TKK Dissertations 177
Espoo 2009

TWO-DIMENSIONAL AQUATIC HABITAT QUALITY MODELLING

Doctoral Dissertation

Markku Lahti

Helsinki University of Technology
Faculty of Engineering and Architecture
Department of Civil and Environmental Engineering

TKK Dissertations 177
Espoo 2009

TWO-DIMENSIONAL AQUATIC HABITAT QUALITY MODELLING

Doctoral Dissertation

Markku Lahti

Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the Faculty of Engineering and Architecture for public examination and debate in Auditorium R1 at Helsinki University of Technology (Espoo, Finland) on the 21st of August, 2009, at 12 noon.

Helsinki University of Technology
Faculty of Engineering and Architecture
Department of Civil and Environmental Engineering

Teknillinen korkeakoulu
Insinööritieteiden ja arkkitehtuurin tiedekunta
Yhdyskunta- ja ympäristötekniikan laitos

Distribution:
Helsinki University of Technology
Faculty of Engineering and Architecture
Department of Civil and Environmental Engineering
Water Resources Engineering
P.O. Box 5200 (Tietotie 1)
FI - 02015 TKK
FINLAND
URL: http://civil.tkk.fi/en/research/water_resources/
Tel. +358-9-451 3821
Fax +358-9-451 3856
E-mail: Markku.Lahti@fortum.com

ISBN 978-952-248-026-2
ISBN 978-952-248-027-9 (PDF)
ISSN 1795-2239
ISSN 1795-4584 (PDF)
URL: http://lib.tkk.fi/Diss/2009/isbn9789522480279/

TKK-DISS-2632

Yliopistopaino
Helsinki 2009

ABSTRACT OF DOCTORAL DISSERTATION	HELSINKI UNIVERSITY OF TECHNOLOGY P.O. BOX 1000, FI-02015 TKK http://www.tkk.fi

Author Markku Lahti

Name of the dissertation
Two-Dimensional Aquatic Habitat Quality Modelling

Manuscript submitted	Manuscript revised
Date of the defence 21st of August, 2009	
☒ Monograph	☐ Article dissertation (summary + original articles)

Faculty	Faculty of Engineering
Department	Department of Civil and Environmental Engineering
Field of research	Water Resources Engineering
Opponent(s)	Professor Juhani Kettunen
Supervisor	Professor Pertti Vakkilainen
Instructor	Professor Pertti Vakkilainen

Abstract

Two-dimensional modelling of aquatic habitats of different organisms was developed, analysed and validated. The habitats and abundance of salmon, brown trout, grayling, pikeperch, stone loach, bullhead, crayfish and Persicaria Foliosa were modelled. In fish habitat modelling, two-dimensional hydraulic modelling was used, where wind induced potential lake bed erosion was calculated for crayfish. Models were calibrated with many types of biological material and tested. The effect of different methods of using biological information and of carrying out field measurements and hydraulic modelling were analysed. The selection of habitat preference curves and the density of field measurements were found to have the greatest effect on results. The models for salmonids and Persicaria Foliosa were found out to work consistently in sensitivity tests. The model was validated against observed habitat use. With the models, abundance of salmonids and Persicaria Foliosa could be predicted. Transferability of the habitat model of crayfish to different types of lakes must be further developed and confirmed.

Two-dimensional habitat models were found to work consistently if appropriately applied and used, in prediction of abundance of organisms despite a large natural variability and dynamics of habitat selection and the difficulty to accurately observe habitat selection making the validation of habitat models difficult.

Keywords habitat, watershed

ISBN (printed)	ISBN 978-952-248-026-2	ISSN (printed)	ISSN 1795-2239
ISBN (pdf)	ISBN 978-952-248-027-9 (PDF)	ISSN (pdf)	ISSN 1795-4584 (PDF)
Language	englanti	Number of pages	279
Publisher	Department of Civil and Environmental Engineering		
Print distribution	Department of Civil and Environmental Engineering		

☒ The dissertation can be read at http://lib.tkk.fi/Diss/

VÄITÖSKIRJAN TIIVISTELMÄ	TEKNILLINEN KORKEAKOULU PL 1000, 02015 TKK http://www.tkk.fi

Tekijä Markku Lahti

Väitöskirjan nimi
Two-Dimensional Aquatic Habitat Quality Modelling

Käsikirjoituksen päivämäärä	Korjatun käsikirjoituksen päivämäärä

Väitöstilaisuuden ajankohta 21.8.2009

☒ Monografia	☐ Yhdistelmäväitöskirja (yhteenveto + erillisartikkelit)

Tiedekunta	Insinööritieteiden ja arkkitehtuurin tiedekunta
Laitos	Yhdyskunta- ja ympäristötekniikan laitos
Tutkimusala	Vesitalous ja vesirakennus
Vastaväittäjä(t)	professori Juhani Kettunen
Työn valvoja	professori Pertti Vakkilainen
Työn ohjaaja	professori Pertti Vakkilainen

Tiivistelmä
Työssä kehitettiin kaksiulotteinen eliöiden elinympäristöjen mallinnusmenetelmä, jonka toimintaa analysoitiin ja testattiin. Menetelmää käyttäen mallinnettiin lohen, taimenen, harjuksen, kuhan, kivennuoliaisen, kivisimpun, ravun ja lietetattaren elinympäristöjä ja esiintymistä. Kalojen elinympäristön ennusteissa käytettiin kaksiulotteista virtausmallia, kun taas ravun mallinnuksissa keskeisenä fysikaalisena ohjausmuuttujana oli tuulen aiheuttama potentiaalinen pohjaeroosio. Mallit kalibroitiin ja testattiin useilla erilaisilla biologisilla aineistoilla. Biologisten aineistojen käsittelymenetelmien ja maastomittaus- ja virtausmallinnusmenetelmien vaikutusta mallintamistuloksiin arvioitiin. Mallinnusten tuloksiin vaikuttivat eniten elinympäristön soveltuvuuskäyrien valinta ja maastomittausten tiheys. Kalojen ja kasvien elinympäristömallien havaittiin herkkyystesteissä käyttäytyvän johdonmukaisesti. Malleja validoitiin havaittua elinympäristön käyttöä vastaan. Malleilla kyettiin ennustamaan lohikalojen ja lietetattaren elinympäristön käyttöä. Ravun elinympäristömallin yleistettävyyttä erityyppisille järville tulee kehittää ja varmentaa.
Kaksiulotteisten elinympäristömallien havaittiin oikein sovellettuina ja käytettyinä toimivan johdonmukaisesti eliöiden esiintymisen ennustamisessa huolimatta mallien testaamista vaikeuttavasta suuresta elinympäristön valinnan luonnollisesta vaihtelusta ja dynamiikasta ja tarkan havainnoinnin vaikeudesta.

Asiasanat elinympäristö, vesistö

ISBN (painettu)	ISBN 978-952-248-026-2	ISSN (painettu)	ISSN 1795-2239
ISBN (pdf)	ISBN 978-952-248-027-9 (PDF)	ISSN (pdf)	ISSN 1795-4584 (PDF)
Kieli	englanti	Sivumäärä	279

Julkaisija Yhdyskunta- ja ympäristötekniikan laitos

Painetun väitöskirjan jakelu Yhdyskunta- ja ympäristötekniikan laitos

☒ Luettavissa verkossa osoitteessa http://lib.tkk.fi/Diss/

Acknowledgements

This work was started as development of the Finnish habitat model (FISU) in Imatran Voima Ltd. in co-operation with the North Ostrobothnia Environmental Centre, the Finnish Game and Fisheries Research Institute, and Kemijoki Oy, continuing at Technology of Fortum Power and Heat Ltd. I wish to thank Mr. Jukka Muotka, Dr. Timo Yrjänä, Mr. John Forsius, Dr. Ari Huusko, Dr. Aki Mäki-Petäys, Dr. Teppo Vehanen, and Mr. Mika Marttunen for their important roles in launching the project and during the development of the model. Jukka Muotka had a major role in launching the development of the model and acquiring the financial resources for it. Timo Yrjänä provided the biological knowledge, literature, and valuable co-operation for the development of the fish habitat model. John Forsius acquired the hydraulic model for the fish habitat model and provided hydraulic modelling knowledge. I wish to thank Ilkka Kylmänen and associates from Kemijoki Oy, who developed field measurement methods based on echo sounding and provided field measurement data. The model was represented, including a case study, in a Work for a Diploma by Lahti in 1999.

The validation of the model and writing of the thesis has been carried out at the facilities of Hydro and Wind Engineering branch of Fortum Service Oy at Espoo, the heads of which, Mr. Jukka Muotka and Lic. in Tech. Juha Laasonen, I wish to thank. I wish to thank Professor Pertti Vakkilainen for directing the work, giving valuable advice, and helping in getting the financing for the work. Dr. Aki Mäki-Petäys, Dr. Ari Huusko, Dr. Teppo Vehanen, and Dr. Mari Nykänen from FGFRI and Dr. Timo Yrjänä provided the most important high-quality fish preference and observation data for the case studies of the thesis and valuable biological knowledge for the fish habitat model development. I wish to thank Mr. John Forsius for providing hydraulic modelling knowledge and for valuable discussions and Mr. Esa Erkamo from FGFRI for providing most of the biological knowledge and data for the development of the crayfish model and for a very important co-operative role in the development of the crayfish model. I wish to thank Mr. Mika Marttunen and Dr. Seppo Hellsten for providing erosion knowledge for the crayfish model, Mr. Juha Riihimäki for providing the biological knowledge and calibration data for the modelling of *Persicaria Foliosa*, Dr. Tauno Ulvinen for providing the validation data, and Mr. Markus Huolila at the Employment and Economic Development Centre for South Savo for providing the Ripatinkoski

Rapids data. I wish to thank Mr. Jukka Muhonen at the Employment and Economic Development Centre for Häme for the Tainionvirta Rapids data. I wish to thank Mrs. Tuulikki Miettinen and Mr. Jukka Hassinen and the measurement group from the North Savo Regional Environment Centre for the Konnuskoski Rapids data. Mr. Olli van der Meer (T:mi), Mr. Ilkka Kylmänen, Mr. Marko Talvensaari, and Mr. Veli-Pekka Sirniö from Kemijoki Oy and Mr. Juha Arola and Mr. Seppo Hihnala from Suomen Salaojakeskus Ltd. made most of the field measurements. I wish to thank Ruth Vilmi Online Education Ltd for language checking of the thesis.

I wish to thank with all my heart the above-named people and all others who contributed to this work.

Fortum's foundation, Hydro and Wind Engineering branch of Fortum Service, Sven Hallin's foundation and Tekniikan Edistämissäätiö provided financing for the work. The development of the crayfish model and a part of the writing by the project Sustainable regulation of large water courses: principles, indicators, and methods, PRIMEREG (52793). The habitat modelling of the delta of the Oulujoki River was financed by the town of Oulu, the original Ripatinkoski River modelling was financed by the Economic Development Centre for South Savo and the South Savo Regional Environmental Centre and the hydraulic modelling of Pyhäkoski was financed by FGFRI.

List of terminology

available habitat	**the area inside which the organisms can select their position**
log book fishing	**places where fish are caught are marked on a map while fishing**
field measurements	**measurements of physical variables, e.g. topography, river bed particle size, and water level in situ**
field observations	**observation and location of organisms in situ, e.g. of fish**
grid	**a square or irregular net of data points**
habitat	**a place where an organism lives**
habitat quality	**the suitability of the place for living. In modelling, an index is calculated to represent it**
habitat suitability	**approximately the same as habitat quality, but refers more limitedly to the value of the suitability index calculated**
habitat use	**an organism being positioned in a habitat**
preference curve	**a curve which represents the suitability at each value of a factor affecting the suitability of habitats**
preference surface	**a surface which represents habitat suitability, taking several factors into consideration simultaneously, also called two-dimensional multivariate preference**
physical model	**a grid or grids comprising the values of a physical variable or variables and the boundary conditions and modelling methods**
physical variable	**a variable representing the physical conditions for living in a place, e.g. flow velocity, river bed particle size**
restoration	**returning the state of a place to a state that existed before**
rehabilitation	**constructing e.g. a dredged river to a better state from some viewpoint, e.g. for a fish species**
substrate	**river or lake bed characteristics, also specifically river bed particle size**
suitability index	**index for habitat suitability, takes values between 0 and 1**
telemetry	**a radio transmitter is attached to the fish and the movements of the fish are observed**

TWO-DIMENSIONAL AQUATIC HABITAT QUALITY MODELLING

1 INTRODUCTION

1.1 Development of habitat models

Human activities have changed the ecology of many rivers and streams. According to Macklin & Lewin (1997), rivers that have not been changed in some way are even rare. In dredged rivers and brooks changed by logging (Allan 1995), habitat structure and fish species diversity are poorer (Cowx & Welcomme 1988), and e.g. the production potential of the fry of migratory fish is much smaller (e.g. Karlström 1977). The damming and regulation of rivers mean changes in water levels and flow rates, which change habitats (e.g. Ruohomäki 1984, Mills 1989, Joensuu et al. 1996, Riihimäki et al. 1996, Cowx & Welcomme 1998).

Hydrological (Hynes 1972, Janauer 1994, Muotka & Tikkanen 1995) and geomorphological factors (Brookes 1996, Yrjänä et al. 1999) have been found to be important for stream ecology, and they determine (Arthington 2002, Pieterse & Murphy 1990) many of the properties of ecosystems in running waters. Geomorphology means the form and properties of the channel and banks and the structure of the bed (DVWK 1996). Flow rate and the temperature of water are, according to Hynes (1972), the most important factors affecting morphology, physiology, ecology (Rossoll & Werth 1992), and species in streaming waters. The biological system in watersheds is based on their physical and chemical conditions, of which geomorphology (Jungwirth & Winkler 1983) and the dynamic processes of the watershed are especially important (DVWK 1996). Water depth and flow velocity (Dittrich & Schmedtje 1995, Joensuu et al. 1996) affect the communities indirectly via the structure and material of the bed.

