# RESTORATION OF RIVERINE HABITAT FOR FISHES - ANALYSES OF CHANGES IN PHYSICAL HABITAT CONDITIONS

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OULU 2003

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Academic Dissertation to be presented with the assent of the Faculty of Technology, University of Oulu, for public discussion in Raahensali (Auditorium L10), Linnanmaa, on October 31th, 2003, at 12 noon.

OULUN YLIOPISTO, OULU 2003

Reviewed by
Docent Timo Muotka
Professor Pertti Vakkilainen

ISBN 951-42-7117-3 (URL: http://herkules.oulu.fi/isbn9514271173/)

ALSO AVAILABLE IN PRINTED FORMAT
Acta Univ. Oul. C 188, 2003
ISBN 951-42-7116-5
ISSN 0355-3213 (URL: http://herkules.oulu.fi/issn03553213/)

OULU UNIVERSITY PRESS
OULU 2003

**Yrjänä, Timo, Restoration of riverine habitat for fishes - analyses of changes in physical habitat conditions**
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Oulu, Finland
2003

***Abstract***

The subject of the study was to search and test restoration measures for the most common physical habitat degradations in Finnish rivers.

Methods for constructing nursery and spawning habitats for salmonid fishes were tested in small rivers dredged for timber floating in the Iijoki watercourse. Physical habitat modelling was used to simulate the effects of restoration measures to the hydro-physical conditions and potential fish habitats. The rehabilitation of the river bed and the placement of boulder structures, especially large boulder dams, made the rapids spatially more complex and increased the availability of potential physical habitat for brown trout (*Salmo trutta*).

The physical habitat model was applied in the river Siikajoki to estimate the impacts of flow regulation patterns on the physical habitat quality. No single flow event causing a bottle-neck effect on the potential habitat suitable for brown trout was found. In a sensitivity analysis of habitat modelling, modifications of the suitability criteria appeared to have a major influence on habitat suitability for young brown trout.

The applicability of low reefs and narrow side channels for fish habitat improvement was studied, using the large river impoundment of Oulujoki as a test area. Limited validation experiments of the model results were carried out on the basis of fish telemetry experiments and observations by local rod fishermen. The restoration measures appeared to diversify the channel structure and increase sheltered lateral habitats for grayling (*Thymallus thymallus*).

Habitat structure and fish populations of seven small forest streams and two modified streams were surveyed using visual evaluation and electrofishing studies. None of the studied streams was found to be in pristine condition in all of its reaches. Brown trout was the most abundant species in most of the study streams. In most streams the brown trout distribution correlated positively with substrate size. The accumulation of fine materials on the stream bottom due to forestry operations was estimated to be the most harmful human impact on the studied streams. Some restoration suggestions were made for each of the streams.

*Keywords:* dredging, forestry, habitat, model, physical habitat simulation, regulation, restoration, river, salmonid fishes

# Acknowledgements

The writing of this doctoral thesis has been made possible by my work at the North Ostrobothnia Regional Environment Centre (NOREC) with river restoration projects since the end of the 1980s. The Environment Centre has supported all the research projects introduced in this work. I thank my superiors for having been given the possibility to participate also in scientific work in side with the practical tasks. I thank all my associates who have participated in this work in its different phases from sampling till finishing the layout of the figures. Jukka Pekkala deserves my special thanks; he has participated in development of the restoration technique since from the first restoration project in the river Iijoki. Docent Ari Huusko from the Finnish Game and Fisheries Research Institute has helped in the designing of this thesis from the beginning and given his irreplaceable contribution to several studies of the thesis. He has also been one of the two supervisors. Docent Kalevi Kuusela of the Department of Biology at the University of Oulu guided the first subprojects and Pertti Tikkanen from the same department guided the planning of the middle phase works. Emeritus Professor Jussi Hooli from the Department of Process and Environmental Engineering acted as the other supervisor for the final phase of my doctoral dissertation. My thanks to all of them.

I would like to extend my thanks also to the researchers of Oulu and Paltamo units of the Finnish Game and Fisheries Research Institute for their constructive dialogue concerning river fishery and its development.

I thank Päivi Timonen for cooperation in choosing statistical methods for this work and Eeva-Kaisu Kemppainen, Sirkka-Liisa Leinonen, Susanna Maaranen and Hanne Peltokorpi for their contribution to the English language in this work.

I thank the Academy of Finland, the National Technology Agency (TEKES), and the Land and Water Technology Foundation for their awards that enabled the finishing of this work. Financing for the project “Mitigation of Environmental Problems in Build-up Rivers” was received through the “Research Programme on Ecological Construction” of the Academy of Finland. TEKES granted financing for the wide-scope research project “The Biodiversity, Ecological Management and Restoration Methods of Northern Water Systems (BEMARES) that is a part of the “Finnish Biodiversity Research Programme” (FIBRE).

“The Regulation Development Project of the River Siikajoki” and the research project “The Impacts of Short-Term Regulation by Hydropower Plants” offered me the opportunity to familiarise myself with questions concerning regulation and to realise habitat model applications in the rivers Siikajoki and Oulujoki. I thank the persons involved with these projects, particularly Olli van der Meer and Tuomo Sinisalmi from Fortum Ltd and Juha Riihimäki from the Finnish Environment Institute. My thanks to Markku Lahti from Fortum Ltd for his fundamental role in the development of the new habitat model FISU used in these studies. Thanks to Teppo Vehanen (Finnish Game and Fisheries Institute) and Riitta Kamula (Department of Process and Environmental Technology) for their expertise in the river impoundment studies. Thanks to the field measurement group at Kemijoki Ltd, particularly to Ilkka Kylmänen and Veli-Pekka Sirniö, for their cooperation in the field measurements of the river Oulujoki. My thanks also to all the individuals who have participated in the habitat measuring of Kutinjoki.

I thank all the individuals who have participated in the inventory of forestry streams, particularly the group leaders Eero Hartikainen and Matti Suanto from Pudasjärvi and Eero Moilanen from Taivalkoski. My thanks to Pirkko-Liisa Luhta from Metsähallitus for her constructive cooperation in the progress of the stream inventory project.

My special thanks to my family, Ritva, Veera and Vili, for their support and patience.

Oulu, August 2003 Timo Yrjänä

# List of original papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals (I-VII):

I Yrjänä T (1998) Efforts for In-stream Fish Habitat Restoration within the River Iijoki, Finland - Goals, Methods and test Results. In: de Waal L, Large A & Wade M (eds) Rehabilitation of Rivers: Principles and Implementation. John Wiley & Sons Ltd. Sussex, p 239-250.

II Huusko A & Yrjänä T (1995) Evaluating habitat restoration of rivers channelized for log transport: a case study of the river Kutinjoki, Northern Finland. Bull. Fr. Peche Piscic 337/338/339: 407-413.

III Huusko A & Yrjänä T (1997) Effects of in-stream enhancement structures on brown trout habitat availability in a channelized boreal river. Fisheries Management and Ecology 4:453-466.

IV Yrjänä T, van deer Meer O, Riihimäki J & Sinisalmi T (2002) Contributions of short-term flow regulation patterns to trout habitats in a boreal river. Boreal Environment Research 7:77-89.

V Yrjänä T, Lahti M & Kamula R (2003) Enhancement of fish habitat in a hydropeaking river impoundment. Manuscript.

VI Vehanen T, Huusko A, Yrjänä T, Lahti M & Mäki-Petäys A (2002) Habitat preference by grayling (Thymallus thymallus) in an artificially modified hydropeaking river bed: a contribution to understand effectiveness of habitat enhancement measures. Journal of Applied Ichthyology. 19: 15-20.

