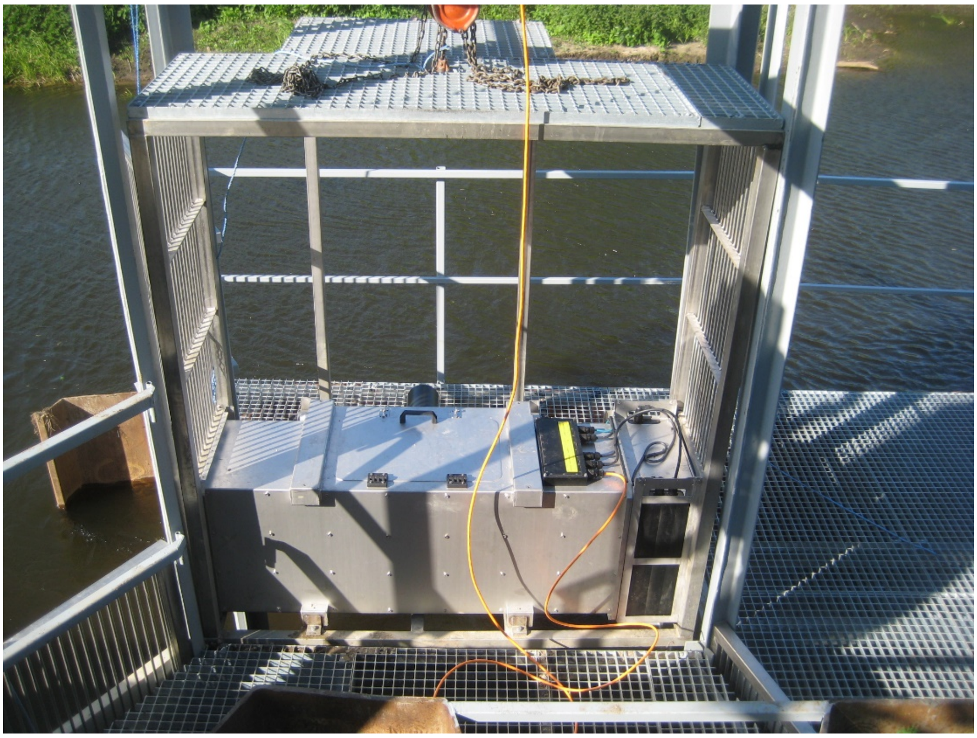


Figure 4 Vaki RW fish counter

From the knowledge gained, it is possible to decide where and how counters are to be placed to register migrating eels successfully. A good location may be in an existing fishway where a relatively high proportion of the flow passes through the fishway and the counter. In this survey, two control stations with fish counters were deemed to work well for registration of eels. These were Köpingebro in Nybroån and Herting in Ätran.

For control stations to be installed to record downstream migration of eel, the appropriate location may be at power plants fitted with screen adapted to prevent the passage of fish. The counters can be placed in connection with escape opening and migration path. A suitable location is proposed at Herting in Ätran, where a β–fish screen has been installed that directs downwards migrating fish to an opening and a bypass. The bypass has an integrated fish trap where placing a fish counter would be suitable. Other suitable stations may be at power plants that are equipped with fish screen, such as Ålgårda in Rolfsån, Finsjö in Emån and Hedefors in Säveån.

There are good possibilities for monitoring eel stocks by creating a control station customized for downstream migrating fish where the majority of the downstream migrating adult eels passes and are counted with a fish counter. The results can provide valuable information about the eel stock in the river basin and how the stock changes over longer periods of time.

3.8 ALTERNATIVE TRAP FOR COLLECTION OF JUVENILE EELS

Project managers: Jonas Elghagen (fd Christiansson), Elghagen Fiskevård and Johan Watz and Olle Calles, Karlstad university.

During July and August, 2016, a floating trap for collecting juvenile eels was evaluated downstream of the hydroelectric power plants Laholm and Ätrafors in Rivers Lagan and Ätran. The floating and mobile trap was designed to reduce the length of the climbing distance while maximising the width of the entrance. During the trials, the trap was compared to a conventional eel ladder, fastened to the river bank.