Many studies have been carried out to find the most important physical factors affecting the suitability of habitats for different species of organisms. Individual organisms select their habitats according to specific preference criteria. For example, young Atlantic salmons select their habitats according to flow velocity, which is linked to energetics, often in combination with substrate, and water depth in small streams (Heggenes 1994a). According to Rabeni and Jacobson (1993), the major cause of losing streamwater fish populations or their degradation is the alteration of the physical habitat within and adjacent to the channel.

Common and widespread salmonids in Europe are salmon, *Salmo salar,* brown trout, *Salmo trutta* and grayling, *Thymallus thymallus*. The habitat requirements of other salmonids are rather similar although some, e.g. trout are more flexible in their needs (Cowx &Welcomme 1998). The habitat requirements of a competitor of salmonids, bullhead, *Cottus gobio*, have been found to be rather similar to those of salmon. Availability of nourishment may be a more important factor in smallest microhabitat selection of bullhead than other factors (Huusko et al. 2003).

Spawning sites are the first habitat requirements of salmonids. Gravel size, intragravel flow, water depth, stream velocity, temperature and cover are important factors. Water depth should be more than 15 centimeters but less than double the female fish fork length (Cowx &Welcomme 1998). Too high flows causing moving of gravel beds and too low flows causing drying may be harmful during incubation. Availability of oxygen to the eggs is very important, pH should not be less than 4.5, and toxic metals should not be present. Juveniles and smolts prefer temperatures of 13-17 $^{\circ}$Celcius depending on species for their growth, dissolved oxygen concentrations of over 9 mg/l, and 25 mg/l or less suspended solids in water. All salmonids begin their lives in relatively shallow, slow flowing habitats. Cover; rubble, boulders, undercut banks, logs and vegetation provide shelter from predators and flow and visual isolation of territories (Hunter 1991). Feeding focal points occur where a swift water mass flows next to a slower flowing water mass or in eddies. Drift feeding salmonids try to minimize energy consumption of swimming and to maximize available drift prey (Mäki-Petäys et al. 1999). Brown trout and Atlantic salmon use certain habitats selectively depending on fish size and species (Heggenes 1994). There is a general movement of salmon and trout to deeper waters as they grow (Cowx & Welcomme 1998). For migration and spawning, temperature, oxygen concentration and river flow must be suitable. Cover is needed as shelter from predators and for protection from bright sunlight. During night, salmonids are less active and move nearer shore. Seasonal shifts in habitat preferences are important (Mäki-Petäys et al. 1997). During winter, fish spend more time in shelter, and need places to survive under low flows and ice. Pools have been found to be beneficial (Hunter 1991). A natural sequency of riffles and pools provides different habitats needed (Cowx & Welcomme 1998). Important physical variables influencing habitat selection are water depth, water velocity and current shear, substrate particle size and cover. Many streamwater fishes need shelter. According to Heggenes et al. (1994b), flow velocity, water depth, and substrate, i.e. the bed material and its size, best explain the habitat selection of salmon and trout from seven variables examined. Excluding temperature, the values of the rest of the variables depended on these three variables (Heggenes 1994a). The values of these variables and the amount of vegetation are often measured when studying habitat selection of salmonids, e.g. in Mäki-Petäys et al. (1997). This information can be combined with hydraulic models for predicting habitat suitability under different hydraulic conditions.

Increasing ecological awareness and a change in the use of watersheds, e.g. the cessation of logging and an increasing demand for recreational fishing opportunities and for the recreational use of lakes and a demand for carbon dioxide-free energy production (Muotka 1991) have set new challenges for watershed planning.

Today, more natural hydraulic engineering is in demand in new construction projects and many new rehabilitation projects have been launched. Environmental river engineering and restoration aims at the conservation and restoration of structural and functional diversity in running waters. The objective is an ecosystem in which the organisms typical of that region can live (Schiechtl 1982).

Thus, dredged rivers are being rehabilitated throughout Europe, e.g. Järvelä & Vakkilainen (1996a&b), Järvelä (1998), Yrjänä et al. (1999), and North America, and the regulation schemes of lakes and rivers have been changed, for example. It has been shown that with rehabilitation (Yrjänä 1995a, b), the diversity of habitats (Huusko & Yrjänä 1995, 1997, Kuusela 1995, Laasonen et al. 1995) and the amount of suitable habitats for streamwater fishes and fry can be increased (Jutila 1987, Hunter 1991, Jutila et al. 1994, Kuusela 1995, Muhar 1996). Many successful structural habitat rehabilitation projects have been carried out. The density of age 0+ trout increased significantly after rehabilitation with boulders and gravel, and it was positively correlated with the area of reconstructed gravel beds (Palm et al. 2007). An increase in the number of coho salmon juveniles and smolts after rehabilitation was found by Solazzi et al. (2000) in coastal streams of Oregon. Findings in a study carried out in southeastern Australia found support for the use of timber structures as a means of increasing local fish abundances, creating drought refugia (Bond et al. 2005). A total of 30 habitat restoration projects in Wyoming were analysed. The results demonstrated that well-built, properly located, and properly maintained instream structures can provide better habitat and increase stocks of trout in carefully selected reaches (Binns 2004).

But if the whole life cycle with its varying needs of the fish species is not taken into consideration, rehabilitations may not meet expectations. The effectiviness of instream habitat rehabilitation techniques was estimated to vary from low to high also depending on target fish species (Roni et al. 2002). Their review on various restoration techniques indicated that knowledge about the effectiveness of most techniques is incomplete and comprehensive research and monitoring would be needed. In addition to instream physical rehabilitations, connectivity and the processes forming the habitats should also be taken care of.

Lepori et al. (2005) found out that the spatial scale might be important for the success of rehabilitations. Fish typically have broad home ranges that encompass different habitats each fulfilling different functions, including spawning, feeding, and refuge provisioning. A restoration carried out only in one, lotic, area of these, didn't remarkably increase fish species diversity. In a restorated boreal Finnish forest stream a non-significant decrease in densities of age-0 trout was noticed, indicating no effect of restoration. In another stream, trout density increased after restoration, indicating a weakly positive response. The overall weak response of trout to habitat manipulations probably related to the fact that the restoration did not increase the amount of pools, a key winter habitat for salmonids (Muotka & Syrjänen 2007). In some cases, attempts at enhancing stream habitats in summer may have negative consequences for wintering fish (Cunjak 1994). The cost of river rehabilitation in northern Finland has been 3500-7000 eur/ha in the period 1988-1996 (Yrjänä 1998a).

Evaluation and planning are necessary e.g. when dealing with rehabilitation, habitat and species conservation, construction work (Elliot 1994), and water level or discharge regulation scheme changes. Monitoring of the effectiveness of different habitat rehabilitation techniques should be carried out systematically (Roni et al. 2002). Evaluation of the success of rehabilitation work would require several years of fish stock observation before and after the rehabilitation (Yrjänä 2003). Yet there would still be unknown factors affecting the reliability of the evaluation. And it may take ten years for the vegetation to grow afterwards, and species other than the target species may take over the river reach after the rehabilitation. Thus, if the effect of the rehabilitation should be estimated, e.g. about five years before the rehabilitation, stocking with target species could take place, and also again right after the rehabilitation work, and after the vegetation has grown, in order to estimate the capacity of the river section to support fish populations (Yrjänä). But it is another question, whether this kind of fish stocking would be a sensible or cost effective means of fisheries management and whether such measures should be carried out only in order to estimate the effect of rehabilitations routinely. These stockings and observations might take 20 years altogether, and still there would be unknown factors, e.g. weather, fish diseases, competing species, and water quality. If there was a model with which the success of the rehabilitation work could be assessed, the process would be less resource-consuming and much faster. A model with which rehabilitation could be planned before the work would be even better. And if that kind of a model is developed, it should also be well validated.

A few decades ago, effective tools for the planning inside a mesohabitat scale and accurate representation of the state of stream habitats did not exist. There exist many inventory methods that are excellent for their specific purposes, but a spatially precise and illustrative evaluation and planning tool is lacking.

For evaluation of stream habitats, different methodologies with different spatial and time scales exist (Wesche & Rechard 1980, Yrjänä 1992). Questionnaires can be used for assessing the size and changes in the fish stock over the years. With electric fishing, a view of the location and the quality of nursery areas can be achieved. But, while still very important for monitoring, and although they give some hints for specialists about the causes of spatial variations in habitat quality, these methods alone often do not give enough information on the factors lying behind the numbers, and do not give a consistent picture. Therefore, the factors affecting habitat quality must also be considered.

So, index-type methods were developed for predicting fish biomass from different variables. With the Habitat Quality Index (HQI) method (Binns & Eisermann 1979), the trout biomass of the river was predicted by nine variables selected out of 21 that were studied. The variables were late summer flow, variation of flow rate, maximum water temperature in summer, nitrates, cover, the erosion of banks, substrate, flow velocity, and the width of the channel. A single value of each was used for a stream section in the formulae that were constructed. With this method, it was possible to predict fairly precisely the trout biomass in the brooks and rivers of Wyoming in the United States. Raleigh et al. (1986) described a method based on indices that are calculated e.g. for each life stage of fish and then considered together. A total of 18 variables were used, e.g. indices based on temperature, pools, substrate, cover and shade percentages, and flow velocity. The method is applicable for overall estimations of the habitat suitability of a larger study area.

Wesche, Goertler, and Hubert (1987) tested and developed a method for predicting trout biomass in 30 study areas in nine rivers. The variables that gave the best correlation were the annual base flow rate divided by average flow in late summer and in winter and different variables depicting cover whilst other correlated variables depicted variation of water depth, flow velocity, substrate, and fluctuation of flow rate.

These methods based on several variables have been found to be relatively expensive and laborious (Yrjänä et al. 1999). With these methods, preliminary estimations of potential fish stocks can be made, but they are not spatially explicit. Reliable detailed spatial planning and evaluation of the consequences of habitat rehabilitation for habitat hydraulics are not usually possible. These methods are good for their purposes, e.g. preliminary or larger area assessments, but do not give a homogeneous spatial picture of habitats. So, other methods should be used for more precise evaluations and construction planning.

The effect of the local structure of the river channel on habitats was taken into consideration later on. This is called habitat mapping, e.g. Maddock & Bird (1996), Yrjänä (2003a), which means, e.g. measuring, at some points, such parameters as slope, water depth, flow velocities, river bed quality, cover and water quality. This method is cost-effective and good for rough estimations for a part of a river or the whole river, and necessary for preliminary studies, e.g. highly necessary for assessing the importance of different variables for water habitats. This kind of mapping needs often to be applied for defining the reaches of a subsequent habitat modelling Maddock & Bird (1996). For more spatially detailed evaluations and planning, greater precision is needed. This means more measurements, and only the most important and cost-effective variables can be included.

Time, logistical restrictions, and financial resources usually limit the number of variables taken into the study to a small number out of all those that are possible. Because of this, Oswood & Barber (1982) developed a method for the prediction of fish biomass on the basis of the classification of habitats, in which a smaller number of variables were used. They mapped the river habitats by drawing a sketch map of the river, on which the habitats of different types were marked. The habitats were divided into four classes according to flow velocity and water depth. In addition to this, sheltered and spawning areas were marked according to their substrate. The slope of the river and a time-dependent factor describing the life stage of the fish were used. Equations for fish biomass were calculated with regression analysis. The prediction of fish biomass succeeded well. But it is still time-consuming e.g. to measure flow velocities at each point of a large area, and many times during different flow situations during a year or perhaps during many years.

A further step is to use hydraulic models in the planning, which give a continuous picture of the river at different hydraulic situations with fewer measurements. Only topographic measurements of the area and boundary condition and calibration data measured at a few points are needed.

Therefore, hydraulic models have begun to be included in habitat models. For this purpose, mapping of the local structure of the river channel with precise measurements of e.g. topography and particle size has become more common. But, from these and the hydraulic modelling, only maps of the values of the physical variables can be drawn, and the question remains; what is the habitat quality?

The optimum could be that the habitat suitability could also be drawn as a map. Information on the habitat preferences of different organisms could be compared with the physical conditions measured and modelled in the area. It would often be difficult to carry out this comparison without modelling because there are so many different variables, e.g. water depth, flow velocity, and substrate affecting the habitat quality simultaneously. Hence the solution is a habitat model: a model which takes both the habitat preferences and the physical conditions into account, and thus gives the habitat quality as output. Using this kind of a tool together with inventory and preliminary mapping methods assists in making reliable assessments and planning physical habitat rehabilitation projects in watersheds.

With a habitat model, the current state of habitats and the effects of changes can be assessed. The amount of suitable habitats (e.g. Valentin et al. 1994, Huusko & Korhonen 1995, Yrjänä 1995c and 1998a, Elliot et al. 1996, Riihimäki et al. 1996, Tamai et al. 1996) for different life stages of organisms, at different flow situations, and in different seasons can be assessed.

The most important, critical, situations (Bovee 1988, Heggenes 1994a, Bird 1996, Mäki-Petäys et al. 1999, Vehanen et al. 1999, Vehanen et al. 1999) can be found and evaluated. For example, Capra et al. (1995b) found out that the first year of life was the limiting factor in trout population dynamics in a study in three French rivers, while Mäki-Petäys (1999) found it to be the first winter in northern Finland. With a dynamic two-dimensional hydraulic model, dynamic hydraulic situations can also be calculated. The effects of short-term fluctuations (Forsius 1983, Pohjonen 1991, Sinisalmi et al.

1996) of water level or flow rate can be evaluated by comparing the positions of suitable habitats from maps of different hydraulic situations, calculating durations of habitat values being below or exceeding a threshold limit, or e.g. by means of the minimum habitat value principle and other methods (Bovee 1985, Nestler et al. 1989, Milhous 1990, 1991). E.g. a continuous duration of 20 days with spawning habitat values under a value lower than 80% of optimum for spawning habitat was found to be a limiting factor for the number of 0+ trout (Capra et al. 1995a).