VII Yrjänä T, Luhta P-L, Pekkala J, Moilanen E & Hartikainen E (2003) Brown trout abundance related to habitat features in small boreal streams with intensive forestry in their catchment, with suggestions for habitat restoration. Manuscript.

# Responsibilities of Timo Yrjänä in the articles of this thesis

VIII I was responsible for all phases of the study.

IX I was responsible for study design, field work, data analysis, and writing of the manuscript equally to Ari Huusko.

X I was responsible for study design, field work, data analysis, and writing of the manuscript equally to Ari Huusko.

XI I was responsible for study design and writing of the manuscript. I participated in the field work and data analysis.

XII I was responsible for study design, statistical analysis, and writing of the manuscript. I participated in the field work.

XIII I participated in the study design, field work (excluding radiotelemetry experiments), and writing of the manuscript.

XIV I was responsible for study design, data analysis, and writing of the manuscript. I participated in the field work.

# Contents

# 1 Introduction

Many rivers have been dredged for log floating in Fenno-Scandian wooded areas (Lammassaari 1990, Eklöv 1997, Iversen *et al*. 2000). According to Brookes (1988), Mills (1989), and Allan (1995), the habitat structure and aquatic communities of a dredged river are more monotonous than those of a natural river. Dredged rapids produce less salmonid smolts than non-dredged rapid areas (e.g. Karlstöm 1977, Jutila 1987, Mills 1989).

Approximately 66 % of the total stream flow in the world is controlled by dams (Cowx & Welcomme 1998). Dams cut the natural continuity of rivers (Kristensen & Hansen 1994, Cowx & Welcomme 1998). Lack of flood peaks eliminates or decreases the flushing effect of high flow and thus causes narrowing or shallowing of channels, as well as decreases depth variation and consolidation of bottom material (Allen 1995).

Short-term regulation is typical in rivers which are used for hydropower production (Liebig *et al*. 1996, Alfredsen *et al*. 1999). It is used to adapt power production to the daily and weekly variations in the consumption of electricity. The fast variations in flow significantly affect the habitats of river dwelling organisms. Continuous variation of water velocity and depth forces many organisms capable of moving to search for new habitats each time there is a significant change in the flow rate. Variation in flow rates causes fish to be displaced downstream, potentially leading to total disappearance of the fish stock suitable for catch (Cowx & Welcomme 1998). In some regulated rivers restoration measures have been carried out to improve fish habitat (Eie *et al*. 1997, Soimakallio & Savolainen 1998).

Centuries of intensive use of forests resources have substantially reduced biological diversity in Finland. Forestry practices such as intensive logging and the draining of nutrient-rich wetlands and natural brooks have reduced the number of key biotopes (OECD 1997). During the 20th century more than 5 million hectares of Finnish wetlands were transformed into productive forestland, and at present there are increasing numbers of ditch cleaning activities in progress (Joensuu *et al*. 1999, 2001). The smallest stream channels are heavily affected by forestry operations (Vuori *et al*. 1995).

The effects of clear-cut logging have been well documented (Kedzierski & Smock 2001). Studies have shown a variety of effects including increased nutrient and sediment input (Hartman & Scrivener 1990, Nieminen 2003) and changes in algae and macroinvertebrate communities (Holopainen & Huttunen 1995, Vuori & Joensuu 1996, Kedzierski & Smock 2001).

During the last decades, several altered rivers have been restored. Based on the fact that hydraulic conditions are important factors that govern the distribution and dynamics of stream organisms, stream rehabilitation programmes have employed in-stream structures to modify local hydraulic conditions to provide preferred microhabitats for fish species, macroinvertebrates and plants as well as to increase the retention of organic material. Since the 1970s, a number of restoration projects of earlier timber floating channels in Fenno-Scandia have been carried out (Karlström 1985, Näslund 1987, Lammassaari 1989, Jutila 1992, Majuri 1998, Turunen & Äystö 2000). According to Turunen & Äystö (2000), river restoration projects in Finland include the restoration of 1700 rapids or other running water sections, approximately 700 spawning grounds, and the construction of 53 fishways (Turunen & Äystö 2000). Restoration of small streams altered by forestry measures has also recently been started in Finland (see Virtanen & Virtanen 2000, Tossavainen *et al*. 1999).

Habitat analysis in flowing waters developed in the 1960s and 1970s in the USA, when scarce water resources had to be divided between a river channel and other utilisation purposes (Stalnaker *et al*. 1995). Physical habitat modelling combines physical and biological survey into an estimate on the state of the physical habitat, and thus gives the possibility to measure the intensity of the impacts of human actions on the aquatic ecosystem (Stalnaker *et al*. 1995, Parasiewicz & Dunbar 2001). Depth, water velocity, substrate, and cover are generally considered the main variables affecting the distribution of stream-dwelling fishes at the within-reach scale (Heggenes 1990). Suitability criteria for these in-stream variables are commonly used as biological components in physical habitat simulation models (Bovee 1982). Habitat simulation models are most often used to estimate the quantity of habitat suitable for salmonid fishes at different flows (Mäki-Petäys *et al*. 2002).

In general, there are very few studies addressing the effects of river restoration on the physical habitat or the biota (Kondolf & Micheli 1995, Laasonen 2000, Purcell *et al*. 2002). A few habitat enhancement studies have concentrated on reporting flow-related habitat conditions after the installation of habitat enhancement structures (Shuler 1993, Harby & Arnekleiv 1994, Elliot *et al*. 1996). However, as more information becomes available on how different manipulations modify river channels and affect fish habitats, more efficient and economic rehabilitation strategies should follow (Rabeni & Jakobsen 1993).

# 2 Composition and aim of the study

The main goal of this thesis was to describe the major restoration measures used to mitigate the harmful human actions in rivers and streams in Finland and to characterise the restoration induced changes on the local physical habitat features. This was carried out mainly by physical habitat modelling, including both hydraulic modelling and habitat evaluation procedure, performed both before and after restoration actions. The generalised criteria of the main variables affecting the distribution of stream-dwelling salmonids were applied to the habitat evaluations to give a “fish-eye” view on the relative habitat quality before and after the implementation of restoration measures. In this case, physical habitat modelling gives us a tool for understanding the habitat-hydraulic dynamics of the river reaches. It allows us to draw conclusions from the actions carried out to improve the physical habitat, either by changing flow regulation patterns or by re-structuring the river bed. Thus the main focus of this thesis was on studying restoration-induced impacts on the physical habitat, while the biological responses, such as changes in the abundance or growth rate of fish and other stream organisms, were mainly out of the scope of this study.

Impacts of restoration were surveyed in several kinds of man-modified rivers and streams. First, the habitat enhancements in streams dredged for timber floating (papers I–III) were studied. Paper I discusses the restoration of riverine habitat for fishes in dredged boreal rivers. It also offers a review of the results from studies concerning the restoration of streams and rivers in the Iijoki watercourse in 1988–1998. Papers II and III describe the physical habitat changes due to in-stream restoration measures in a river dredged for timber floating. Brown trout (*Salmo trutta*) was used as a test fish species. Paper III includes an account of how EVHA, the French version of the physical habitat simulation model, was used to simulate the effects of in-stream restoration measures to physical habitats in rivers dredged for timber floating.