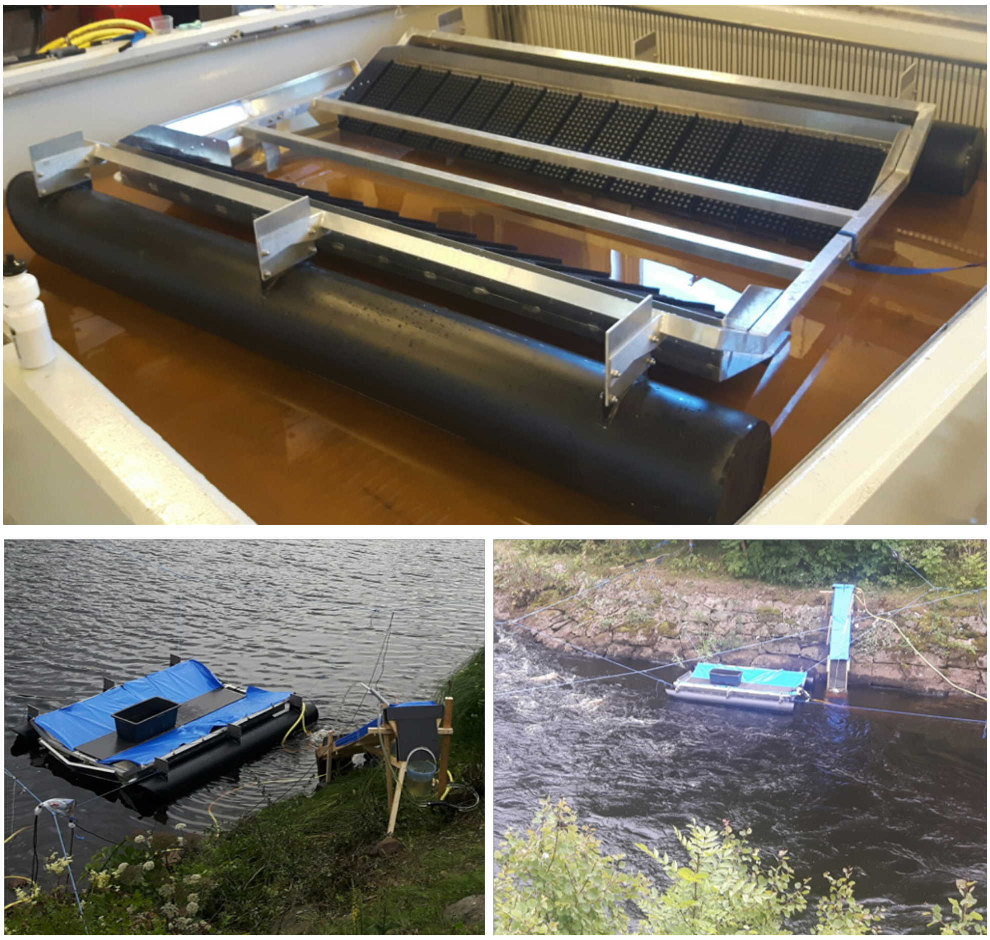


Figure 5 Above: The floating collector under construction. Below: Testing the floating and control, A) Laholm. B) Ätrafors

The Laholm hydropower plant was only in operation during the day throughout the study period due to little rain and warm air temperatures. Therefore, the trap was tested during the day between 08:00 and 14:00 when the hydropower plant was in operation and at night between 20:00 and 08:00 in zero discharge. To test the trap also in running water at night, the trap was moved to Ätrafors hydropower plant, which was in operation both day and night. At Laholm, the floating trap caught on average 11 eels per day and 44 eels per night, whereas the conventional trap did not catch any eels during the day and 8 eels per night. In Ätrafors, the floating trap caught 1.5 eels per night, whereas the conventional trap did not catch any eels. Wilcoxon signed-rank tests revealed that the floating trap caught more eels per hour than the conventional trap in all three trials (Lagan, night: $Z = 2.52$ $P = 0.012$; Lagan, day: $Z = 2.81$, $P = 0.005$; Ätran, night: $Z = 2.81$, $P = 0.005$). Furthermore, we evaluated the possibility to pump juvenile eels with ejector technique (by means of the venture effect) to facilitate transport of collected eels from the trap. The venture pump successfully pumped juvenile eels through a 5-m-long tube up to 1.5 m height, and the pumped eels did not show any signs of injuries. The results from this study show that the efficiency of today's conventional method of collecting upstream migrating juvenile eels can be improved by using a floating trap, enabling managers to better use the natural migrating juvenile eels as a resource in trap-and-transport stocking.

3.9 THE IMPORTANCE OF BAR SPACING IN LOW-SLOPING RACKS

Project managers: Daniel Nyqvist and Olle Calles, Karlstad university and David Aldvén, Vattenfall AB

The purpose of this project was to study how the bar spacing in low-sloping racks impacts the guidance of eel. The hydraulic properties and problems regarding floating debris were also to be investigated. The theory was that low-sloping racks divert eels both by physical and behavioural means, which means that eels that physically could pass through the rack would not always do so. Due to delays in construction and to reasons of animal welfare, it was decided to postpone the experiment. The plan is to conduct trials with three different bar spacings during 2018, outside Krafttag ål.

The knowledge about downstream passage solutions is limited, as a result there are uncertainties about how to design solutions that provides both good conditions for generation and safe downstream passage conditions for fish. Today there are a number of downstream passage facilities at small and mid-sized power plants, which have shown to efficiently pass eel, trout and salmon without any negative consequenses for operation and safety.

Figure 6 The new test facility, a flume at Vattenfall Laboratory. Photo: David Aldvén

4 Communication

Projects, reports and news from the programme were communicated via Energiforsks' website www.energiforsk.se.

Two leaflets (in Swedish only) have been published. One final leaflet in English and Swedish will be produced.

Two well-attended seminars have been arranged. One in the autumn of 2016 in Stockholm. A year later the final seminar was held, also in Stockholm. Presentations from the events were published on the website energiforsk.se.

The release of glass eels in the summer of 2017, created some attention in the local media.

Figur 7 A leaflet presenting results from measures and R&D projects.

5 List of references

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HYDRO POWER AND EEL (KRAFTTAG ÅL)

The programme Krafttag ål consisted of two parts; protective measures and research and development. The programme was carried out through the cooperation of several hydro power companies and the Swedish Agency for Marine and Water.

This final report gives an overview of the research, development and measures from 2015 to 2017. Between 2015 and 2017 about 47 000 downstream migrating eels were transported past hydro power plants in four rivers. 1.2 million imported quarantined glass eels were released on the Swedish west coast. Seven R&D-projects resulted in new knowledge on eel migration, adaptive hydropower management and the use of low sloping intake racks.