The environmental effects of hydro power construction and use, different hydrographs (Schneider & Nestler 1996, Yrjänä 1998b), river rehabilitations (Huusko & Korhonen 1995, Gore et al. 1996, Huusko & Yrjänä 1997, Yrjänä 1998b & 2003), and the construction of weirs and other structures can also be assessed. With easy-to-use editing tools, work can be planned and evaluated before construction. The necessary assessment of the success of rehabilitations (Elliot et al. 1996) can be carried out with the model, and restoration methodology can be improved in this way (Huusko & Korhonen 1995). Compensation flows needed to support moderate habitats and minimum and maximum releases can be assessed (Yrjänä 2003).

Based on measurement data in dimensionally exact coordinates, different types of habitat metrics can be developed and calculated (Bovee 1996). Habitat models can also be used in fish behaviour studies, in mapping best habitats, in evaluation of the potential of the river reach for fish production (Mäki-Petäys 2003). So the model can be used for evaluation, licencing, planning, and in study purposes.

Habitat models with a one-dimensional hydraulic model could be the solution in practice. But a one-dimensional approach is usually hydraulically adequate only when the form of the river is relatively near a straight uniform channel. So, a methodology for calibrating the one-dimensional model with two-dimensional measurements in situ to make a quasi-two-dimensional model (IFIM methodology) was developed (Bovee 1982). It has been found to be useful (Huusko & Korhonen 1995), if used in right context remembering the limitations of the model (Bourgeois et al. 1996). In many studies, the amount of calculated habitats and the fish biomass have been found to correlate (Orth & Maughan 1982, Bovee et al. 1988, Souchon et al. 1989, Jowett 1992, Nehring & Anderson 1993, Tamai et al. 1996, Boudreau et al. 1996), but in some cases not (Bowlby & Roff 1986, Nuhfer & Baker 2004), e.g. because of assumptions of the model, deficient field work, or the physical model (Bird 1996). The model is still used in many countries, e.g. it is even obligatory in construction projects in watersheds in many states of the United States. But this methodology is, indeed, a combination of measurements in three different flow situations and a hydraulic model. This means that the cost and time of the measurements is high, and the result is still not truly two-dimensional (Ghanem et al. 1994, Boudreau et al. 1996). The results are more accurate near the measurement points and when the modelled flow situation is near the situation that prevailed under the measurements. In the model version, the input and the editing of the geometry are difficult. And because the model is calibrated to the measured situation in a special manner, changes in geometry cannot be well modelled and well predicted by model calculations. The French version of the model, EVHA 1.0 (Malavoi & Souchon 1989, Ginot 1995 & 1998), has been tested e.g. in Finland (Yrjänä 1995c, Piironen et al. 1999). In these tests of usability, and the foreign ones with PHABSIM, its use was found to be difficult and time-consuming, the calculation principles insufficient, and the description of habitats deficient and unillustrative (Ghanem et al. 1994, Nuhfer & Baker 2004, Bovee 1996, Boudreau et al. 1996, Piironen et al. 1999).

A more user-friendly version of PHABSIM has been developed (Payne 1994). In Norway, a habitat model called HABITAT (Vaskinn & Saltveit 1995) in a computer software system called RIMOS (The River Modelling System), using a one-dimensional hydraulic model (HEC-2), was also developed (Riihimäki et al. 1996).

Two-dimensional spatially explicit habitat models do not need such expensive field and data input work as their one-dimensional predecessors, because only topography and substrate (river bed particle size) have to be measured, plus some data points for calibration. Data measuring and processing are geographical coordinate-based and can be automated (Hardy 1996). Spatial explicity makes editing and planning possible, and, in hydraulic modelling, the most suitable hydraulic models can often be selected for use. And, most important, with two-dimensional modelling more accurate results can be achieved (Ghanem et al. 1994, Leclerc et al. 1995, Bartsch et al. 1996, Bovee 1996). Three-dimensional modelling is still considered to be too time-consuming, but it has been applied in Norway (Heggenes et al. 1996).

Thanks to advances in computer technology and software, especially in processor speeds and user interfaces in hydraulic models, two-dimensional habitat modelling has become the latest direction of development. In the seventies, two-dimensional hydraulic models already existed, e.g. RMA2 in 1973, but easy-to-use models were not common, and the calculations needed costly computer time, so one-dimensional or quasi-two-dimensional models (PHABSIM) were the most usable solutions before the nineties.

The first international conference dealing with purely habitat hydraulics was held in 1994 in Norway. At this conference, and at a second conference in Quebec in 1996, the lack of two-dimensional habitat models was a central concern.

Because of these many uses and advances, two-dimensional models have started to be developed independently (COST ACTION 626 2002) in Canada (Ghanem et al. 1994, Leclerc et al. 1995, Boudreau et al. 1996), Germany (Schneider et al. 2008), Finland, and France during the last few years. All of these models share the same basic principle; they are two-dimensional and spatially explicit. So, the same conclusions about the direction of model development have been reached in many countries.

These new two-dimensional models have not been validated with large sets of data from different conditions; some single-study comparisons between calculated habitats and observed abundance of fish have been made, e.g. Boudreau et al. (1996), Guay et al. (2000). The validations of one-dimensional models have usually been comparisons between average habitat values and total densities of fish occurrences at study sites, because they are not spatially explicit. The factors affecting the validity of modelling results have not all been studied at the same time. The accuracy of physical models made of study sites has been tested only partly, and testing of the precision needed in habitat modelling was not found in the literature either.

Yrjänä (2003) states that investigations about the relationship between simulated habitat area and fish population should be conducted to increase the reliability and accuracy of habitat modelling. The validity of different types of calibration data has not been studied comprehensively in the literature. Studies on the usability of single preference curve sets Souchon et al. (1989) have been made, but large comparisons based on calculations and observations between different preference curves and analysis have not been made.

Habitat modelling with the help of suitability indices, i.e. preference curves, has been found useful but many problems related to the reduction of natural phenomena in the methodology need further studies. There has been much criticism against the use of preference curves, e.g. Bird (1996). Habitat selection studies based on only flow velocity, water depth and substrate may not be appropriate where other factors limit populations (Bird 1996). Water quality, nourishment, predation and competition (Mäki-Petäys et al. 1997, Harvey & Nakamoto 1996) affect habitat use. Microhabitat gradients usually not included in the models, e.g. snout velocity and shear stress may be important, and microhabitat preferences may differ between mesohabitat types (Bird

1996). Habitats of adjacent areas may affect habitat use (Mäki-Petäys et. al. 1999). Stream size, discharge and its variability may have an effect on habitat preferences (Heggenes 1994). The effect of using different types of preference curves as biological calibration material on the reliability of modelling has not been studied comprehensively. There has been much discussion whether there would exist universally valid preference curves or should the curves be determined locally, e.g. Mäki-Petäys et al. (1997), Heggenes (1994) and Bird (1996). Therefore, despite there being many articles about the validity of habitat modelling with IFIM methodology, as two-dimensional modelling is relatively new, not much information has been published about the validation of two-dimensional habitat modelling as a whole or modelling and how modelling should be done, especially taking the features of two-dimensional hydraulic modelling into consideration. Neither modelling of shallow areas near banks nor the effect of roughness and kinematic viscosity on results has been studied. No comprehensive scientific representations of two-dimensional habitat models were found in the literature, except the Canadian model, e.g. an introduction to modelling and a user's manual by Steffler & Blackburn (2002). The validity and use of different preference curves has not been studied comprehensively.

A study of these issues would give an answer to the questions of whether the habitat modelling principle is valid and whether the models work in practice. Furthermore, it would provide an answer to the question of whether preference curves or preference surfaces should be used, and how these should be derived from data and selected for each use. The study would also give an extensive picture of two-dimensional habitat modelling. Whether the habitat modelling methods developed for fish habitat modelling could be used for modelling the habitats of other organisms should also be studied. For example, substrate, water depth and shear stress near the river bed are important variables affecting the habitats of many herbs and benthos. Modellings have been carried out for different species of fish, but single and rare modellings of the habitats of crayfish, in this work, pearl mussel (Lahti 1998), benthos (Kopecki 2008, Lahti 2009), and an herb, in this work, have been carried out. Modellings of all of these are useful in environmental impact assessments. In this work, in addition to fish habitat modellings, modellings of the habitats of an herb, *Persicaria Foliosa*, and crayfish are represented.

Objectives and structure of the study

The objective of the study is to study the applicability of two-dimensional aquatic modelling of habitats of organisms. The capability of two-dimensional modelling in predicting densities of organisms is tested. Models are calibrated and preliminary tested with data in Chapter "Calibration and testing". First, the physical model is tested; field measurement methods, data models and the hydraulic model are tested with measured data. Then, the biological model is preliminarily calibrated with different data. After that, the effect of habitat modelling grid density is studied. Finally, it is studied, whether the model would predict organism abundance, biomass or position most accurately. In Chapter "Verification and sensitivity analysis", the behaviour of the model is studied, and the sensitivity of results to different factors is tested. The logicality of modelling is tested with artificial data, and sensitivity analyses are carried out with these and also with measured data. Different field measurement and topographical data interpolation methods are tested. Sensitivity of the hydraulic model to parameter value changes and different modelling methods are tested. The relative importance of the effect of different factors on model results is studied. In Chapter "Validation of the model", the results of the modellings are compared with observed densities of organisms. Both types of fish habitat modelling are validated; modelling based on directly measured physical data and modelling based on hydraulic modelling. The results from fish, crayfish and herb modellings are compared with observed habitat use (Figure 1.1).

The study is carried out with data for different organisms: fish: salmon (*Salmo salar*), both fry and juveniles; brown trout (*Salmo trutta*), both fry and juveniles; grayling (*Thymallus thymallus*), both fry and adults; stone loach (*Noemacheilus barbatulus*); bullhead (*Cottus gobio*); adult pikeperch (*Stizostedion lucioperca*), and adult crayfish (*Pacifastacus leniusculus*), and an herb: *Persicaria Foliosa*.

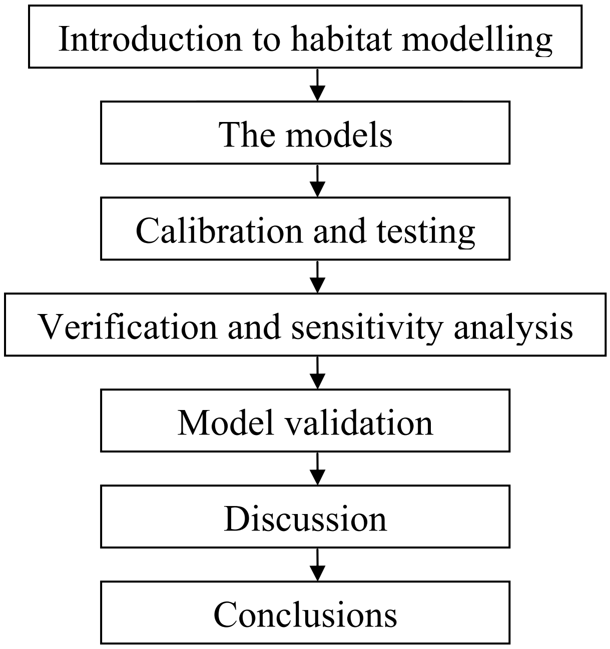


Figure 1.1 Themes of the main chapters of this work.

1.2 Principles used in testing and validation of the model

First, principles used in building the models, and the data used, are represented. After that, models created are calibrated with biological data and tested. In verification and sensitivity analysis, the behaviour of the model is studied, and sensitivity analyses are carried out. Finally, the models are validated against observed habitat use (Figure 1.2). Distributions of modelled habitat values at organism observation points are compared with the distributions of modelled habitat quality of whole the study area.

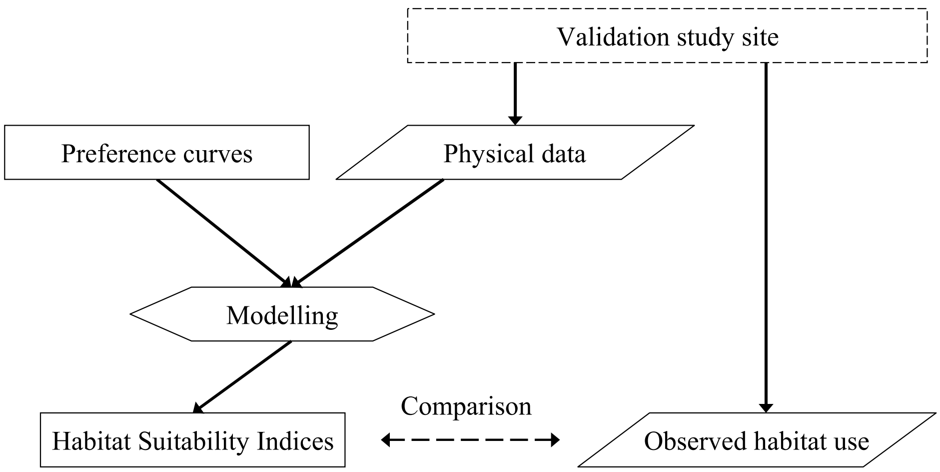


Figure 1.2 Model validation.

The observed habitat selection is called habitat use and the habitat quality distribution of the whole study area is called habitat availability. The question which this study tries to answer to is whether organisms select their positions coherently with modelled habitat quality. It is assumed that organisms can select their position freely inside the study areas. With juvenile fish data from the Rivers Simojoki and Ala-Koitajoki this is true, possible except the smallest fishes, because the study areas are relatively shallow and the habitats of high quality, and also in the Laukka area and Pyhäkoski impoundment, despite their deeper mid-channels, the modelled adult fish are easily able to move inside the study area. *Persicaria Foliosa* seeds in water and the seeds can probably spread to the study area, depending on weather and hydraulic conditions. The study areas for crayfish are also small, compared with the ability of crayfish to move.

The factors causing inaccuracy in modelling are studied. The sources of inaccuracy in modelling are, first, in the model, and second, in the calibration of the model with the biological material. What is meant by calibration of a habitat model is the selection of preference material. The sources of inaccuracy caused by the model are possible defects in the principles of modelling, e.g. in the habitat value calculation formula and in the physical model characterising the environment. Sensitivity analyses are made for different factors and methods, and for whole the model.

