

# **HYDROPOWER – environmental impacts, remedial measures and costs in regulated waters**

**Assessment by the Scientific Review Panel**

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# Conclusions and Recommendations

## Conclusions

This programme has funded five different projects, aiming at applied research into the environmental consequences of hydropower. The scientific quality and project success are variable. Two of the projects are very similar, studying fish migration past hydropower dams, and both have been very successful. The others exhibit lower rates of success, for different reasons. One general short-coming of the projects is the very low rate of publication in peer-reviewed journals.

The most successful projects are numbers 1 and 2 in the listing below. They are similar in their approach and methods applied, but one is conducted in a large mountain river and the other in a smaller lowland river. Both have generated new knowledge, published papers in international journals and occupied a number of students in their work, two of which have obtained their doctoral degrees as a result. Project 3 has failed to demonstrate the validity of its basic research hypothesis (that of an impoundment-driven oligotrophication process in reservoirs), and the project fails to provide *new* useful and scientifically sound solutions. Project 4 has successfully performed a series of parametric experiments, but because it is not based on proven possible mortality factors, it has not generated any practically applicable measures. Project 5 has tested a new innovation for the attraction of fish to fishways, but it has failed to generate any successful results, partly due to the fact that the innovation was not designed and ready for field trials at the commencement of the tests.

The project administration has generally functioned well, but the role of the programme committee in supervising project progress could have been stronger. Calculated risks were taken in decisions on funding, given that one highly-rated project was excluded and two lower-rated projects were selected for funding for this 2<sup>nd</sup> phase.

## Recommendations

A future funding period is recommended, and it should ideally focus on two different aspects: a) limiting factors for fish production in regulated rivers and; b) methodologies for remedial actions. It is recommended to define the production potential of a river system and/or a reservoir after regulation. Only then can studies of remedial actions be evaluated from a cost-benefit point of view. The search for remedial methodologies should not focus on blind testing of new, untried variables, but be based on identified impacts and what could be done about these. In the case of hatchery-reared fish, we recommend testing effects of early-influencing factors on later performance in nature. Stronger focus on habitats and the importance of production-limiting factors for natural and/or restored systems is emphasised. Further, continued attention to fish migration in regulated water courses as well as the environmental impacts of short- and long-term fluctuations of water levels and flows. An ecosystem approach is highly supported. The upcoming implementation of the EU framework directive on water means that research into the river system impacts on and from the entire society should be encouraged. The wider relationships between human needs and ecosystem services and sustainability need serious investigation. Inter-disciplinary studies of system impacts are, therefore, strongly encouraged.

One approach which could be employed is that of replicating the same type of experiment in several different environments in order to develop more generally applicable knowledge. Conversely, an approach where several different studies are conducted in the same river

system could cover many different parameters influencing fish production. This would facilitate learning and cross-fertilisation in the scientific community.

One possible way of accomplishing the intended targets would be to stringently define the actual projects/needs and then have an open bidding for the execution of such research and/or methodology development. The possibility of opening the programme for non-Swedish research groups (with a primary focus on the Nordic countries), should be considered, given that there have been problems in finding interested Swedish researchers for certain identified needs.

In a future phase it is recommended to be very stringent with the funding. Only projects with high overall scientific quality and practical feasibility should be funded. This is true even if the budgets of such projects do not exhaust the allocated programme budget. It is not necessary to find projects for each defined research area.

## **The Research Programme and Evaluation**

The programme has run for a period of six years, 2000-2005, and was the subject of a mid-term review in 2002. The present three-year period has a budget of 19.5 million SEK and funds five projects. Funding is derived from a group consisting of Elforsk (joint research agency for the electricity-generating industry in Sweden), Energimyndigheten (The Swedish Energy Agency), Naturvårdsverket (the Swedish Environmental Protection Agency) and Fiskeriverket (the Swedish Board of Fisheries). For more details on funding, past results etc., please refer to the programme's web site; [www.vattenkraftmiljo.nu](http://www.vattenkraftmiljo.nu)

The programme aims at providing answers to questions generated by the work with the 16 national environmental objectives and the EU framework directive for water.

### **Strategic targets of the programme**

- to test and evaluate hypotheses and theoretical models in laboratory environments and natural water bodies;
- to contribute to a long-term strengthening of relevant competences at universities and in industry;
- to promote co-operation between institutes of higher learning, research groups and industry both nationally and internationally;
- to strengthen inter-disciplinary research, given that most research issues are of a cross-cutting nature;
- to identify and fund projects of a good enough quality that their results are published in peer-reviewed scientific journals.