Second, a case of impacts of different flow regulation patterns on fish habitat potential was evaluated in the river Siikajoki (IV) using EVHA habitat model. In this case only the effects of different flow regulation patterns were analysed, since the geomorphological structure of the river section did not require any modification. The aim of the study was to test a physical habitat simulation model in Finnish rivers and to perform a preliminary research of a more ecological regulation pattern for a hydropeaking river with moderate structural naturalness. The simulation in the river Siikajoki was carried out by using generalised suitability criteria for brown trout. Two habitat restoration measures were designed and tested for the hydropeaking section of a large, completely harnessed river (V). The impacts of the restoration measures were analysed in the study area of the river Oulujoki using the Finnish physical habitat simulation model FISU (papers V–VI). The studies adopted generalised suitability criteria for grayling (*Thymallus thymallus*) with some validation measures.

Paper VII deals with problems caused by forestry actions on small streams. The purposes of this study were to estimate the state of habitats in forest streams, to search factors controlling brown trout distribution and to find measures for restoration of riverine habitat.

This work belongs to the group of doctoral theses in Finland concerning riverine fishes and their habitats in boreal rivers. Mäki-Petäys (1999) studied habitat requirements of salmonids, Laasonen (2000) the effects of restoration on benthic communities, Laine (2001) fish passage problems during spawning run and the effects of land-derived particulate matter on riffle bed quality and Kamula (2001) scaling equations for fishway structures. Another thesis is being prepared by Lahti on the development and testing of a physical habitat simulation model (Markku Lahti, unpublished data).

# 3 Study area

Experiments and measures included in this study have for the most part been carried out in three watercourses, Iijoki, Oulujoki, and Siikajoki, which flow into the Bothnian Bay, the northernmost gulf of the Baltic Sea. Most of the rivers of the three watercourses have been dredged for log floating, and their main channels are used for hydropower production. The location of the watercourses is illustrated in Figure 1. All the studied rivers and streams belong to the area 22, Fenno-Scandian shields in the classification of the ecoregions for rivers and lakes of the European Water Framework Directive (2000/60/EY). The studied waters are oligotrophic and humic rivers of the boreal forest zone. In wintertime they are covered with ice, generally from November to April–March, after which follows the flooding period caused by melting snow. The studied watercourses, with the exception of the headwaters, are located 0–250 m above the sea level.

The catchment area of the Iijoki watercourse (Fig. 1) is 14 000 $km^2$ wide, the mean flow (MQ) at the river mouth is 173 $m^3s^{-1}$, the mean high flow (MHQ) 887 $m^3s^{-1}$ and the mean low flow (MNQ) 35 $m^3s^{-1}$. Most of the restoration activities were directed to the tributaries which are 10–100 m wide with a mean flow of 0,5–25 $m^3s^{-1}$, high flow of 10–500 $m^3s^{-1}$ and average gradient 0,1–0,5 %. The tributaries are located 100–300 m above the sea level (I). The river Kutinjoki, a tributary of the river Iijoki, was dredged for log floating in the1950s. The MQ of Kutinjoki is 1.4 $m^3s^{-1}$ and the MHQ 17.4 $m^3s^{-1}$. Kutinjoki is 12 km long and its average gradient is 0.3 %. The first habitat quality study included one test area in the river Kutinjoki (II), while at the second stage there were three test sites (III).

Siikajoki (Fig. 1) is a regulated river with a dam and both short-term and long-term flow regulation. The river also comprises large non-built-up sections. The size of the Siikajoki river catchment area is 4 318 $km^2$, the MQ 44 $m^3s^{-1}$, the MHQ 332 $m^3s^{-1}$ and the MNQ 7.3 $m^3s^{-1}$. The study area is situated in a mainstream section where hydropeaking is intensive (IV).

The large regulated river Oulujoki (Fig. 1) represents a watercourse completely harnessed for hydropower production. Oulujoki consists of a series of river impoundments and its flow is heavily regulated. The catchment area of the river Oulujoki is 22 925 $km^2$, the MQ being 254 $m^3s^{-1}$, the MHQ 508 $m^3s^{-1}$ and the MNQ 56 $m^3s^{-1}$. The study site was located in a 38,4-km-long river impoundment between two power plants. (V, VI).

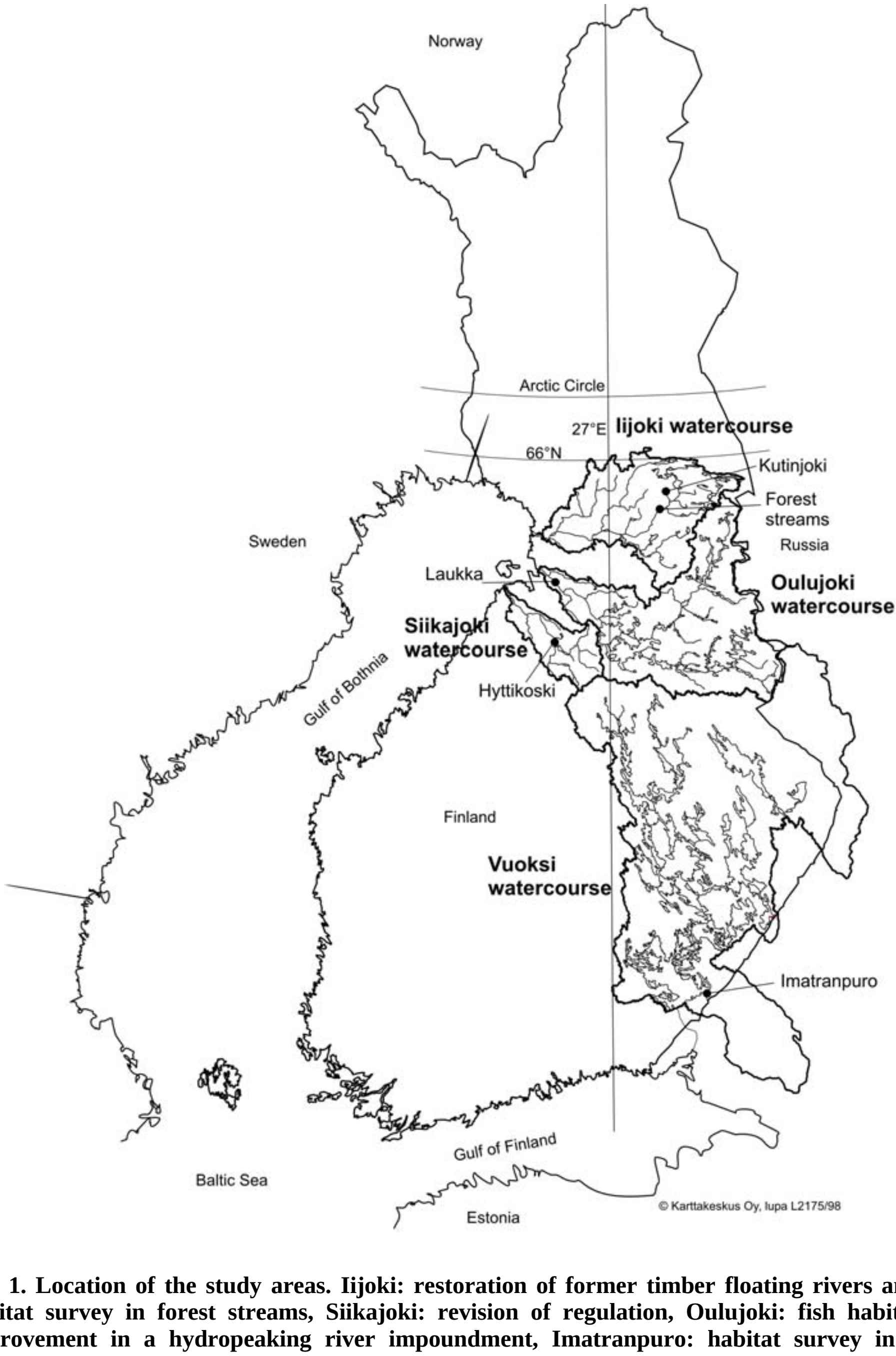


**Fig. 1. Location of the study areas. Iijoki: restoration of former timber floating rivers and habitat survey in forest streams, Siikajoki: revision of regulation, Oulujoki: fish habitat improvement in a hydropeaking river impoundment, Imatranpuro: habitat survey in a manmade stream.**

The seven typical forest streams and one modified forest stream located in the central part of the Iijoki watercourse that were included in this study (Fig. 1) have a mean flow of 22–317 $ls^{-1}$. Their length varies from 1,3 to 12,7 km and their average gradient is 0,31–1,35% and average width 0,86–2,45 m. The streams have been objects of forestry measures of varying intensity. In order to study the influence of various human activities, also one entirely manmade stream was included in the study. The length of this stream, Imatranpuro, located in the watercourse of Vuoksi, is approximately 1 km, gradient 1,9 % and average width 1,6 m (VII).