Biological data

A habitat model is calibrated with biological information e.g. from fish studies, e.g. with preference curves. Most of the variability in the results of habitat modelling may be caused by the selection of preference criteria.

Different types of preference curves are used; first, preference curves made from material from a study in situ, second, curves from a single fish study elsewhere, and third, curves made on the basis of many fish studies and physiological-type ones. Applying preference information from conditions of one type to another is also studied: using curves from small rivers in large rivers; the effect of a change in season and discharge, and a comparison between local curves and curves made elsewhere. Fourth, a preference surface is also tested. Biological habitat preference functions used are represented in Table 1.1.

Table 1.1 Different organisms and habitat preference functions used in this work.

where used	preference functions
Introduction	brown trout (Mäki-Petäys et al. 1997)
Harrikoski Rapids	salmon <10 (Mäki-Petäys 2000, Heggenes 1999), salmon >10 (Mäki-Petäys 2000, Heggenes 1999), grayling 5.1-25.4 (Hubert et al. 1995), stone loach (Lamouroux et al. 1999), bullhead 2-7 (Lamouroux et al. 1999), salmon 4-6 cm August, October, February and April (Mäki-Petäys 2005)
Ala-Koitajoki Rapids	salmon <10 cm (Mäki-Petäys 2000, Heggenes 1999), salmon >10 cm (Mäki-Petäys 2000, Heggenes 1999), brown trout <10 cm (Mäki-Petäys 2000), brown trout 16-25 cm (Mäki-Petäys 2000)
Laukka area	adult grayling (Vehanen et al 1998) for 110 m^3/s and 300 m^3/s, adult Grayling (Greenberg et al. 1994, calculated with methods O/E and Jacobs', adult grayling (Hubert et al. 1985), adult grayling, before and after rehabilitation and these combined (book keeping fishing, Leinonen 1999).
Pyhäkoski impoundment	adult pikeperch: summer, early winter, late winter (Vehanen & Lahti 2003), from which the early winter curves: with 5 different methods and a preference surface
Comparison of curves	brown trout fry: <10 cm (Mäki-Petäys & Huusko 2001), 4-9 cm (Mäki.Petäys et al. 1997), < 1 years but > 5 cm (Souchon et al. 1989), <14.5 cm (Raleigh et al. 1996)
Delta of River Oulujoki	*Persicaria Foliosa* (Lahti & Riihimäki 2000)
Crayfish modellings	crayfish *Pacifastacus leniusculus* at Lamminsaari Island in Lake Pääjärvi, Lake Katumajärvi study areas 4-5 and Pukettisaari Island, Lake Slickolampi, crayfish *Astacus astacus* Lake Valkjärvi in the Lake Haarajärvi area (Erkamo (FGFRI) 2002)

Organism observation methods

Different organism observation methods are represented briefly. The classification and descriptions of fish observation methods are mostly adapted from Huusko et al. (2003), where a number of sources for more detailed information can also be found.

Electric fishing is suitable for smaller-sized fish. All the fish from an area are collected in order to see the fish densities or the fish-catching sites can also be mapped to study the habitat preferences of fish. The fish are stunned with electricity and collected in a bag. Afterwards, the fish are released back into the river. When locating fish, a smaller anode is used than is used when only counting the number. The distance between fishing points can be e.g. 0.5 metres. If the water surface is smooth, the position of fish can be seen. When this is not possible, electricity causing taxis and an escape reaction may cause inaccuracy of positioning (Huusko et al. 2003, Mäki-Petäys et al. 1997). The equipment is portable, and can be placed on shore, on the river bed, or in electric fishing boats.

Radio telemetry can also be used. A radio or acoustic transmitter is put into the fish and the movements of the fish can be monitored. The fish must be big enough to be able to carry the transmitter. A maximum weight for the transmitter of 2 % of fish weight has been used as a rule, but without experimental evidence; even 12 % has been reported to show no adverse effects in some conditions (Bridger, C.J. & Booth, R.K. 2003). A PIT mark is smaller than radio transmitters, but its detection distance is short.

In echo sounding, vertical or horizontal echo sounding sectors are used for locating. This method is for relatively rough locating and is used in small but deep and larger rivers.

While keeping a fishing journal or log book, fish catching places can also be marked on a map during normal fishing. The time of the observation and the length and weight of the fish are marked down.

Nets, traps etc. and explosives can be used for rough estimations on the mesohabitat scale. The positions and the behaviour of fish can also be observed with surface or equipment diving in rivers with good visibility. When making visual observation over the water surface, the places of fish or e.g. plants are mapped by observation with the naked eye in rivers with good visibility. Water binoculars and video cameras can also be used. The habitats used by crayfish can be studied by placing traps at given distances.

The sources of inaccuracy in physical modelling

The accuracy of the field measurements (e.g. topography, river bed substrate, water level, and discharge) is the basis of the quality of the model results. Then, in the creation of e.g. the topographic model, interpolation to a grid is used, and in hydraulic modelling, a flow calculation grid with a limited number of calculation cells is constructed. Every time there is interpolation, especially when interpolating to the hydraulic modelling grid, some of the original accuracy is lost. In the calibration of the hydraulic model and in the calculations, inaccuracy is also caused.

Measurements and modelling

On the Rivers Simojoki and Ala-Koitajoki, the measurements were originally made by FGFRI for habitat preference studies and have large amounts of observation data. The coordinates of places where the fish were caught were measured with a tacheometer. The flow velocities and water depths at organism observation points and on the whole of the study area were measured directly on site. The topography necessary for hydraulic modelling was not measured. Habitat values were calculated directly for all availability and observation measurement points. Because preference curves and field observations are based on the same measurement method, no difference between calibration and validation data exists. In the Laukka study area, field measurements were originally made for assessing the effects of habitat rehabilitation. After field measurements, a two-dimensional hydraulic modelling was carried out. Fish observations were made by keeping a log book with a map while fishing. Water depth and flow velocity for the habitat availability and fish observation points were both calculated with the hydraulic model, and the substrate values were interpolated from measurements in the modelling. In the Pyhäkoski area the measurements were made for studying fish populations and habitat use in a hydro power impoundment with the help of one- and two-dimensional hydraulic modelling. Fish were observed with telemetry. The modelled and observed values of water depth and flow velocity were produced with the hydraulic model. The calculation methods for crayfish and *Persicaria Foliosa* were somewhat different than with the fish habitat models. Crayfish were observed from traps bound with constant intervals to ropes along or perpendicularly to the shore line. Observations were made during summers, and the traps were removed after each summer, which means that the positioning may vary. The values of the physical variables were measured during a couple of summers from the trap sites. The preference curves for *Persicaria Foliosa* were got from measurements located with GPS equipment, and the observations for validation by studying herb abundance in cells of a grid defined on the study area.

For the sensitivity analysis, both artificial data providing an absolute reference for comparisons and measured data with corresponding validation measurements were used. The artificial and physical field measurement data used in different chapters of this work are shown in Table 1.2. The measurement data of fish habitat use are shown in Table 1.3.

Table 1.2 Field measurement and artificial data of physical habitat variables used in different chapters.

chapter	data
2	Rapid Keijulankoski on Tainionvirta River, Konnuskoski Rapids, Rapid area on tributary Siltapuro B at the River Oulujoki, Kuurnankoski Rapids on the Korvuanjoki tributary of the River Iijoki, Laukka area on the River Oulujoki, Siikakoski Rapids on River Kymijoki
3	Ahmaskoski area of the River Oulujoki, River Ripatinkoski, Konnuskoski Rapids, Valajaskoski Rapids, Pyhäkoski impoundment on the River Oulujoki
3.1, 4.2, 5.2	Lamminsaari Island in Lake Pääjärvi, Lake Katumajärvi study areas 4-5 and Pukettisaari Island, Lake Slickolampi, Lake Valkjärvi in the Lake Haarajärvi area
3.1.1.4	River Ripatinkoski, Rapid area on tributary Siltapuro B at the River Oulujoki
4	figurative test data 1, figurative test data 2, figurative test data 3, Tolpankoski Rapids on the River Kiiminkijoki
4.1.4	Hotilankoski Rapids on the River Tainionvirta
5.1.1	River Simojoki: Harrikoski Rapids, Iso Tainikoski rapids upper and lower parts
5.1.2	River Ala-Koitajoki: Hiiskoski Rapids, Tyltsykoski Rapids
5.1.3	Laukka area on the River Oulujoki
5.1.4	Pyhäkoski impoundment on the River Oulujoki
5.3.1	The delta of the River Oulujoki

Organism observation data

Salmon (*Salmo salar*), brown trout (*Salmo trutta*), grayling (*Thymallys thymallys*), stone loach (*Noemacheilus barbatulus*), and bullhead (*Cottus gobio*) were studied in small to medium-sized rivers (Rivers Simojoki and Ala-Koitajoki), grayling (*Thymallys thymallys*) at quite a fast-flowing place on a large river (the River Oulujoki in the Laukka area), pikeperch (*Stizostedion lucioperca*) at a rather slow-flowing place on a large river (the Pyhäkoski impoundment on the River Oulujoki) in winter, and crayfish (*Pasifastacus Leniusculus*) in small lakes in Southern Finland, and an herb (*Persicaria Foliosa*) was studied in the delta of a river (the River Oulujoki). Data of field observations of organisms are summarized in Table 1.3. The locations of the study areas are shown in Figure 1.3.

Table 1.3 Different fish observation data used or represented in the chapters of this work.

source, method and location		organism
River Simojoki, Mäki-Petäys (2000), FGFRI, electric fishing	Harrikoski rapids	salmon <10 cm, salmon >10 cm, stone loach 5-12 cm, bullhead 4-7 cm, October data for salmon 4-6 cm
	Iso Tainikoski Rapids lower part	salmon <10 cm, salmon >10 cm, stone loach 5-12 cm and 5-13 cm, bullhead 2-7 cm and 4-7 cm, grayling 4-9 cm
	Iso Tainikoski Rapids upper part	salmon <10 cm, salmon >10 cm, stone loach 5-12 cm and 5-13 cm, bullhead 2-7 cm and 4-7 cm, grayling 4-9 cm
River Ala-Koitajoki, Mäki-Petäys et al. (2002), FGFRI, electric fishing	Hiiskoski Rapids	salmon >10 cm summer and autumn, brown trout <10 cm, brown trout 16-25 cm
	Tyltsykoski Rapids	salmon <10 cm summer and autumn, salmon >10 cm summer
River Oulujoki, Leinonen (1999), North Osthrobotnia Environment centre, log book fishing	Laukka area, adult grayling	Laukka area, adult grayling
River Oulujoki, Vehanen & Lahti (2003), FGFRI, fish telemetry	Pyhäkoski impoundment	pikeperch: summer, early winter, late winter
Town Oulu, Ulvinen (2000), University of Oulu, mapping	Delta of River Oulujoki	*Persicaria Foliosa*
Lake Pääjärvi, Lake Katumajärvi Lake Slickolampi and Lake Valkjärvi in the Lake Haarajärvi area, Esa Erkamo (2002), FGFRI, traps	Lamminsaari Island in Lake Pääjärvi	crayfish *Pacifastacus leniusculus*
	Lake Katumajärvi study areas 4-5	crayfish *Pacifastacus leniusculus*
	Lake Katumajärvi Pukettisaari Island	crayfish *Pacifastacus leniusculus*
	Lake Slickolampi	crayfish *Pacifastacus leniusculus*
	Lake Valkjärvi	crayfish *Astacus astacus*

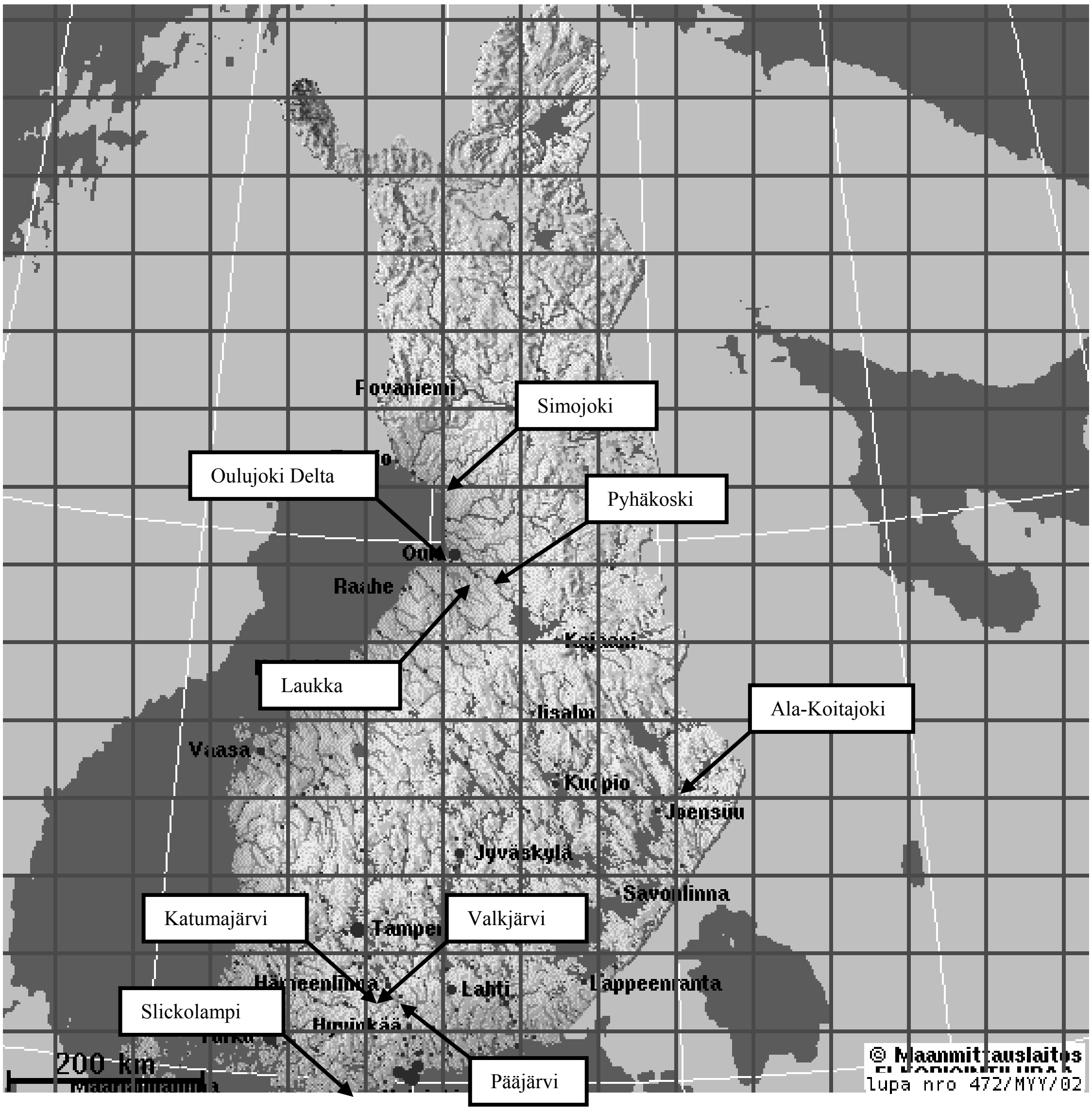


Figure 1.3 Location of study areas.