### **Research emphasis**

- The ambition is to develop approaches which can cut remediation costs and/or show a better cost-benefit ratio;
- Cost-efficiency in environmental remediation necessitates a focus different from that of across-the-board increases of in-stream flow.

### **Prioritised research problems for the 2<sup>nd</sup> phase of the programme**

- Improved preconditions for migrating aquatic organisms (projects 1, 2 and 5);
- Habitat restoration (project 3);
- Flow regimes – ecological flows, short-term fluctuations etc. (no project);
- Compensation stocking of fish (project 4).

### **The evaluation**

The evaluation is concerned with the five research projects funded during the 2<sup>nd</sup> phase and focuses on the following main aspects:

- Scientific quality and results;
- Industrial relevance;

- Inter-disciplinarity and co-operation between research and industrial actors;
- Fulfilment of stated research targets;
- Programme administration.

# The Projects

## **1. The influence of flow regime on salmon migration in a bypass system. (Project leaders: H. Lundqvist, SLU, Umeå & L. Bergdahl, Chalmers, Göteborg).**

### **Background and project objectives**

The main objective is to improve the understanding of migratory fish behaviour in flow-regulated rivers with hydropower plants, dams and other migration obstacles. This has been subdivided into three major components:

- to identify any problems which may exist for the species migration;
- to evaluate consequences that these potential passage problems could cause for the populations;
- suggest solutions to these problems.

In many regulated rivers migratory fish are prevented from migrating by dams and power stations and other constructions associated with hydropower schemes. Adult migratory fish may be prevented from reaching their spawning grounds, while downward migration of smolts also might lead to high mortalities in turbine passage or over dams. Fish ladders have frequently been constructed in connection with dams to alleviate the problems, primarily addressing those of upward migration. However, many fish ladders are far from effective.

The total funding is SEK 6 000 000, which constitutes approximately a third of awarded funds from the programme and the project also has other funding of approximately equal size, from other sources.

The project has high scientific quality and has provided new knowledge on upstream migration of salmon in a large mountain river. Problem areas have been identified and their contribution to population loss described. Modelling of the fish movements in response to varying flow regimes has been undertaken. Proposed improvements which would facilitate increased up-stream migration success of adults and down-stream migration of smolts have been identified. The potential effect of these measures on the fish population has been predicted.

### **Strengths**

International and inter-departmental co-operation as well as capacity development in the form of one PhD and one PhLic graduation have been very successful. Co-operation with the power industry has been considerable, with an open exchange of ideas, possibilities and priorities.

This project is clearly interdisciplinary, combining expertise in fish biology with hydraulics in order to find appropriate design of fishways and to suggest measures to increase the proportion of fish using certain migration routes. The project makes use of modern techniques in telemetry and 2- and 3-dimensional modelling.

The project has worked in a large river with all the difficulties that this entails. The ambition to address real problems in spite of logistical difficulties should be applauded.

The project appears well devised and managed.

## Weaknesses

There is an obvious need for more thorough cost-benefit analyses of the different suggested solutions. This should be addressed in any future work and the concept presented in Håkansson et al's conference paper should be elaborated upon. The project should direct more international co-operation towards Atlantic species with a biology similar to that of Baltic salmon.

The prediction calculations for future population growth, given higher migration success rates, suffer from a lack of attention to production-limiting factors. This may erroneously inflate the value of remedial measures.

The review team expects more peer-reviewed publications given that the project has been well funded.

## Overall evaluation

	High	Moderate	Low
Originality		X	
Cost-benefit analysis			X
Relevance for end users	X		
Scientific quality	X		
Attainment of goals	X		
Overall score	X		

## Conclusions and recommendations

This project scores moderate for originality, low for cost-benefit analysis and high for relevance, scientific quality and goal attainment. The overall score is high, a fact that is well illustrated by the high quality of Rivinoja's doctoral thesis.

The costing of the various alternatives, along with their advantages and disadvantages is a necessary prerequisite for possible implementation of measures to improve fish passage. This should be implemented in the future. Problems associated with carrying capacity of parr in Vindelälven, as well as downstream migration of smolts and surviving adults, need to be addressed.

Strengthened co-operation with other researchers in the Nordic area, specifically Finland, and the rest of Europe is recommended, as is a stronger emphasis on peer-reviewed publication of the results.