# 4 Material and methods

## 4.1 Physical habitat simulation models

The physical habitat simulation model procedure (Bovee 1982) has been selected as a tool for simulating the effects of restoration measures on the physical habitat conditions in the study rivers. Physical habitat simulation is a commonly used method for assessing impacts of river discharge modifications (Modde & Hardy 1992, LeClerc *et al*. 1995, Holm *et al*. 2001), but it has not been widely applied for evaluating the effects of river bed modifications (Parasiewicz & Dunbar 2001). The two most important game fish species of the study rivers, brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*), were used as test animals. The variables used are depth, water velocity, and substrate size, which have been found to belong to the main variables controlling the distribution of fishes in running waters at the within-reach scale (Heggenes 1990).

The physical habitat simulation model combines a hydraulic model and a habitat model. The habitat model integrates habitat quality of combinations of depth, velocity and substrate into an index of microhabitat, weighted usable area (WUA). The WUA is a sum of all streambed units (cells) of a cell area multiplied by suitability of depth by suitability of velocity by suitability of substrate (Beecher *et al*. 2002). A series of WUA values can be calculated for other flows in a similar manner. By repeating the entire process, a curve relating WUA with a flow can be determined for each life stage of a fish species and also for other species.

The habitat qualities of different depths, velocities and substrates are entered into the habitat model as habitat suitability criteria for selected life stages of selected species. Habitat quality is estimated by fish use or selection, which is a result of fish density, dominance, interspecific interactions, and availability of habitat. Habitat suitability criteria are weighting factors that range from 0 for totally uninhabitable values to 1 for optimal values (Beecher *et al*. 2002). The suitability criteria can also be drawn up on a generalised level on the basis of several studies (Bovee 1982, Stalnaker *et al*. 1995, Parasiewicz & Dunbar 2001). Although suitability criteria are often derived from either actual data or existing library sources, professional judgement is commonly used to modify the final criteria (Modde & Hardy 1992).

There are three underlying principles in the physical habitat simulation procedure (Bovee 1982): "(1) each species exhibits preferences within a range of habitat conditions that it can tolerate; (2) these ranges can be defined for each species; and (3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure."

Previously, cross-sectional profiles of studied stream sections were drawn in field measurements (Bovee 1982, Ginot & Souchon 1995, Ginot & Trocherie 1995). A reasonable number of transects should be measured to adequately document stream features and changes in substrate and channel width. Measurement points were chosen to describe the channel shape at each transect. Water velocity, water depth, and substrate size were measured at each measure point. At present stream measurements are often carried out by applying a co-ordinate system (e.g. GIS) without cross-sectional approach. Extra habitat cells can be formed by interpolating the measurement data (Bovee 1996, Lahti 1999).

Stream hydraulic during other flow events can be measured in the field or simulated using different types of hydraulic models (one-dimensional – three-dimensional) with different field sampling procedures and spatial modelling scales (Scruton *et al*. 1996, Alfredsen *et al*. 1997, Lahti 1999). The physical habitat simulation model is then used to examine incremental changes in flows to predict the corresponding effect on the availability of suitable microhabitat over the full range of flows.

There are a number of different model versions created by applying the physical habitat simulation concept of Bovee 1982. The present study first applies the French model version, EVHA (Ginot & Souchon 1995, Ginot & Trocherie 1995), and then the Finnish FISU (Lahti & Sinisalmi 1998, Lahti 1999).

## 4.2 Dredged rivers

The original paper I describes fish habitat restoration measures designed for the rapids sections of the dredged rivers in the Iijoki watercourse on the basis of the measures used in North America (see e.g. Wesche 1985). Paper I also presents a brief review of several other studies related to the restoration of the Iijoki river headwaters: Jutila *et al*. (1994) studied fish stock before and after restoration, Pekkala & Pekkala (1995) the evaluation of artificial spawning grounds and Laasonen *et al*. (1993, 1998), Tikkanen *et al*. (1994), Valovirta & Yrjänä (1996) and Laasonen (2000) the effects of restoration on benthic fauna (cited as a manuscript).) The methods of the cited studies will not be presented in this study, but some of their results will be used to describe the effects of restoration or for further development of the restoration measures.

The river Kutinjoki was used as a test river when evaluating the impacts of the applied restoration measures on the physical habitat features and on the magnitude of habitat suitable for young brown trout in rivers dredged for timber floating. The measurements of habitat variables were carried out using the cross section method (Bovee 1982, II, III). Habitat data of the river Kutinjoki was examined in the first phase (II) by comparing the frequency distributions of the measured variables before and after the restoration works. The statistical analyses are described in the original paper II.

In the second phase (III), a physical habitat simulation model EVHA (Ginot & Souchon 1995, Ginot & Trocherie 1995) was used to simulate restoration-induced changes in the physical habitat. The study areas were situated in the river Kutinjoki. The study applied the summer and winter habitat suitability criteria of three brown trout classes that originated from the nearby river Kuusinkijoki (Mäki-Petäys *et al*. 1997). The flow events of 0.8 and 4.8 $m^3s^{-1}$ were simulated. The hydraulic model belonging to the EVHA program set is a stepbackwater one-dimensional model with lateral calculations of velocities, which were shown to be more accurate for high to medium streambed roughness (Scruton *et al*. 1996). The methods used in the application are described in more detail in the original papers II and III.

## 4.3 Regulated rivers

EVHA physical habitat simulation model was applied to compare flow regulation patterns in the river Siikajoki to the potential physical habitat for brown trout. Instantaneous flow rates in the Hyttikoski study areas were calculated in accordance with the 1-dimensional flow model. The model simulation was performed for four brown trout size classes on the basis of the generalised habitat suitability criteria for brown trout as presented by Souchon *et al*. (1989). The modelled flow range was 3–225 $m^3s^{-1}$ and it covered all of the commonly presented single flow events. Flow statistics from the year 1990 were used to create flow and habitat time series during normal use of the reservoir. Habitat time series were created also for four summertime and two wintertime flow regulation patterns, and a sensitivity analysis was performed for the modelling results. The methods used are described in more detail in the original paper IV.

To evaluate the restoration-induced changes, a habitat model simulation was carried out in the Laukka area of the river Oulujoki. Grayling, the most important game fish species of the area, was used as a test fish species (V). The restoration measures include the construction of four low-profile reefs in the middle of the main channel and the digging of a network of narrow side channels to a running water area of a large regulated and dammed river section. The size of the study area was approximately 500 x 200 m (V). A longer area was measured and modelled (VI) for the fish telemetry study (see below). Two of the commonly occurring flow events, base flow 110 $m^3s^{-1}$ and peak flow 300 $m^3s^{-1}$, were simulated (V).