There were fish observation data at seven sites, including 19 different sets of data with at least 20 observations and one or more preference curves in each, all together a total of 859 fish observations. The validity of the habitat value calculation principle was checked with modelling with good-quality physical models and appropriate calibration data, especially with the River Simojoki and River Ala-Koitajoki data. The accuracy of the whole model, including the hydraulic model, was tested by habitat modelling in the Laukka area and Pyhäkoski impoundment study areas and the hydraulic model was additionally tested by comparison of the hydraulic modelling results with measured values. To test the use of different types and quality of calibration data, results with different preference curves were compared with each other. The model for the herb *Persicaria Foliosa* was validated with 89 sampling areas, and, in testing and validation of the crayfish model, three sets of data with a total of 611 crayfish observations were used. The fish observations were obtained by means of keeping a log book with a map while fishing, electric fishing, or by fish telemetry, discussed later in this chapter. *Persicaria Foliosa* was mapped in situ and crayfish were trapped. The observation data collected by electric fishing and telemetry mostly reflect the average site selection of the fish. Observations gathered by keeping a log book with a map while fishing may represent the feeding habitats of the organisms slightly more than their average living habitats.

The calculation of the distribution of available habitat

The distributions of available habitats were calculated by weighting the habitat values of calculation cells by area. If the flow situation changed during fish observations, as was the case in the Laukka and Pyhäkoski study areas, the distributions were calculated for each situation individually and those distributions were added together, weighted by the number of observations in each flow situation. In the Laukka area, values calculated as the averages of a circular area around the observation point were also used. In the case of the delta of the River Oulujoki, the area was divided into a grid, in which the organism was either found or was not found; therefore the available habitat value distribution was calculated from the values of all the cells of the grid.

The calculation of the distribution of habitat use

The observed habitat use distributions were calculated with the same method as the distribution of habitat availability, except that the habitat values were taken from those points with observations of organisms. The values used in the habitat value calculations were the values at observation points or at the nearest habitat value calculation grid point to the fish observation point found by a computer program, as was the case in the Laukka and Pyhäkoski areas. In the Laukka area, values calculated as averages of a circular area around the observation point were also used. In the case of the delta of the River Oulujoki, the area was divided into a grid, in which the organism was either found or was not found; therefore the observed habitat values were the average habitat values of the cells with the organism.

Habitat availability and use, and the proportion of use to availability

For visual assessment of habitat use and availability of different habitat value classes, the values were classified with a uniform interval, usually 0.05, except zeros and ones may have separate classes, or if the distribution was not suitable for this kind of a representation, a scale of e.g. logarithmic or as close as possible to an even number of availabilities per class type was used.

To directly visualise the habitat preference, the proportions of habitat use to habitat availability in each habitat value class were calculated from classes with an amount of available habitat as close to uniform as possible. The number of classes used was chosen according to a rule for chi square tests, from the formula:

$$N_c=2*n^{0.4} \qquad (1.1)$$

to get as many classes as possible to find trends, but still with a sufficient amount of observations in each class. In the Laukka and Pyhäkoski areas, these rules were not followed exactly, because the large calculations that had to be automated, which produced discretisation of data. When crayfish data were being classified, if the number of traps was less than the number of crayfish observed, the number of traps was used to guide the selection of the number of classes.

The goodness of fit tests

The available habitat was divided into two areas that were as close as possible to being equal in size; high and low habitat values. In this case, when most of the preference curves used in the case studies were made by dividing the habitat uses in different classes by availability, which means that the preference values of different curves are not comparable with each other, this is a better way than a division at a certain habitat value, e.g. 0.5. Using two classes as equal in size as possible makes the statistical test more effective. Goodness of fit tests were used to test whether the half of the habitats with higher habitat values was used statistically significantly more often than the areas with lower habitat values. Tests indicate at which risk level, p-value, the expected and observed distributions differ from each other. If the p-value is smaller or equal to 0.05, the difference is considered to be significant, and at 0.01 strongly significant.

The null hypothesis of the test is that habitat selection does not depend on habitat values, whether the value is low or high. The chi square test requires the probability distribution of an event to be constant. If the organism densities and territories were small compared with the area of preferred habitats, this would be true. If organism density is high, individual organisms will choose from different available habitats. The densities at Rivers Simojoki and Ala-Koitajoki were rather high. In the case of organisms preferring areas with higher habitat values, this reduces the probability of selection of preferred areas, which increases the risk of type II error, i.e. a false rejection of the research hypothesis that habitat selection would somehow depend on habitat values. On the contrary, if the organisms shoaled, the risk of type I error would increase.

With goodness of fit tables of two classes, both the Pearson's (e.g. Spiegel 1972) and log likelihood tests (Sokal & Rohlf 1995) approximate the chi square distribution (Sokal & Rohlf 1995). These tests are used to compare the perceived distribution of organisms with the expected. In Pearson's test, a test variable resembling the chi square variable is calculated:

$$\sum_i ((o_i-e_i)^2/e_i), \quad (1.2)$$

where e_i is the expected and o_i the observed frequency in each class.
The likelihood ratio test statistic is derived from maximum likelihood method, and it approximates a chi square distribution. It does this through a natural log transformation (-2∗log) of the ratio between the maximum likelihood based on the null hypothesis and the maximum likelihood based on the actual data values found.

According to Cochran (1954), in Pearson's test, at least 20 observations are needed. To maintain the validity of the tests; if the number of observations lies between 20 and 40, all classes must have an expectation of five or greater. According to Sokal & Rohlf (1995), if the number of observations is less than 25, exact probabilities should be calculated. This is not practical, because the expected distributions are not integer values in this case. In this study, sets of data with at least 20 observations are used which means that there usually are at least ten expected observations per class. Some reservations are in order when reading the results of cases with less than 25 observations.

Pearson's test, often called "the chi square test", has been used widely in science up till now, while these days the log likelihood test is gaining in popularity. Sokal &

Rohlf recommend using the log likelihood test. Both tests result in type I errors at a higher level that intended. A correction, correction of continuity, has been developed, but it results in excessively conservative tests. Instead, Williams' correction to the log likelihood test is recommended (Sokal & Rohlf 1995). The results of both tests with corrected and uncorrected values are shown, because on one hand people are used to Pearson's test, but on the other hand, the log likelihood test is likely to produce more accurate results.

Interpretation of the results

The null hypothesis of the test is that the habitat use would not depend on habitat values. If it is rejected, that does not necessarily imply that a habitat model would work well. The higher habitat values should be preferred, and a good habitat model also puts habitats in an order of preference. The following are required: the null hypothesis is rejected and the trend of habitat preference, i.e. the proportional habitat use, is clearly ascending towards higher habitat values. No sensitivity analyses for the proportions of habitat use divided by availability were calculated; it is assumed that the formula (1.1) ensures a sufficient reliability, and only clear trends are used as evidence. Additionally, the significance depends on the number of observations; the higher the number of observations, the easier it is to observe differences as significant, and, with few observations, relatively large differences may be rated as insignificant. Rejection of the research hypothesis indicated by the test does not necessarily imply that there wouldn’t be dependence, especially, if habitats get populated. On the other hand, the risk of a false rejection of the null hypothesis indicated by the test increases e.g. if the organisms shoal or the same organism is sampled many times.

The results should be analysed by studying the habitat value maps with observations, the distributions of use and availability, the relative preferences of higher values, the graphs of the proportions of use to availability in different classes, and the statistical tests, bearing in mind the possible factors, e.g. territorial behaviour or shoaling, represented in the text, affecting them.

2 THE MODELS

2.1 Two-dimensional habitat modelling

The basic principle of habitat modelling is to combine information on the physical state of the study site with information on the biological needs of the organism being studied to create a presentation of the suitability of habitats. Some of the physical variables are measured in situ, some are modelled. The biological preference information is usually in the form of curves indicating the suitability for each value of the physical variable, e.g. water depth. This information is combined in habitat value calculation to produce suitability maps, curves, and numerical data. The basic phases of habitat modelling are shown in Figure 2.1. In fish habitat modelling, after field measurements, a hydraulic model is run.

Some basic assumptions are made in habitat modelling. It is assumed that individual organisms select the most desirable conditions within a steady state stream but will use less favourable areas as the stream becomes more crowded. Desirable conditions can be adequately represented by habitat suitability criteria curves and each cell can be evaluated independently. The area-weighted arithmetic sum of available habitat (as WUA) in each cell is indicative of total habitat conditions at a specific discharge. Physical habitat, not water quality and/or other factors, limits the population size. (U.S. Geological Survey 2005)

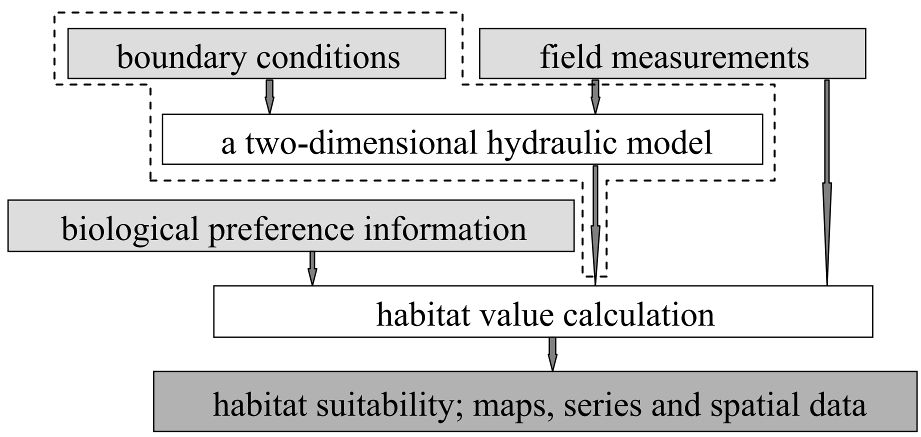


Figure 2.1 The phases of modelling. In fish habitat modelling, the dashed area is included.

2.2 Fish habitat model

The model consists of modules for hydraulic modelling, habitat value calculation, and data processing and output. For hydraulic modelling and in basic interpolation and output, commercial and free software, SMS/RMA2 and Surfer, are used. The other parts of the model are specially programmed for the habitat model. The modular structure allows different types of input data, the most suitable hydraulic models and different types of output, to be used, and developing the model is easy. In Figure 2.2, the structure of the habitat model and the data flow in habitat modelling are shown.

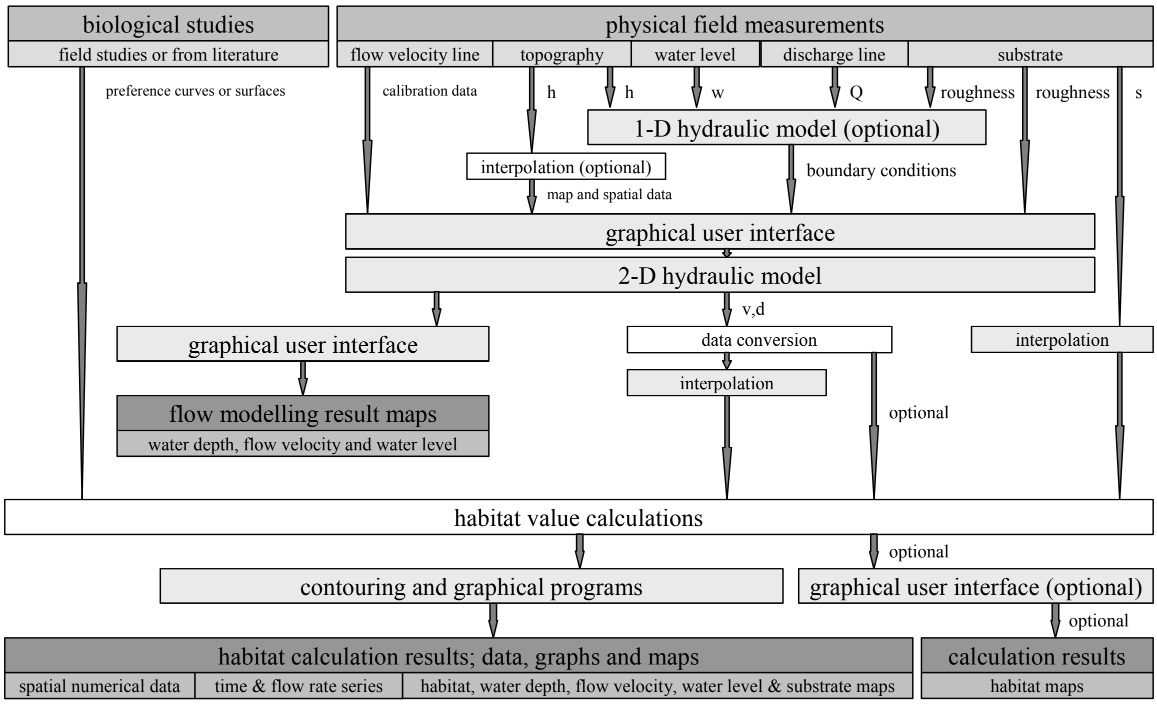


Figure 2.2 The structure of the habitat model and the data flow in habitat modelling. Input data are marked with a medium/lighter colour, model-specific programs with white, commercial programs with a very light colour, and the results with a darker colour. The flow of data is shown with arrows. The flow velocity data is marked v, water depth d, substrate s, topographic height h, and water level w.