## **2. Fishways as remedial measures for fragmented fish populations in regulated water courses. (Project leader: L. Greenberg, Karlstad University).**

### **Background and project objectives**

In many regulated rivers dams form a barrier to the passage of migratory fish such as salmon and sea trout. Adult fish may be prevented from reaching their spawning grounds. Fish ladders have frequently been constructed in connection with dams to alleviate the problem primarily connected to upward migration. However, many fish ladders are far from effective and there is a clear need to improve fish passage for migratory species such as Atlantic salmon and sea trout in regulated rivers. The objective was to:

- assess the passage of fish in the river, Emån, both through the fish ladder at Karlshammar and two new bypass channels at Finsjö;
- undertake an economic assessment of the measures in Emån.

The project funding from the programme has been SEK 3 100 000.

### **Strengths**

Natural reproduction is preferable to stocking programmes, and it is expedient to bring ecosystems back to their original state, or as near as possible. In this respect, this project responds to a clear need for knowledge and better understanding of natural fish behaviour.

This project has been strong in its interdisciplinarity, combining expertise in fish biology with economic aspects. The project makes use of modern techniques in telemetry. Species other than salmonids are also considered. This may be important in certain areas.

The project is well managed, with clearly defined objectives and has high scientific quality. There has been extensive contacts with the power company and the local fisheries organisations as well as local and regional conservation authorities. Relevance in terms of national environmental targets as well as the EU framework directive on water is very high.

A doctoral student is involved in the project, and will defend his thesis shortly after this review. The quality of this work is first-rate. Inter-departmental contacts with other researchers in Sweden has been extensive.

The reporting from the project is first class; clear, well written and easy to follow. It clearly describes project successes and failures alike, and gives a clear and accurate picture of project performance.

The economic assessment may not be definite, but is a positive initiative aiming at clearly quantifying the costs and benefits of studied measures. A strong general focus on such work, but with an aim at wider societal benefits, is recommended in research efforts of this type.

In relation to the size of the funding, this is the strongest of the five projects in terms of peer-reviewed publications.

### **Weaknesses**

One aspect which is less well attended to is that of the potential production in the river system, including the new river sections made available to migrating fish. What are the limiting factors for fish production in the river system?

The project would benefit greatly from several more field seasons' measurements in order to improve sample size, given the low number of studied individuals.

The project has not evaluated the marginal increase in adult fish stock caused by the remedial measures.

We would have liked even more peer-reviewed publications of the results.

The international contacts have been limited.

### **Overall evaluation**

	High	Moderate	Low
Originality		X	
Cost-benefit analysis		X	
Relevance for end users	X		
Scientific quality	X		
Attainment of goals	X		
Overall score	X		

### **Conclusions and recommendations**

This project has high relevance and scientific quality, a fact that is well illustrated by the high quality of Calles' doctoral thesis. The combination of biological and economic assessments of the new fish bypasses is a particular strength. Objectives are clearly defined and most of the project's targets are reached. The project should be prioritised in deliberations on future funding. However, this would necessitate a stronger focus on habitat restoration.

### **3. Restoration of impounded lakes: optimizing plankton and fish through balanced nutrient enrichment. (Project leader: Göran Milbrink, Uppsala University).**

#### **Introduction and project objectives**

The research hypothesis is that many regulated sub-alpine lakes suffer from oligotrophication. Heavy erosion along the shoreline due to water-level fluctuations and ice erosion causes gradual degradation of the littoral zone. However, in the initial phase of water-level regulation an increase in nutrient content due to inundation of terrestrial areas is observed. Nutrient enrichment is one method to manage degraded ecosystems in North America.

The main aim of the project is to develop a strategy for restoration and management of reservoirs, and to optimise the production of salmonid species, e.g. Arctic charr.

Project aims are:

- To estimate the amount of biologically available phosphorus removed by water-level regulation;
- To estimate the flux of pelagically added nutrients to sediments and downstream systems;
- To evaluate the effect of nutrient enrichment on Arctic charr;
- To describe the effect of nutrient enrichments on phytoplankton and zooplankton populations and on nutrient cycling;
- To follow material fluxes in the nutrient chain using stable isotope analysis;
- To sustain the local population of Arctic charr by nutrient enrichment

The total funding from the programme is SEK 3 800 000.

#### **Strengths**

Several different competencies are involved and the research addresses a problem of high relevance to the power industry.