Habitat measurements in the river Oulujoki were carried out using a combination of an echo sounder for the bottom topography points and acoustic Doppler device (Acoustic Doppler Current ProfilerTM) for water velocity sampling. A tacheometer was used in horizontal positions. All equipment was carried by a small hovercraft able to move also in shallow water. Data was saved on computers on on-line basis (Kylmänen 1998, Kylmänen *et al*. 2001). The habitat model employed was the Finnish FISU with a two-dimensional RMA2 hydraulic model (Lahti *et al*. 1998, Lahti 1999, V). The generalised habitat suitability criteria for three different arctic grayling (*Thymallus arcticus Pallas*) size classes (Hubert *et al*. 1985) was adopted for this study. The used statistical analyses are described in the original paper V. Catch statistics of ten local rod fishermen were used for validating the habitat modelling results. Validation data included the location of 45 adult grayling (V). Also a fish telemetry experiment of 12 graylings, carried out in the restored river section, was used to confirm the model results (VI).

## 4.4 Forestry streams

The habitat quality in small boreal streams was surveyed by applying a method mainly based on visually estimated variables. Fish populations in the study streams were studied using a single-pass electrofishing technique. The nine study streams were divided into 175 uniform reaches (13–33 per a stream). Each reach was ranked using 65 habitat variables describing the channel morphology, hydro-physical habitat types, vegetation, and human impacts. The factors affecting the distribution of brown trout in a stream were studied in each study stream separately using the Spearman's rank correlation test. The need for restoration was analysed, suggestions about potential restoration measures presented, and resulting costs estimated (VII).

# 5 Results

## 5.1 Dredged rivers

The main single in-stream restoration measure designed to improve habitat quality in dredged rapids of the Iijoki headwaters was the construction of large boulder dams (I). Large boulder dams characteristic of the river Iijoki were constructed by piling rock material ranging from cobble to boulders in several layers along a long stretch of the river bottom. Besides the boulder dams, also other in-stream structures such as cobble ridges, deflectors, and groups of boulders were designed. Gravel with particle size of 8–45 mm was found to be suitable to create artificial spawning grounds for salmonids. As based on the results of the spawning site selection experiment, the spawning gravel should be piled in small patches with a couple of large boulders (I).

The restoration increased the channel width in the river Kutinjoki by 22–53 %, approaching the original width so that the channel reached the natural banks and trees bordering the river. The cross section of the channel changed from a U- or V-type to a wider and more diversified shape (II, III). Restoration increased the patchiness of available depths, velocities, and dominant substrate size classes, making the rapids spatially more complex (II, III). Successive pool-riffle stucture was clearly seen at the study sites after restoration, in contrast to the more or less homogenous pre-restoration flow pattern. (II, III). Water depth and velocity median values decreased following restoration at all simulated flows (III). On the other hand, boulder dams caused the formation of small sections with very high water velocity III).

The assessment of the potential habitat suitability for brown trout indicated that substrate availability was a limiting habitat factor for 0+ and 1+ trout, and depth availability was a limiting factor for older trout before and after restoration during low summer flow (II). The restoration procedure appeared to favour 1+ and older trout (II).

Physical habitat simulation (III) indicated that rehabilitation improved the water velocity conditions for the three size classes (4–9 cm, 10–15 cm, >15 cm) of brown trout both in winter and summer. In the post-rehabilitation state the availability of suitable depth and substrate became more limiting for all trout size classes. The habitat modelling results indicated that the potential habitat area (WUA) for brown trout size classes 10–15 and >15 cm increased, following the enhancement measures at almost each of the simulated flows. In contrast with the changes found in larger trout size classes, the potential physical habitat area of the smallest size class (4–9 cm) was smaller in the post-restoration state at nearly all of the simulated flow events during both winter and summer (III).

## 5.2 Regulated rivers

The physical habitat model simulation indicated that the availability of potential habitats for the different size classes of brown trout was dependent on the flow rate in the study area of the small regulated river Siikajoki (IV). The habitats in the side channel test area were more resistant for flow variation than those in the main channel test area. On a seasonal scale, the minimum WUA values for young brown trout were obtained during the spring and autumn floods. In the model simulation of the summer test period, no significant differences between the studied alternative regulation patterns were found in the WUA for brown trout fry. In the winter test period the magnitude of WUA for brown trout fry was 20% lower in the "natural flow" alternative than in the "implemented flow" during the peak flow. In the sensitivity analyses of physical habitat modelling, modifications of depth suitability criteria seemed to have major influence on the WUA for young brown trout (IV).

In the large regulated river Oulujoki, the shape and location of the frequency distribution of depth, water velocity, and dominant bottom substrate changed significantly owing to restoration at both the base flow (110 $m^3s^{-1}$) and peak flow (300 $m^3s^{-1}$) (V). Shallow areas with moderate flow and coarse bottom increased significantly following restoration measures. According to the FISU simulations, before restoration there was a lack of grayling fry habitat in the study area especially at peak flow. There was plenty of habitat for larger grayling both at the base and peak flow. The model simulations indicated that the restoration made hydro-physical conditions more favourable for all the three grayling size classes in both of the studied flows. The dredging of narrow side channels increased suitable fry habitat also during the peak flow (V).

In the river Oulujoki, most of the fish located by local fishermen were encountered in the habitat cells that, on the basis of the model simulation, had high habitat value Ci,s. Graylings appeared to avoid "unsuitable", "poor" and "moderate" cells and prefer the "good" and "excellent" ones. In the telemetry test of adult graylings, a majority of the monitored graylings held position in the restored reach of the river in the vicinity of constructed reefs or river banks, where the model simulation showed the habitat quality to be high. No movement away from the restored area due to hydropeaking was observed in the telemetry test (VI).

## 5.3 Forestry streams

In the habitat survey 57 % of the reaches of seven typical forest streams were classified as pristine or near pristine, while 7 % of the reaches were classified as heavily or totally modified. The most typical examples of human impact were accumulation of sand or other fine material on stream bottom, ditching of riparian forest, cutting of riparian forest, dredging of stream channels, and pre-plantation ploughing in riparian forest (VII).

1–8 fish species per stream were encountered in the study, the median number being 5 (VII). Brown trout was found in all of the studied streams. Density of the brown trout varied from 0.2 to 35 individuals per 100 $m^2$. The smallest sized brown trout (< 65 mm) was encountered in 34, the medium sized (65–150 mm) in 98 and largest (> 150 mm) in 70 of the studied 175 reaches (VII).

The most common habitat variable correlating with the density of the smallest brown trout size-class in the study streams was the substrate size variable "S2–10 cm". A substrate variable correlated also with the medium sized and large brown trout in four streams. Brown trout appeared to prefer coarse (gravel-cobble) bottom material in the studied forest streams.

The habitat survey showed that the quality of aquatic habitats vary significantly within one forest stream. Some restoration measures were suggested for all the streams, but most of them also had some "pristine" or "near pristine" sections. The two most common suggested habitat restoration measures were the removing of fine sediments and the construction of deflectors. The costs of restoration measures were estimated to be 0.3–6.8 EUR per stream meter in typical forest streams and 10.7–11.6 EUR per stream meter in modified streams (VII).