In the habitat modelling process, the topography and substrate, i.e. river bed particle size, are measured first and the whole area is covered. Water level and flow velocity cross-sections, if needed, are measured at some places for boundary conditions and calibration. The data are input to hydraulic modelling, in which the water depths and flow velocities are calculated for the habitat value calculation. The biological preference information is usually input to the calculation as preference curves. As a result, suitability maps, numerical suitable habitat area values, and curves of habitat area versus time or versus flow rate can be made. Different data-handling programs are used for these phases. Next, the modules of the program and the phases of the modelling are discussed in greater detail.

Measurements of the physical variables in situ

Usually, the topography and substrate are measured for the whole study area. Water level and flow measurement lines are measured at some points for calibration and for boundary conditions of the model. In Figure 2.3, the measurement of water level with a tacheometer is under way in the Ripatinkoski River.

The topography is usually measured as scatter points directly to coordinates. The density of measurement points is increased in the most important and spatially varying places. The shoreline, often the bottom and the top of the river bank, and any structures are marked as line data. Tacheometer method is used for topography measurements for small or very shallow or rocky areas and places with a good deal of covering vegetation. Echo sounding is faster and usually has a higher density of points for larger, more open places with access by boat. Soil radar can be used when measuring on ice. The coordinates of substrate measurement points are located with a tacheometer or a GPS equipment. Where the river bed can be seen, the measurement is performed by observing visually, with the help of water binoculars if needed. Below the visible depth, a probing method using a rod is usually used, but soil radar can also be useful. The methods can be calibrated by measuring e.g. shallow, easily visible areas and comparing the results with observations. A photogrammetric method also exists. Diving has also been used sometimes. It is recommended that measurement points are selected in such a way that when the data are interpolated with the nearest point method, the most accurate result is achieved. The classification of the substrate is performed according to the size of the particles on the river bed, e.g.: <0.5 mm, 0.5-2 mm, 2-8 mm, 8-16 mm, 16-32 mm, 32-64 mm, 64-128 mm, 128-256 mm, 256-512 mm, 512-1024 mm, >1024 mm, rock. Usually, the coarsest, the most common, and the second most common substrate are measured. The water level is measured to obtain boundary conditions and points for calibration. Flow velocity cross-sections are measured for the calibration of flow velocity distributions and to find out the flow rate in each river branch for calibration and for use in boundary conditions. In Figure 2.4, the measurement of a flow velocity cross-section with Doppler-based equipment from a turbine-powered boat is shown.

Figure 2.3 Measurement of water level with a tacheometer on the Ripatinkoski River. *(Photo Markku Lahti)*. The substrate can be seen through the water surface.

Figure 2.4 Measurement of flow velocity cross-section with Doppler-based equipment from a turbine-powered boat giving access to shallower depths near banks than a traditionally motored boat. *(Photo Kemijoki Oy)*. Echo sounding equipment for the measurement of topography can be placed on the same boat. The resulting flow velocity distribution is shown in the figure in colour; the ground is black.

Creation of the topographic model

The topographic model is usually created in a commercial interpolation and contouring program (Surfer). Before contouring, the measurement points marked to characterise linear forms in the river channel are converted to dense point lines with a model-specific line interpolation program (Lahti 1999). The linear interpolation software adds points in three dimensions with a given density between adjacent points in a line. The resulting points are added to the measured scatter points. The program is used to save measurement time, because only the corner points of linear forms have to be measured. The points should be measured in such a way that they come in the right order for the input file or they can easily be put into it. This can be done by measuring totally or mostly in order, or by making marks in the data or on a map.

Kriging is usually used as an interpolation method when the topography is measured as scatter points. Kriging is a geostatistical interpolation method that makes visually appealing maps from irregularly spaced data. Kriging attempts to express trends suggested in the data, so that, for example, high points might be connected along a ridge rather than be isolated by bull's eye-type contours. (Golden Software 1999)

Other methods can be used, e.g. inverse distance, if Kriging is too slow. Triangulation is used if straight forms predominate in the topography and the measurements are made from the corner points of such forms. In triangulation, triangles are drawn between measurement points in three dimensions, following a procedure to make the resulting surface.

Processed measurement data and the resulting topographic model of the Keijulankoski Rapids section on the River Tainionvirta are shown in Figure 2.5. Measurements were made with a tacheometer from optimal places. The waterline and the upper bank were measured and marked as lines. The measurements of the waterline and the upper bank line were converted to dense lines consisting of points. After that, the data were interpolated to a topographic model using Kriging.

If the longitudinal variation in the form of the channel is small, and especially if the measurements are mostly cross-sections, a curvilinear anisotropic interpolation method may be useful. In this method, the sinuosity of the river is taken into account, and specific software (Lahti 1999) is used together with a commercial interpolation program (Surfer). The method is based on coordinate system transformations and anisotropic interpolation. First, the centre line of the channel is digitised. After that, the measurement points are input to the program in coordinates. Then the software creates a new coordinate system for the river, the coordinates being the distance from the beginning of the mid-line and the orthogonal distance from the centreline to the right and left. Some values which are needed in adjusting the calculation grid density and size are input into the program. After that, the program transfers the coordinates of the measurement points to the new coordinate system. An anisotropic interpolation, usually with Kriging, is made with any suitable commercial program. The result is printed out from the commercial software, and the resulting topography is converted back to the original coordinate system, and, if a grid is needed, one interpolation is made. A contour plot is drawn to check the validity of the resulting topography. With this method, it is possible to enhance the quality of the topographic model in many cases when measurement data are sparse. If the channel is measured densely enough, only the commercial interpolation program is used in order to save labour costs.

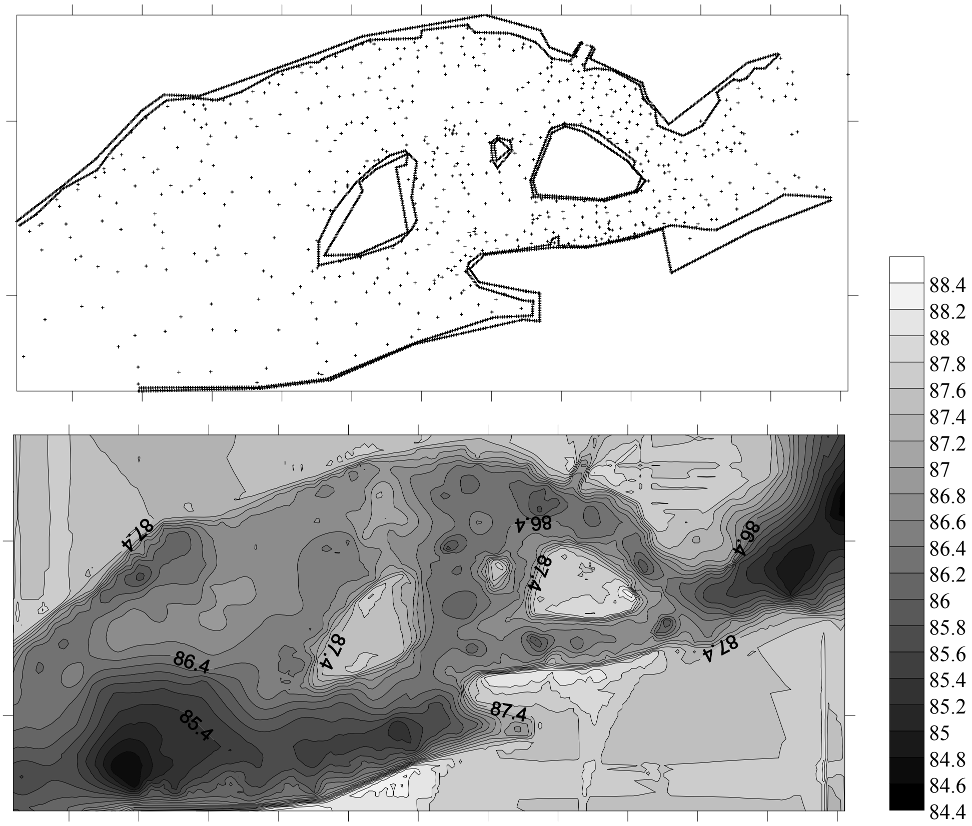


Figure 2.5 Processed measurement data and the resulting topographic model (height from sea level, metres) for the Keijulankoski Rapids section of the Tainionvirta River.

Hydraulic modelling

In hydraulic modelling, a commercial graphical user interface (SMS by Brigham Young University) is used together with a freely distributed hydraulic calculation program (RMA2 by US Army Corps). A base map of the study area, usually a contoured topographic map, is input to SMS. The hydraulic modelling grid is constructed on the base map, on which it is positioned according to the coordinates of three known points on the map. The hydraulic calculation grid is created with the semi-automatic tools of SMS. The topographic data are input to the hydraulic model in a format consisting of the coordinates and elevation of a point in each row. The topography is corrected and edited in the user interface, if necessary. After the calculation parameters, boundary conditions, and physical parameters have been given, a geometry conversion program (GFGEN by the US Army Corps of Engineers) is run to convert the information into a form suitable for the actual hydraulic calculation model named RMA2, which is then run. RMA2 is a depth-averaged finite element hydrodynamic numerical model. It computes water surface elevations and horisontal velocity components for subcritical free-surface flow in two-dimensional fields (US Army Corps of Engineers 1996).

The results (water depth, flow velocity, and water level) can be viewed via the graphical interface (SMS), and are also printed out in a special ASCII format. An example of hydraulic modelling output from the Konnuskoski Rapids in Eastern Finland is shown in Figure 2.6.

Data processing

The results of the hydraulic modelling are processed with a software (Lahti 1999), which picks up and combines the information from the files created by SMS and RMA2. It can also be used to correct some errors in water depths and the water level caused by the calculation algorithm and restrictions in computer power in many choosable ways. It can also be used to add dry land depth values in areas outside the hydraulic calculation grid to the water depth file. This makes further use of the data in interpolation easier.

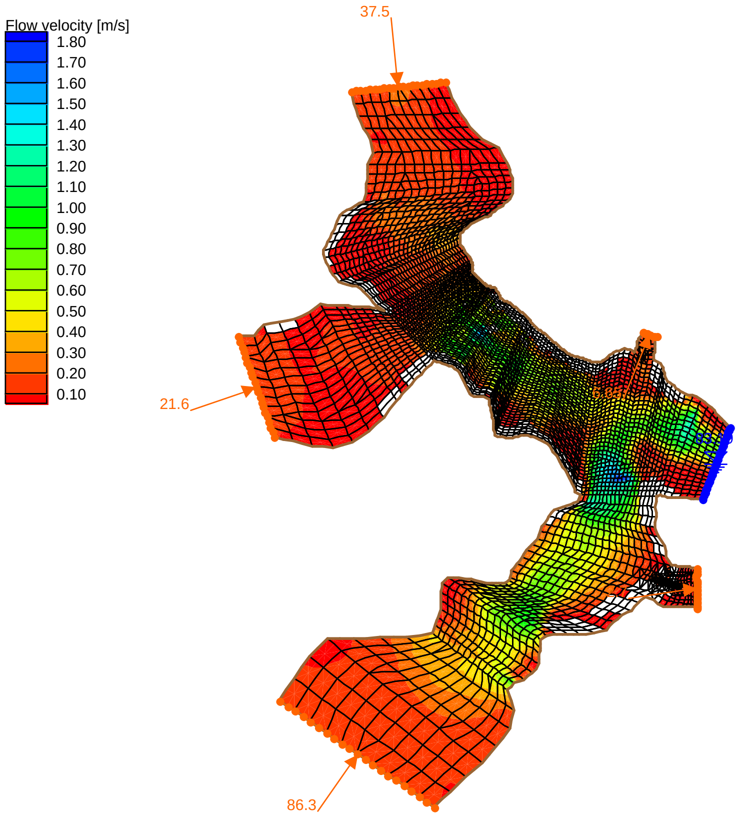


Figure 2.6 Flow velocity as an example of hydraulic model output from the Konnuskoski Rapids in Eastern Finland with a discharge of 191.1 m^3/s. Grid cells are shown with rectangles. The white colour means dry cells. Boundary conditions can be seen on the up- and downstream borders of the model. In the model, additional areas are included up- and downstream from the area of interest with a higher grid density near the centre of the model.

The results used most frequently are water depth, water level, and flow velocities in coordinates. Selected ones of these are interpolated in the contouring program (Surfer) to make grids of water depth and flow velocity suitable for input to the habitat value calculation. Grids of 100-900 points on a side, usually at a distance of from 0.2 to 20 metres from each other, are often used. The most precise method for creating water depths is to use water level and the original topography, because in the input to the hydraulic model interpolation is used and the density of points is often reduced, and therefore the precision of water depths taken from the hydraulic model is reduced. Furthermore some near-bank areas are usually lost if the depths created by the hydraulic model are used because of the limited number of elements and the properties of the wetting and drying algorithm of the model. The interpolation method used in gridding the water depth and the flow velocity is Kriging. The values of the coarsest, the most common, and the second most common substrate are also interpolated to grids with the same corner points and densities as the other grids, but with a nearest-neighbour method. The method is used because the substrate data are classes that cannot be interpolated. In this method, the points of the grid are given the value of the nearest measured point.