The contacts with local stakeholders has been extensive. The Sami people have been able to voice their opinions, and communication and exchange of ideas with local fishing associations and the power company has been important.

An interesting aspect of the project is the view of eutrophication and oligotrophication as different spatial aspects of a river system.

#### **Weaknesses**

The project shows no clear evidence that oligotrophication phenomena exist in the studied reservoirs due to degradation of the littoral zone. The reservoir volume is larger than that of the original natural lake but the natural input of nutrients remains the same. This could explain a possible lower concentration of nutrients in the post-regulation reservoir. This potential explanation to lower nutrient concentrations is not investigated.

The isotope study has been excluded from the work on the basis of insufficient funding, but might be carried out at a later date.

An up-stream reservoir is used as reference, while a natural un-regulated lake would have been a more appropriate choice, both in order to demonstrate a possible oligotrophication and possible effects of nutrification.

The consideration of alternative explanations, e.g. temperature, fish densities, habitat use, catch effort etc., for improved fish status are not attended to.

The use of North American experiments as references is less well advised, given that there is a difference in species composition and general environmental parameters.

The project has still not produced any peer-reviewed articles.

The reporting to the scientific review panel was very late.

### Overall evaluation

	High	Moderate	Low
Originality			X
Cost-benefit analysis			X
Relevance for end users	X		
Scientific quality		X	
Attainment of goals		X	
Overall score		X	

### Conclusions and recommendations

This project has low originality, high relevance and moderate applied scientific quality. The tested approach presently lacks a clear demonstration of economic sustainability.

The studied remedial measure is only effective for pelagic fish species, not for epi-benthic littoral species such as brown trout, meaning that the potential economic significance is limited. Some of the stated research goals have not been reached.

A project as complex as this, with its very appropriate ecosystem approach, should ideally include a wider group of scientific expertise.

The review panel does not recommend further funding of this project with the present scientific setup.

#### **4. Production of nature-like fish for stocking. (Project leader: Erik Petersson, Swedish Board of Fisheries, Institute of Freshwater Research, Drottningholm).**

##### **Background and project objectives**

Extensive fish stocking takes place to compensate reduced recruitment resulting from river regulation. However, many of the genetic and ecological consequences of the stocking of hatchery-reared fish are unknown. Hatchery-reared fish show significantly lower survival rates in nature compared to wild conspecifics and the reasons for this are largely unknown. This project forms part of a long-term experimental study of salmon and trout, aiming to determine to what extent different parameters affect the success rate of hatchery-reared fish in nature. The studied parameters are:

- predator training;
- structural complexity of the rearing habitat and;
- rearing density

A smaller separate effort was directed at investigating the effects of lipid content of fish food in the hatcheries.

The project has received SEK 2 700 000 from the present programme.

##### **Strengths**

The project focuses on a highly relevant research issue. The research has been conducted diligently and results are clearly presented. An international workshop with participants from many countries and many fields of competence has been conducted.

One PhLic has graduated as a result of the research. Several more students have been involved and the work has been a collaboration between two departments.

##### **Weaknesses**

No peer-reviewed articles have been produced (1 is submitted for review). The research has contributed very little new scientific knowledge. Ideally, the international workshop should have been conducted at the start of the project, in order to provide a stepping-off point for the work. This could have facilitated a better research focus.

Inter-disciplinarity in the project is low, but natural given the strongly focussed area of expertise.

The experimental samples used for stocking are small in comparison to realistically expected survival rates.

The reporting is well structured but contains many editing errors and unclear passages.

### Overall evaluation

	High	Moderate	Low
Originality			X
Cost-benefit analysis			X
Relevance for end users	X		
Scientific quality		X	
Attainment of goals	X		
Overall score		X	

### Conclusions and recommendations

It is difficult to draw any clear conclusions from the reported research which can be applied for the improvement of hatchery fish for stocking.

There is a limit to what can be achieved with improvements in rearing methods, and future research in this field should include studies on habitat restoration and preservation. There is also a need to study environmental parameters influencing the fish during early rearing, which affect later performance in nature.

Further work on improving the survival rates of hatchery-reared fish is strongly supported, but it has to be aimed at a more practically useful level.

## **5. Testing of a device for the creation of attraction currents in fishways. (Project leader: Håkan Gustavsson, Luleå Technical University).**

### **Background and project objectives**

It is often difficult for fish to find the entrance to established fish passages. This project tests a device designed specifically for this purpose. Trials in a laboratory environment form the background for field applications and tests. Principal research problems were to:

- test flow fields in and around the attraction device in a laboratory and;
- test the effectiveness for actual fish attraction in field environments.