# 6 Discussion

## 6.1 Dredged rivers

The construction of large boulder dams was chosen as the main measure for the restoration of the study rivers dredged for timber floating. The restoration measures also included the construction of deflectors and cobble ridges as well as the reconnection of drained sections of the river channel (I). The restoration structures increased hydro-physical habitat diversity in the studied river (II,III). An increased hydro-physical habitat complexity means that the potential availability of suitable microhabitats for fish and their food resources will be greater, improving the changes for successful enhancement of fish stocks (II). The enhancement structures provided plenty of energetically more favourable locations for fish and macroinvertebrates. However, it is likely that the number of velocity refuges provided by boulder dam structures reduces as the discharge increases. The physical habit simulations showed that the restoration measures used did not increase potential habitat for the smallest trout size classes (III). The latter result is in agreement with the stocking and electrofishing results by Jutila *et al.* (1994). On the basis of the model simulations it would be recommendable to use a higher percentage of boulder material for creating deep winter habitat and to use mostly cobbles and pebbles to build shallow sheltered habitat on the river margins for the smallest fish.

A homogenous biotope increases the amount of intercohort competition in a brown trout population (Heggenes 1994). Habitat diversification due to e.g. restorations can decrease competition between trout year classes, and also reduce interspecific interactions. Bugert *et al.* (1991) report that habitat use by subyearlings of three salmonid species was segregated primarily by hydraulic factors, resulting in an increase in the cohabitation potential of those species with increasing diversity of those factors. Mäki-Petäys *et al.* (2000) reported highly clumped distribution of age-0 brown trout in channelised flumes, which they presume to increases interspecific spatial competition and downstream displacement of young brown trout in channelised streams. Mäki-Petäys *et al.* (2000) state that the potential for interspecific competition between brown trout and grayling increases in winter because both species use lower water velocities in cold water. Increment of depth, water velocity, and bottom coarseness variation in a river section can thus increase its physical carrying capacity. Areas with coarse substratum and other flow refuges for severe winter conditions are especially important in northern rivers. Such refuge can be provided by constructing large boulder dam structures with several layers of boulders and cobbles (see also Shuler 1993). If the hydro-physical production capacity of a river section is desired to be increased, the restoration measures should focus on avoiding extreme low flow situations by e.g. increasing pool areas (Heggenes *et al*. 1996). In stony rapids the construction of boulder dams efficiently creates deep pool habitats between the dams (I, III).

The rehabilitation of natural reproduction of salmonid fishes is a slow process, and hydro-physical improvements in spawning or juvenile habitats cannot ensure it alone. This study does not include any long-term fish monitoring studies, but on the basis of the studies by Luhta *et al*. (2001) carried out on the Iijoki river system it seems to have taken 10 years after the implementation of restoration measures until the recovery of brown trout and grayling were started. Stream mosses, a central habitat-forming factor in rivers of the boreal zone, are very slow to recover, which has been considered as an explanation for the slow recovery of the whole ecosystem after disturbance resulting from e.g. restoration actions (Muotka & Virtanen 1995, Laasonen *et al*. 1998, Laasonen 2000). Beside the quality of nursery areas, there are also other factors that can affect the density of salmonids in rivers and streams, such as fishing and the amount of food available in feeding areas (larger rivers, lakes or the sea). Also the long life cycle of salmonids especially in northern areas (Northcote 1992, Elliot 1994, Erkinaro 1997) causes a delay in the recovery of fish stock after habitat restoration. It is most likely due to the above mentioned factors that restoration measures in the rivers dredged for timber floating have not always been followed by a rapid recovery of the natural life cycle of salmonid fishes (Jokikokko 1987, Kännö 1987, Yrjänä *et al*. 1988). Slow recovery of the fish stock in restored river sections has been documented also in Norwegian rivers (Eie *et al*. 1997).

The installation of restoration structures made of stone increased retention capacity of organic matter in dredged forest rivers, but not to the level of natural river sections (Laasonen 2000, Haapala *et al.* 2003). Many studies have shown the connection between organic matter retention and detrivorous invertebrates (see Laasonen 2000). Beside structures made of stone, also additional enhancement structures, especially woody debris, are needed for effective management of the retention capacity of streams of the above-mentioned type (Haapala *et al*. 2000). The placement of boulders or woody debris are the most common river restoration measures in the Pacific Northwest in the USA (Roni *et al*. 2002). The response of brown trout and rainbow trout (*Oncorhynchus mykiss*) to the introduction of woody debris was positive in the experiment of Zika & Peter (2002) made in Central Europe. The placement of large woody debris is worth testing also in Finnish rivers (see also Laasonen 2000), even though woody structures may not persist as long in northern rivers as in the more southern ones because of severe ice formation. This is why also continuing natural input of woody material should be ensured in northern rivers also after restoration.

On the basis of the evaluation of artificial spawning grounds in the Iijoki headwaters, it is recommendable to favour natural gravel accumulations and wide sections of channels, inner curves of bends and large side channels when making artificial spawning sites (I, Pekkala & Pekkala 1995). On the microhabitat scale, brown trout appeared to favour sheltered gravel and pebble areas with structures guiding and locally accelerating the flow as its spawning site. It is thus not reasonable to construct large gravel areas but rather place gravel for example in the proximity of river banks or in small patches around boulders or other shelter formations (I).

## 6.2 Regulated rivers

There are at least two alternative ways to restore regulated rivers. First, more ecological regulation patterns can be developed to reduce the harmful effects of short-term or long-term flow regulation. Second, channel morphology can be changed to make habitats more resistant to flow variations (IV, V, VI).

According to the EVHA simulations in the river Siikajoki, there were no significant differences in the amount of available habitat for brown trout fry between the implemented flow and alternative regulation patterns during both summer and winter test periods. Thus no single flow event appeared to cause the lack of brown trout in the regulated river Siikajoki. Despite the moderate amount of habitats in all normally occurred flows, short-term regulation appeared to prevent the success of brown trout by other mechanisms in the strongly regulated sections of the river Siikajoki (IV). A potential explanation for that can be the constantly varying conditions. An increased need to change habitat exposes fish to predation and depletes their energy supply (Heggenes 1994). Daily fluctuations in flow rate cause thickening of ice cover in winter (IV). A sudden decrease in flow especially at low water temperature may cause stranding of brown trout and salmon (Halleraker *et al*. 1999).

Suitable habitat for grayling can be constructed in a hydropeaking river impoundment by digging shallow side channels with coarse bottom substrate or by constructing low-profile reefs covered by cobble-to-boulder material in areas where the water velocity is suitable (V). According to the telemetry experiment, both constructed habitats (reefs and side-channels) seemed to be suitable for adult graylings (VI). On the basis of the habitat analysis in the regulated rivers Siikajoki (IV) and Oulujoki (V), it appears that small side channels with varying profiles offer more suitable habitat with a wider flow scale for riverine salmonid fishes than the larger main channels do. Digging shallow side channels was a better single restoration measure than making low reefs in the middle of a channel, because in the river Oulujoki the reefs remained completely submerged at peak flow (V). Thus the youngest graylings would need to migrate over the fast flowing areas to find sheltered habitats with bank cover which they have been found to need (Bardonnet *et al*. 1991, Sempeski & Gaudin 1995, Greenberg *et al*. 1996). Tiffan *et al*. (2002) have found that low lateral slope and limited water velocity are the most important factors controlling the amount of juvenile habitats of Chinook salmon (*Oncorhynchus tshawitsch*) in a large regulated river.

## 6.3 Forestry streams

Small headwater streams are often important habitats for brown trout. The density of brown trout is often higher in streams with plenty of sheltered habitat with bank cover and little competition than in larger rivers in the same area (Degerman & Sers 1992, Eklöv 1997). The brown trout was the most abundant species also in six of the eight forest streams surveyed in this study, as well as in the manmade stream Imatranpuro (VII). Brown trout density (0.2–35.3 individuals/100m$^2$) in the studied streams was lower than that of streams in southern Sweden as reported by Eklöv (1997).