Using the biological preference information

Preference curves

Habitat suitability values are traditionally calculated on the basis of biological habitat preference information and printed out in the form of curves, e.g. Bovee (1982). In a preference curve, habitat suitability is shown as a function of a variable characterising the physical conditions. The preference function gets values between zero and one, so that under the least suitable conditions, the function has the value of zero, and, under the most suitable conditions, the value of one. A preference curve is defined as follows:

$$P(v)=f(v), \quad (2.1)$$

where P(v) is the preference value for a variable, e.g. flow velocity, and v the variable. In Figure 2.7, an example of preference curves is shown. The input form for preference curves in the user interface and a figure of the curve drawn on the same sheet are shown in Figure 2.8.

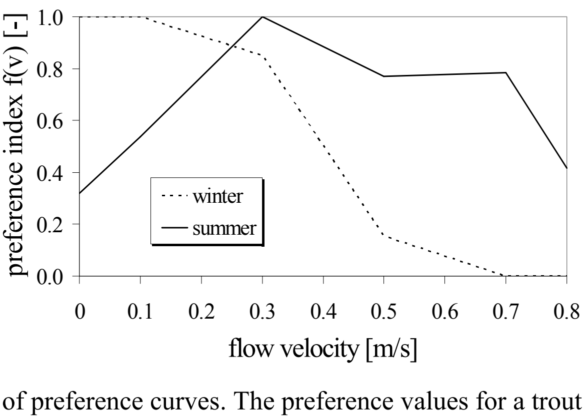


Figure 2.7 An example of preference curves. The preference values for a trout 4-9 centimetres long in summer and in winter for average flow velocity, based on Mäki-Petäys et al. (1997). The curve is drawn by connecting the points formed by the midpoints and values of the classes used in the study.

k	in use (y/n)
fd	name of the function variable

variable	spaces
d	**6**

d	fd
0.0000	0.0000
0.0610	0.0000
0.0914	1.0000
0.6096	1.0000
0.9144	0.0000
1.2192	0.0000

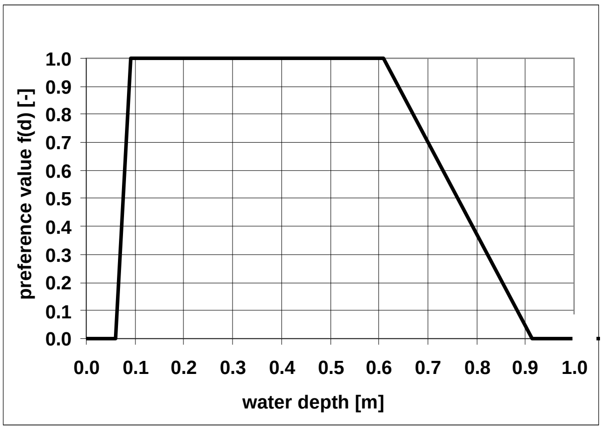


Figure 2.8 The input form for preference curves and the curve input on the same sheet.

Preference curves are determined as follows. A study site that includes as many kinds of relevant habitat types as possible is chosen. Fish observations are made that cover the whole site. At each point where a fish is found, the physical variables, usually water depth, flow velocity, and substrate, are measured immediately. In Figure 2.9, electric fishing is under way in a brook in northern Finland for studying the densities of brown trout juveniles.

The conditions prevailing during the observations of fish must also be known. The values of the physical variables are measured thoroughly from the whole study area. If hydraulic modelling is used, topography, boundary conditions, some measurements for calibration, and the coordinates of the places where fish are caught are measured instead of direct measurements of all variables. After measurements and hydraulic modelling, if used, distributions of the values of the physical variables covering the whole study area, i.e. habitat availability, and the distributions of the variables only at the fish-catching places, i.e. habitat use, are calculated. The values in the two distributions are compared with each other by dividing the habitat use values by the values of availability. After scaling so that the largest value is one, the raw preference curve is validated.

Figure 2.9 Electric fishing in a brook in northern Finland for studying the densities of brown trout juveniles. A burbot, shown in the picture, was also caught. *(Photo Juhani Eskelinen)*

Other formulae to express habitat preference include Jacob's Selectivity Index, calculated as:

$$P_i=(r_i-p_i)/(r_i+p_i-2r_i*p_i), \qquad (2.2)$$

where r is the proportion of habitat used in class i and p the proportion of habitat available in class i (COST ACTION 626 2002). Positive indices indicate selective use of that habitat class and negative values indicate avoidance. These habitat preference scores are often subdivided into three regions: preferred habitat ($0.2 < P < 1$), indifferent habitat ($-0.2 < P < 0.2$), and avoided habitat ($-0.2 < P < -1$) (COST ACTION 626 2002). With this method, the preference index values in curves from different studies are more comparable with each other, but the values of the indices are not in a linear relationship with relative fish densities observed as in the case of the traditional method described earlier.

When modelling longer river sections with pools and riffles, it may be possible that the preference curves made in e.g. a riffle are not valid for use in pools. For example, river bank areas with a flow velocity near zero are often suitable for juvenile trout in the riffle section, but in pools predation makes the situation different. So, near-zero flow velocities should be considered carefully when making preference curves. Often, flow velocity values between 0-0.1 m/s are put in one class in the classification needed to make preference curves, i.e. the same preference value is given to flow velocities of 0.0 and 0.099 m/s, the real preferences for which may be totally different from each other in nature. The classification could have an additional class, e.g. from 0.0-0.01, and then 0.01-0.1, 0.1-0.2 and so on. This could prevent problems with the flow velocity preference curves, because the flow velocity near banks in pools is very near zero, whilst in riffles it may be non-zero, e.g. 0.05 m/s, even relatively near the banks.

Multivariate preferences

Multivariate preferences (Bovee 1982, Lambert & Hanson 1989) should be used if the combined effect (Voos 1981, Bovee 1982, Orth & Maughan 1982, Bozek & Rahel 1991) of variables on suitability is not near-multiplicable (Gibson 1993, Elliot 1994). They are defined as follows:

$$P(v_1,v_2,...)=f(v_1,v_2,...), \text{ where} \qquad (2.3)$$

P() is the preference value for variables, e.g. flow velocity and water depth, and v_1, v_2,... the variables. Multivariate preferences that are visualised by preference surfaces are determined in the same way as the curves, except that there is more than one variable in the distributions, i.e. the distributions are surfaces. An illustrative sketch of what a preference surface could look like is shown in Figure 2.10. In the figure, a fictitious organism prefers both combinations of low flow velocities at deep depths and high flow velocities with shallow depths.

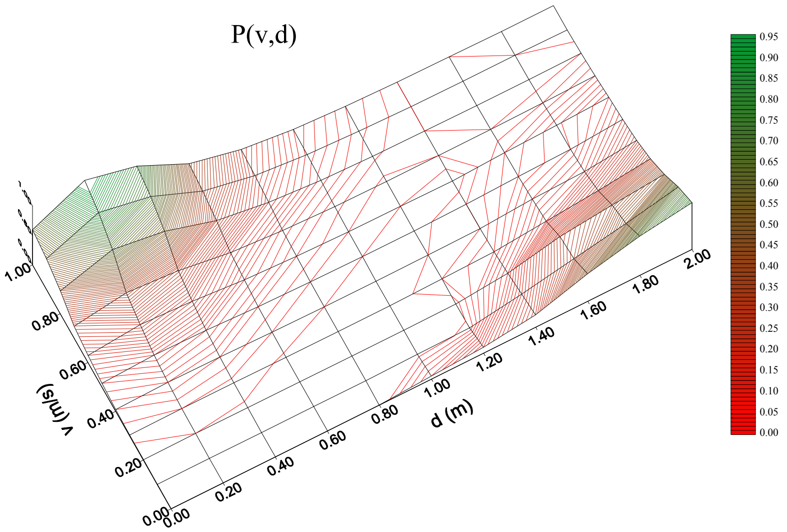


Figure 2.10 An illustrative preference surface for a fictitious organism.

Figure 2.11 shows an input form for two-dimensional preferences at the user interface and a figure drawn from the preference surface from the same input sheet.

E	in use (y/n)							
fvd	the name of the function variable							
names of variables	spaces on axes	The values of axes,write here						
d	6	0	0.2	0.4	0.6	0.8	1	
v	5	0	0.1	0.3	0.5	0.7		

		d					
		0	0.2	0.4	0.6	0.8	1
v	0	0.3	1	1	0.8	0.3	0.1
	0.1	0.15	1	1	0.77	0.25	0.08
	0.3	0.05	0.3	0.82	0.6	0.05	0
	0.5	0	0	0	0	0	0
	0.7	0	0	0	0	0	0

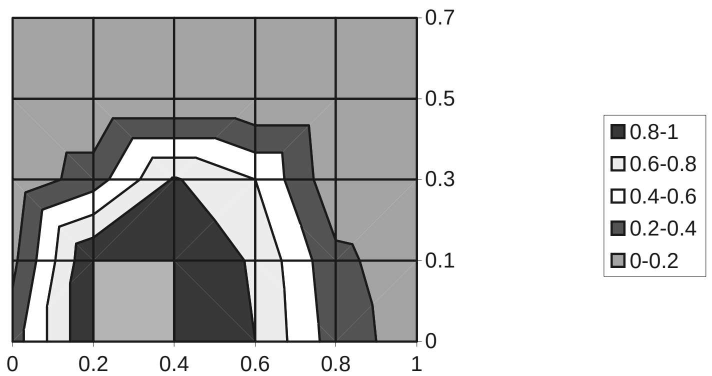


Figure 2.11 The input form of two-dimensional preferences from the user interface and the input surface drawn on the sheet.

Calculation of habitat values

The suitability index or the habitat value representing the suitability of habitat is traditionally calculated as in the PHABSIM methodology (Bovee 1982):

Suitability Index = P(d)*P(v)*P(s), where (2.4)

P(d), P(v), and P(s) are the preference values calculated for water depth (d), flow velocity (v), and substrate (s). P(s) is often calculated by weighting the preferences calculated for the coarsest, the most common, and the second most common particle diameter of the river bed material:

$P(s) = 0.2*P(s_1)+0.4*P(s_2)+0.4*P(s_3)$, where (2.5)

s_1 is the coarsest, s_2 the most common, and s_3 the second most common diameter of river bed material. The Weighted Usable Areas, i.e. the areas [m^2] weighted by the suitability index values, are calculated as follows:

$WUA = \sum A_i*P(d)_i*P(v)_i*P(s)_i$ (2.6)

These are the most commonly used calculation formulae. Boudreau et al. (1996) used a habitat value calculation formula in which the preference values were weighted by exponents determined with a PCA analysis:

Suitability Index = $P(d)^a*P(v)^b*P(s)^c$, where (2.7)

a, b, and c are the weights. The sum of the weights was 1. Matzuzaki & Tamai (1996) multiplied preference values with weights. Other calculation formulae and variables can also be used. In the user interface, the calculation can be edited and constructed relatively freely. The input form for variables is shown in Figure 2.12.

VARIABLES

number of variables

12

NAME of vari-able	TYPE d=data, p=preference, k=formula	BOUNDARY k=shoreline boundary, e=not a b.	FORMULA a formula, or if not a for-mula, by updating auto-matically e. adj, the width Decimal separator point.	For a proposition of file names k=depends on flow situation e=does not	FILE NAMES Flow situation 1 input .grd	output .grd	.dat
v	d	e	e	k	v_ek_110	vc_1	vc_1
d	d	k	e	k	d_ek_110	dc_1	dc_1
s1	d	e	e	e	us1xymyh	s1c	s1c
s2	d	e	e	e	us2xymyh	s2c	s2c
s3	d	e	e	e	us3xymyh	s3c	s3c
fv	p	e	e	k	e	fv_1	fv_1
fd	p	e	e	k	e	fd_1	fd_1
fs1	p	e	e	e	e	fs1	fs1
fs2	p	e	e	e	e	fs2	fs2
fs3	p	e	e	e	e	fs3	fs3
fs	k	e	0.2*fs1+0.4*fs2+0.4*fs3	e	e	fs_1	fs_1
WUA	k	e	fd*fv*fs	k	e	WUA_1	WUA_1

Figure 2.12 The input form for variables. In the columns from the left: names of variables, type of variable, a mark whether the shoreline is defined by the values of the variable, calculation formula, a marking for automated file naming, input grid file names, output grid file names, and output data (xyz format) file names.

In the interface, basic arithmetical operations, exponents, and ten nested parentheses can be used in constructing calculation formulae with different variables. Formulae have also been developed for e.g. characterising connectivity, biodiversity etc.

Series of habitat values can also be calculated, e.g. habitat value versus time or flow rate (Figures 2.15-2.17) automatically by inputting a series to an ASCII file, and the file names of physical data grids and corresponding e.g. flow rates in another file.

Output

Basically, the output from the model is the values of different variables for each cell in the calculation grid, e.g. the values of the suitability index, preference indices for e.g. water depth, flow velocity, and substrate, or any other variable used. The output can be in the form of contour or relief maps or as a file of numerical values in coordinates. In Figure 2.13, as an example, habitat maps drawn with the contouring program and with the hydraulic modelling interface are shown.