The project received SEK 2 000 000 from the present programme.

### **Strengths**

Capacity development is a demonstrated strength of the project. Scores of MSc-level students have been involved in testing the device, giving an unusual input into engineering training. One student who has written her Masters thesis within the project will hopefully pass her PhLic exam in the summer of 2006.

The project is highly relevant since it deals with attracting fish to fish-way entrances.

### **Weaknesses**

The project team lacks fish-biology competence, a lack which has caused many of the problems experienced. In spite of having this pointed out by the reference group and members of the programme steering committee, project management has not been successful in addressing this issue.

Because of this problem, the tests conducted have been less meaningful, and the device has not been tested in the type of environments where it might prove successful.

Far from being able to show an improved attraction on migrating fish, the device has been proven not to scare fish away as well as function as a shelter for small fish, as long as it is painted black.

The project has not produced any peer-reviewed publications and the results in relation to the size of the funding are poor.

### **Overall evaluation**

	High	Moderate	Low
Originality	X		
Cost-benefit analysis			X
Relevance for end users	X		
Scientific quality			X
Attainment of goals			X
Overall score			X

### **Conclusions and recommendations**

The project has not been successful in its stated aim of adapting the fish-attraction device to successfully performing its intended function. Design and hydraulic problems have combined

in making actual measurements of fish behaviour near impossible. The design is questionable as an attraction device, given that the hypothesis of attracting fish with a locally increased current velocity could only work if that increase could be maintained throughout the device. This does not seem possible with the present design.

The review panel does not recommend further funding.

## **Programme Administration**

The programme appears well administered and has a committee with highly relevant members from the funding agencies and companies, but the possibility of strengthening the influence of the committee on progress and management of individual projects should be seriously considered.

The programme is directed at applied research and methodology development, not basic research. This makes it both possible and desirable to have diligent follow-up and a strong guidance of the various projects. Any future continuation of the programme is advised to employ annual reviews based on interim reporting, in order to assist the research groups in their work. The programme committee should be able to instruct the various project managers to amend or focus their efforts, if it finds that the particular project does not perform as expected. Discontinuation of funding would be the most severe of measures available to the committee in these annual reviews. If necessary, the committee should be able to consult independent scientific expertise for these assessments.

The system of appointing a contact person from the committee for each of the projects should be continued and, if possible, strengthened. Ideally this person should be able to follow the on-going work in some detail and have the necessary contacts in industry and/or the scientific community to be able to assist his/her project with advice, contacts etc.

A group of potential implementers which presently is not represented in the programme is the industry and consulting companies (these actors appear as reference experts in existing projects, but play a small part). Provided these were prepared to stay within reasonable budget limits, the review panel sees no reason why such actors should not be able to receive funding.

One weakness we have found in the programme administration is that there could have been a stronger guidance of the projects by the committee in response to the advice given in the 2002 mid-term review. Many of the weaknesses in research focus and/or direction identified by that review panel have not been attended to during the 2003-2005 period. It is clear that in the case of one project, the programme management and committee have been able to push and re-orientate the work in a successful direction, thus moving it from barely receiving funding for this 2<sup>nd</sup> phase, to being the most successful project of all. In other cases where potential for this type of management intervention has existed, this has not happened, for a variety of reasons.

The other, related, weakness we have found concerns the selection process for funding. Some calculated risks were taken in decisions on funding, given that one highly-rated project was excluded and two lower-rated projects were selected for funding for this 2<sup>nd</sup> phase. These latter projects have performed moderate and low respectively, as could have been expected.

## The Scientific Review Panel

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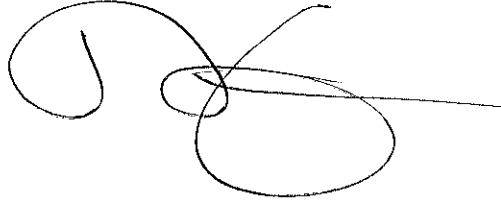
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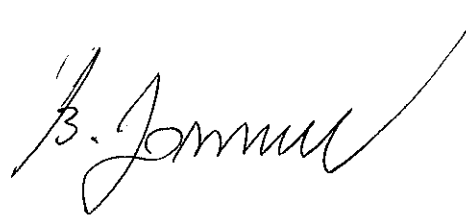
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