The overall quality of habitats is a function of several components. In this study the distribution of 0+ brown trout density was clearly connected with cobble substrate. Also the density of larger trout correlated with coarse bottom substrate in many of the study streams. Correlation with the 0+ brown trout and gravel-cobble habitat have also been reported by Eklöv *et al*. (1997), Jutila *et al*. (1999) and Stoneman & Jones (2000). The large distribution of one-year old trout in the study streams suggests that their habitat may not be the bottle-neck habitat type in the studied forest streams.

The survey carried out in the small forest streams during the summer low flow period does not reveal much about the preferable winter habitat and whether it is situated in the same reaches as the summer one. However, the results by Mäki-Petäys *et al*. (1999) indicate that stream sections with coarse bottom substrate can also be important wintering areas for brown trout in northern streams. In the tributaries of the river Vagnsvatnet in Norway, brown trout migrate into larger streams or lakes for winter (Jonsson 1985).

Forestry operations cause silt load on watercourses (Beschta 1978, Ahtiainen & Huttunen 1995, Cowx & Welcomme 1998). The most common human impact in the study streams was the accumulation of sand on stream bottom, which was registered in 39 % of the studied reaches. The most often suggested restoration measure was the removing of fine sediments. Suction dredging in forest streams is, however, a very expensive measure since it presupposes the use of portable machines suitable for small streams (Virtanen & Virtanen 2000). Dredging in a large scale will also disturb aquatic life. Thus the recommended measures for mitigating the effects of siltation in streams of forestry areas are construction of purifying structures in forest ditches, increment of gravel and cobble bottom material, and construction of in-stream structures to create patches with coarse substratum in streams (VII).

The costs and benefits of stream restoration are difficult to compare because the benefits are for the most part immaterial, while the costs are mainly material. To create a magnitude for the costs of watercourse restoration in forestry areas, restoration costs can be compared to the growth of forests in the catchment area of the specific watercourse of interest (Väisänen *et al*. 2001). For instance, timber production in the catchment area of a typical forest stream studied here would cover the costs of the suggested restoration measures in 1–18 months. A period of three years would be needed to cover the restoration costs of a heavily modified stream.

## 6.4 Habitat analysis

Physical habitat simulation offers a fast way to evaluate the effects of restoration measures with regard to the studied species whose habitat requirements are known (II,III, IV,V). Kondolf & Micheli (1995) recognise channel geomorphology as a framework upon which the ecological system of a river is developed. They recommend the use of geomorphic studies for evaluating the restoration project. Measuring prior to restoration gives information on the quantity and quality of different habitat types in the planning area and enables one to evaluate what types of habitat are missing. Maps describing patches with varying water depth, velocity, and bottom substrate at low, medium and high flow events help the designer to perceive the complicated patchwork of habitat structure. Comparison of the results of physical habitat modelling before and after restoration enables the possible completion and further development of the measures. Habitat modelling has been used in this way in long-lasting restoration projects in the tributaries of the rivers Iijoki (III) and Hossanjoki (Korhonen 1998).

The temporal scale of the present habitat model applications is fairly narrow both concerning the annual hydrological regime and other seasonal variation in the river. The habitat studies of this thesis are for the most part based on single measurements made during the summer low flow period. No flood measurements or winter observations have been done. However, in the habitat simulations of the river Kutinjoki, both summer and winter habitat suitability criteria were used to adapt the different habitat demands of brown trout during different seasons (Heggenes 1994, Mäki-Petäys *et al*. 1997, 1999). In the Kutinjoki case three of the most typical flow events (0.6, 1.7 and 3.4 * MQ) outside the peak flow were simulated. As for Siikajoki, flow and habitat time series for one year were used to search for habitat bottle-necks. Also the flow data of a typical summer week and a typical winter week were used when comparing the brown trout habitat quality regulations with potential regulation alternatives (IV). In the hydropeaking river Oulujoki, two flow events (base flow: 0.4 * MQ and peak flow: 1.2 x MQ) commonly occurring during the hydropeaking pattern were simulated when estimating the effects of restoration on fish habitat quality (V, VI).

The validity of results from a model analysis should always be tested. Also the possible need of calibrating the model should be considered. In the case of fish habitat models, this requires the comparison of simulated habitat quality with observations on fish location, preferably on quantitative basis. No validation was done in the model applications of the rivers Kutinjoki and Siikajoki. In the river Oulujoki validation was limited to adult fishes. Because of this no conclusions about the biological responses caused by the used restoration measures can be drawn in this study. It was only possible to asses the changes in hydro-physical variables (water depth, velocity, substrate) on the basis of field measurements and model calculations. These belong to the main variables characterising the physical habitat of the studied fish species in running waters (Heggenes 1990). The study enabled the making of implications of the effects of restoration on the magnitude of potential habitat for certain fish species.

The use of river-specific habitat suitability criteria is generally the most effective way of predicting habitat quality and fish distribution (Bird 1996, Mallet 2000, Mäki-Petäys *et al*. 2000). This was not possible in the study rivers since the brown trout and grayling populations in the rivers were extremely sparse. There were, however, no substantial differences between the generalised suitability criteria of brown trout (Souchon *et al*. 1989) that was applied in the Siikajoki case and the summer suitability criteria later compiled by Mäki-Petäys *et al*. (1997) in northern Finland.

Most of the adult graylings located in the river Oulujoki were encountered in the cells that have good or excellent habitat value, supporting the view that generalised suitability criteria can be applied when modelling available habitat for grayling. Mäki-Petäys *et al*. (2002) also found that two generalised suitability criteria of salmon transferred fairly well to the test sites of four geographically distinct Finnish rivers with contrasting habitat availability. Beecher *et al*. (2002) report significant positive correlation between fish density and estimated habitat values by using composed habitat criteria for Coho salmon (*Oncorhynchus kisutch*). The use of generalised criteria might be advisable in many modelling contexts if it is not possible to use the criteria compiled in the study area (Mäki-Petäys *et al*. 2002). This is because the site-specific criteria for drift-dwelling fishes are commonly covering only a fragment of the range of habitats suitable for salmonid fishes. Habitat selection of juvenile brown trout and salmon (*Salmo salar*) vary depending on habitat availability, suggesting relatively wide spatial niche with different optima. That is, they adapt habitat selection over a wider range of hydro-physical habitat conditions (Heggenes *et al*. 1996). Habitat availability influences also grayling habitat selection, but possibly only slightly (Mallet *et al*. 2000).

There has recently been a lot of discussion on the changes in fish habitat demands as a function of flow, and if the phenomenon is relevant for the application of physical habitat modelling (Holm *et al*. 2001, Heggenes 2002, Ibbotson & Dunbar 2002). The found dependence of habitat preferences of river flow made detailed physical habitat modelling even more complicated. This can be said to favour the use of the model on a general level ( i.e with reasonable resources) combined with the user's biological knowledge and recognition of the limitations inherent in the model.

Physical habitat simulation modelling is a suitable tool e.g. for estimating the compensation flow needed to support moderate habitats in river sections with reduced flow and for estimating the minimum and maximum releases of a reservoir. In the last few years it has been used also in studies dealing with river habitat rehabilitation (Parasiewicz & Dunbar 2001). As based on the conclusions of Parasiewicz & Dunbar (2001) and the experiences of this study, habitat modelling can be used at the design stage to improve the environmental standard of river engineering works. More sophisticated measurement and modelling techniques combined with new biological information will increase the use of habitat models in the management of rivers in the future. On the other hand, the physical habitat simulation procedure seemed to fail to predict the impacts of short-term regulation of brown trout in the river Siikajoki. Valentin *et al*. (1994a,b), Harby *et al*. (1999) and Vehanen *et al*. (2000) have recently studied fish behaviour in hydropeaking rivers in order to develop predictive models for simulating the ecological impacts of short-term regulation. However, more studies and further development of models are needed before the main effects of short-term regulation on aquatic organisms can reliably be simulated.

# 7 Management implications and future research needs

The construction of large boulder dams was found to be a good method for restoring monotonous rapids sections used for log floating. The construction of deflectors and cobble ridges as well as the reconnection of drained parts of the river channel were recognised as other suitable measures for restoration. Restoration structures increased hydro-physical habitat diversity in the studied river. An increased hydro-physical habitat complexity means that the potential availability of suitable microhabitats for fish and their food resources increases, improving the changes of successful enhancement of fish stocks. However, the velocity refuges provided by boulder dam structures are likely to reduce in number as the discharge increases. On the basis of physical habit simulations it is also obvious that the restoration measures used did not increase potential habitat for the smallest trout size classes. It would be recommendable to use pebbles and cobbles to build shallow sheltered habitats to river margins for the smallest fishes and a larger amount of boulder material for creating deep winter habitats.

The habitat modelling experiment in the river Siikajoki revealed only minor differences in riverine habitats between alternative regulation patterns. None of the modelled flow events proved to be a clear habitat bottle-neck, but large and sudden flow fluctuations may still cause stress to fish. In a sensitivity analysis of habitat modelling, modifications of the suitability criteria appeared to have a major influence on habitat suitability for young brown trout. It was concluded that all effects of continuously varying flow on fish cannot be predicted with the physical habitat simulation model in its basic form.

The excavation of narrow side channels and the construction of low reefs diversified the habitat structure of the river channel and appeared to increase hydro-physical habitat diversity, creating suitable habitats for juvenile and adult grayling. The excavation of side channels also increased the availability of bank cover, giving the fish better changes for finding compensating habitats under hydropeaking conditions. The model results were validated on the basis of observations by local fishermen and fish telemetry experiments.

Forestry operations have had large but varying effects on the aquatic habitats of the studied small forest streams. Each stream included sections with significant human impacts, while on the other hand, about half of the total studied stream length was classified pristine or near pristine. Brown trout was the most abundant species in most of the surveyed streams. Of all the studied 65 habitat variables, coarse bottom substrate

(substrate size 2–10 cm) was the best to explain brown trout density. The accumulation of fine materials on the stream bottom due to forestry operations was estimated to be the most harmful human impact in the studied streams. The cost of the suggested restoration measures was considered reasonable when compared to the economical value of timber production in the catchment areas of the study streams.

The habitat simulation model has been found to be a useful tool for simulating the ecological impacts of restoration of riverine habitat in dredged rivers and for comparing flow regulation practices in regulated rivers, excluding short-term regulation (hydropeaking).

To further develop the restoration methods for dredged rivers, more long-term monitoring studies will be needed in the future. The studies should include monitoring of habitats and fish stocks several years before restoration, and at least ten years after restoration. Also some control rivers or river sections without any restoration activities should be included in the monitoring studies.

To increase the reliability and accuracy of the physical habitat modelling, investigations about the relationship between the simulated habitat area (WUA) and fish population should be conducted in the future. Further studies about the use of multivariate suitability criteria in the physical habitat modelling will need to overcome the problems caused by the use of univariate techniques in order to properly describe the physical complexity of aquatic systems. Also the flow-dependent changes of fish habitat selection need further research. For the validation of physical habitat simulation models, new, e.g. telemetry-based methods would have to be adopted in large rivers and rivers with brown water colour and sparse fish stock. In such rivers traditional diving and electrofishing methods cannot be applied. To compare the effects of alternative restoration measures to physical habitat, better user interfaces to habitat simulation models and links to other environmental engineering softwares should be developed.

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# Appendix 1

**Terminology**

In this thesis, **rivers** refer to flowing water with a catchment area of more than 200 km$^2$ and a mean flow of more than 2 m$^3$s$^{-1}$. **Streams** signify flowing waters which are smaller than rivers, but still form a visible channel on the ground. **Dredged rivers** are rivers whose channels have been altered by human action for different purposes; often in order to make the rivers more straight and thus causing less flow resistance. Rivers dredged for timber floating are often characterised by narrow U or V shaped cross-sections, decrease of watered area, and cut-off of largest meanders. **Regulated rivers** in this connection refer to rivers used for hydropower production by damming the river channel and regulating their flow in a manner different from the natural rhythm. **Long-term** regulation means that the flow patterns differ from the natural flow on a yearly basis. **Short-term** regulation (**hydropeaking**) means that the flow varies on a weekly or daily basis or even on an hourly basis, according to the varying need for electricity. Such hydropower rivers are often dredged, which makes them the most complicated cases from the viewpoint of river restoration. **Forestry streams** are streams flowing mainly in forest areas. Changes in their condition are primarily caused by forestry measures such as ditching, ploughing, and timber felling.

**Restoration** (or rehabilitation) is understood as a non-recurrent, relatively massive measure taken to improve a certain feature. Restoration measures are often realised to remove a defect caused by utilisation and to restore the object to its former state. Muharin *et al*. (1995) have defined restoration as follows: "The totality of measures which change man induced alterations to rivers (primarily flood control measures, but also diversions, hydropeaking etc.) in such a manner that ecological functioning of the new state resembles a more natural river". **Habitat restoration** includes measures which make physical conditions such as river bed structure or flow conditions better for the fish species in question. Habitat restoration includes the idea that measures are mainly designed for increasing habitat for one or few target species, regardless of whether any human-induced degradation exists in the watercourses. River restoration can include also other measures than habitat restoration measures. Different from restoration, **management** of an area is a continuous action based on a relatively small one-time effort. **Mitigation** of defects is the case when a major part of a defect exists even after measures have been taken to prevent it (Cowx & Welcomme 1998). It describes well the habitat restoration measures taken commonly in rivers, which are used for hydropower production. This thesis also mentions the **revising of flow regulation** as a restoration method, meaning that a regulation practice in force is permanently changed to a more natural or an otherwise better practice when considering the river ecosystem.

**In-stream** is the part of a channel that is covered by water in normal flow conditions (Raven *et al*. 1998). **A boulder dam** is an in-stream habitat improvement structure, which is constructed of stone material of different sizes. It is possible for water to partially flow through the construction, but it will nevertheless rise the water level and decrease water velocity directly above. **A deflector** is a habitat improvement structure that is made of stony, wooden or corresponding material in order to direct the water flow and thus cause further development in river channel morphology. It can be located beside a stream bank or in the middle of a river channel, but it does not stress across the whole river width. **A boulder** or a **boulder group** is a habitat improvement structure that does not significantly effect the flow of the whole river reach. It can form a local refugee from the stream flow for river biota and diversify the hydro-physical conditions in the river.

A reach is a length of an individual river that shows broadly similar physical characteristics. Rapids are an area of broken standing waves forming distinctive whitewater conditions, normally over cobble or boulder substrate. Rapids are associated with steep gradient. A pool is a distinct feature of deeper water with no perceptible flow in dry-water conditions (Raven *et al*. 1998).

A **habitat** in this connection implies to those physical conditions which enable an organism to live, broadly corresponding to the definition of ”**a physical habitat**” by Stalnaker *et al*. (1995). In a more general sense, factors defining a habitat would also comprise e.g. water quality and biological factors such as competition and predation. This state of the physical habitat of stream dwelling organisms can be described with **physical habitat simulation models**.

Fish can be classified into different groups based on their age. The classification used a scale where the first two groups were **0+** and **1+**. Fish in the 0+ group are living their first year, while 1+ fish are over one year old but less than two years old.