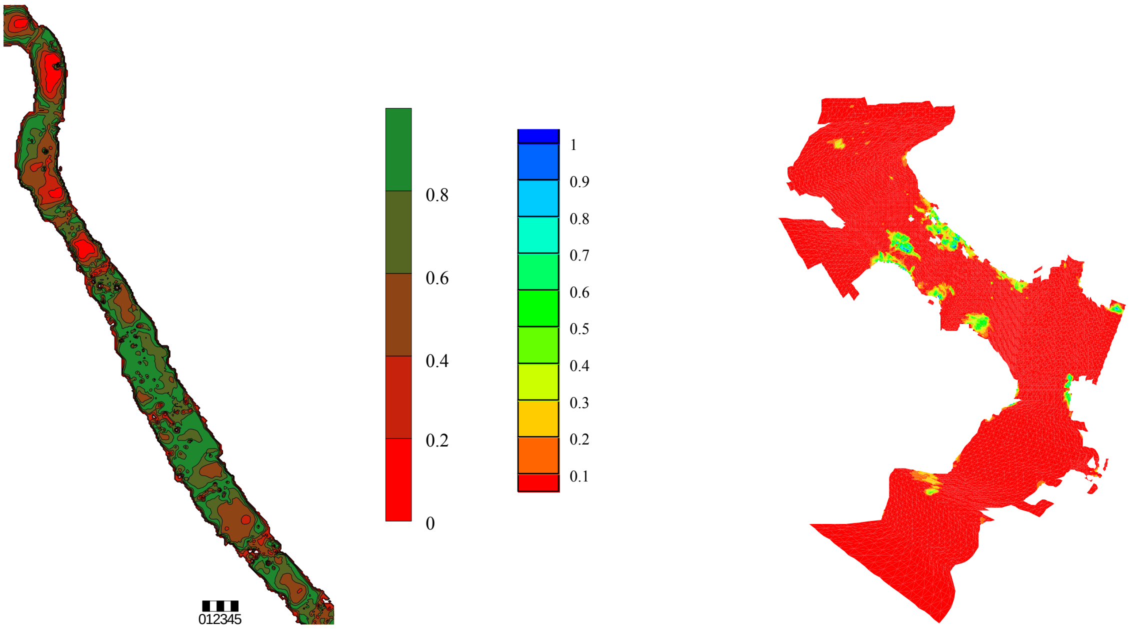


Figure 2.13 Habitat value maps for 4-9-cm trout (*Salmo trutta*) for water depth, flow velocity, and substrate in summer in the Siltapuro tributary of the River Oulujoki, drawn with the contouring program, and for the spawning of trout at the Konnuskoski Rapids, drawn with a hydraulic modelling interface for water depth and flow velocity.

Relief, perspective, or orthographic maps showing the topography and e.g. the habitat values simultaneously can also be used. Figure 2.14 shows a Usable Area map for freshwater pearl mussel for on an orthographic map of the lowest part of the Kuurnankoski Rapids on the Korvuanjoki tributary of the River Iijoki calculated with preference curves from Valovirta (1998).

The sums and the distributions of the values of the variables are calculated automatically and printed to a file. The values of these variables can also be plotted versus time, flow rate etc. Figure 2.15 shows Weighted Usable Areas for different size classes of grayling *(Thymallus thymallus)* in the Oulujoki River in the Laukka area at different flow rates calculated with the preference curves of Greenberg et al. (1994).

In Figures 2.16 and 2.17 Weighted Usable Area and Usable Areas for flow velocity, water depth, and substrate for small salmon *(Salmo salar)* in the Siikakoski Rapids on the Kymijoki River calculated with the preference curves of Mäki-Petäys (2001) are plotted as a function of time.

Minimum habitat value calculation

If the flow rate varies so rapidly during a day that the fish cannot change habitats, the real habitat suitability may be less than the average of the successive situations, e.g. because of drying. In this method, habitat values in selected flow situations occurring during the period to be studied are calculated with the model. The habitat value in each modelling cell of the study area is the minimum of the selected flow situations.

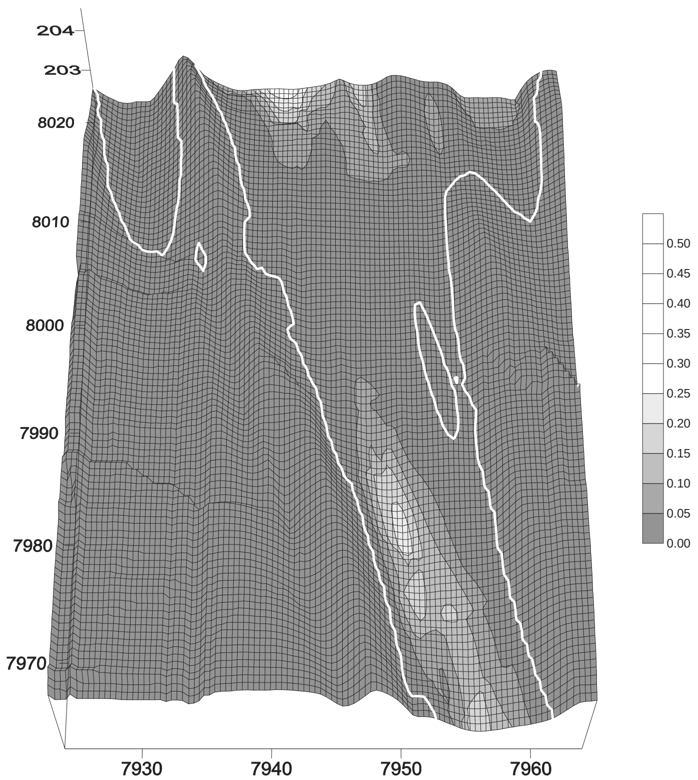


Figure 2.14 The topography and Usable Area for freshwater pearl mussel in the lowest part of the Kuurnankoski Rapids on the Korvuanjoki tributary of the River Iijoki calculated directly from measured values with preference curves from Valovirta (1998). The most suitable areas are shown with a lighter colour and the shoreline with a white line.

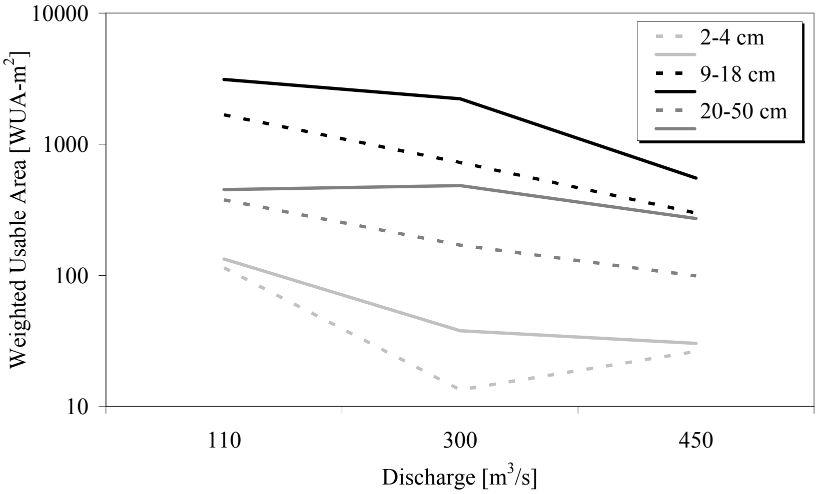


Figure 2.15 The Weighted Usable Areas for different size classes of grayling *(Thymallus thymallus)* in the River Oulujoki in the Laukka area at different flow rates calculated with the preference curves from brooks (much smaller than the River Oulujoki) of Greenberg et al. (1994). The situation before rehabilitation is shown with a dashed line and the situation after rehabilitation is shown with a continuous line.

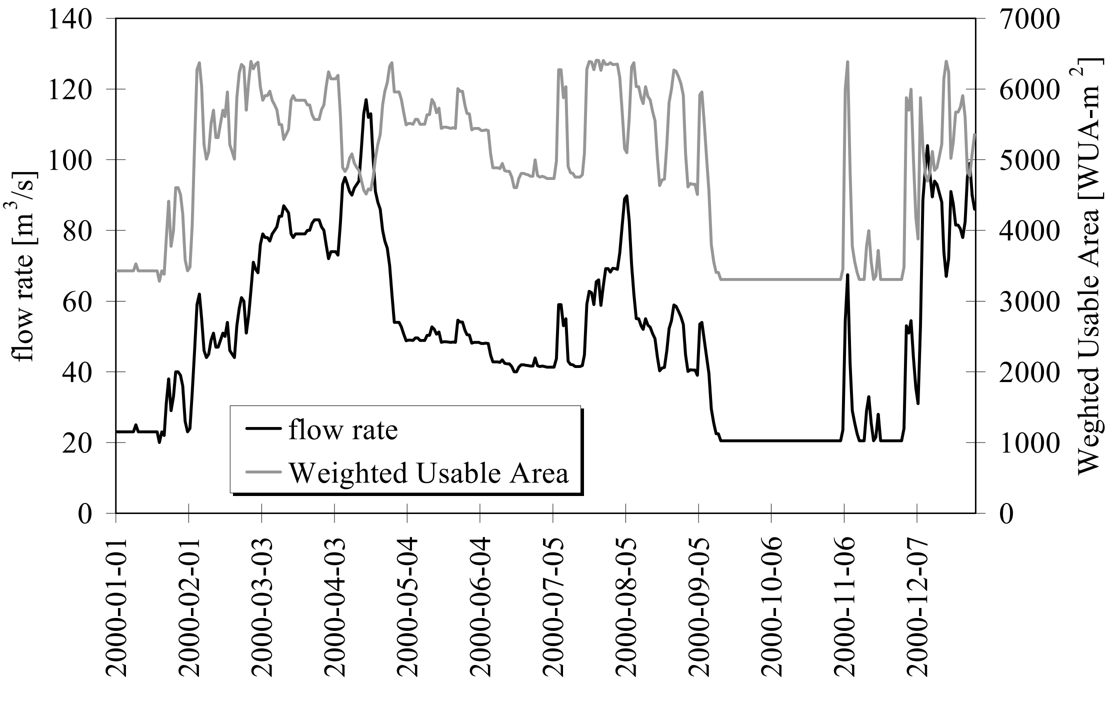


Figure 2.16 Flow rate [m^3/s] and Weighted Usable Area [WUA-m^2] for small salmon *(Salmo salar)* in the Siikakoski Rapids on the River Kymijoki calculated with preference curves from Mäki-Petäys (2001).

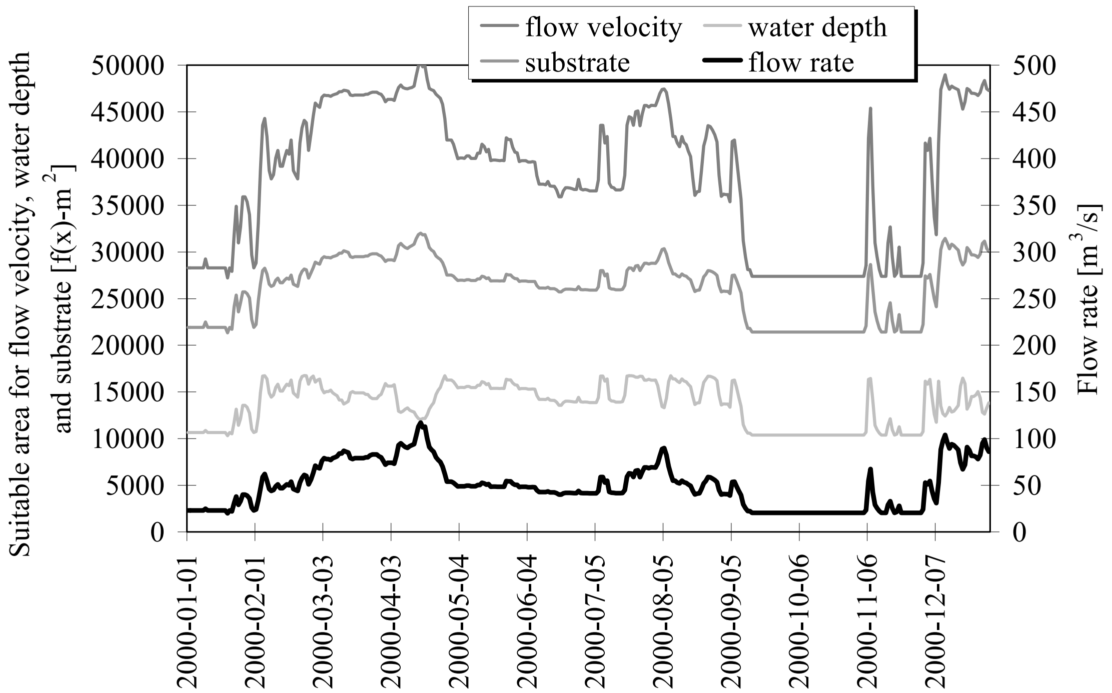


Figure 2.17 Flow rate [m^3/s] and Usable Areas [x-m^2] for flow velocity, water depth, and substrate for small salmon *(Salmo salar)* in the Siikakoski Rapids on the River Kymijoki calculated with the preference curves of Mäki-Petäys (2001).

The spatial scale of two-dimensional models

For assessments of a whole river, when the length/width ratio of the area to be assessed is larger than e.g. 50-100, methods based on habitat mapping, e.g. Yrjänä (2003) and Eisner et al. (2007), or generalised hydraulic parameters, e.g. Lamouroux & Jowett (2005), have been developed. The latter of these is based on Reynold's and Froude's numbers, and possibly should be applied only in statistical assessments of natural homogeneous rivers. The smallest, centimeters-size microstructure of the river bed should usually be assessed visually. The scale between these, on which local rehabilitations are usually planned, is the niche of habitat hydraulic modelling. An IFIM-type methodology based on two-dimensional hydraulic modelling is also the only way to model the effects of structural changes on habitat quality. The columnar flow velocities used in modelling are easy to measure and compare. The resources needed for the calibration of IFIM-type two-dimensional habitat models are less than with individual fish-based or three-dimensional models. Gouraud et al. (2004) have developed a model combining a physical habitat model with a structural biological model.

2.3 Crayfish model

The principles of two-dimensional habitat modelling are tested by making a totally new two-dimensional habitat model, for crayfish. The model is developed from the beginning: from choosing the variables and calculation formulae. The variables used in modelling are initially chosen on the basis of biological knowledge, statistical tests and plots of the relationship between crayfish abundance and the values of variables. Preference curves are made for those variables. Then, for further calibration and testing of the model, habitat modellings are performed with different habitat value calculation formulae at the same lakes. A sensitivity analysis of the effect of preference curves is carried out at a lake. After that, the model is validated at another lake or lakes. Further studies should be performed after this work, and perhaps also with other statistical methods when more data are available. The phases of crayfish model development are shown in Figure 2.18. The model is tested at two lakes. A sensitivity analysis is carried out in Chapter "Verification and sensitivity analysis of the model" to test the effect of using preference data from different physical conditions than prevail at the lake that is modelled. Finally, three validations are carried out in Chapter "Validation of the model".

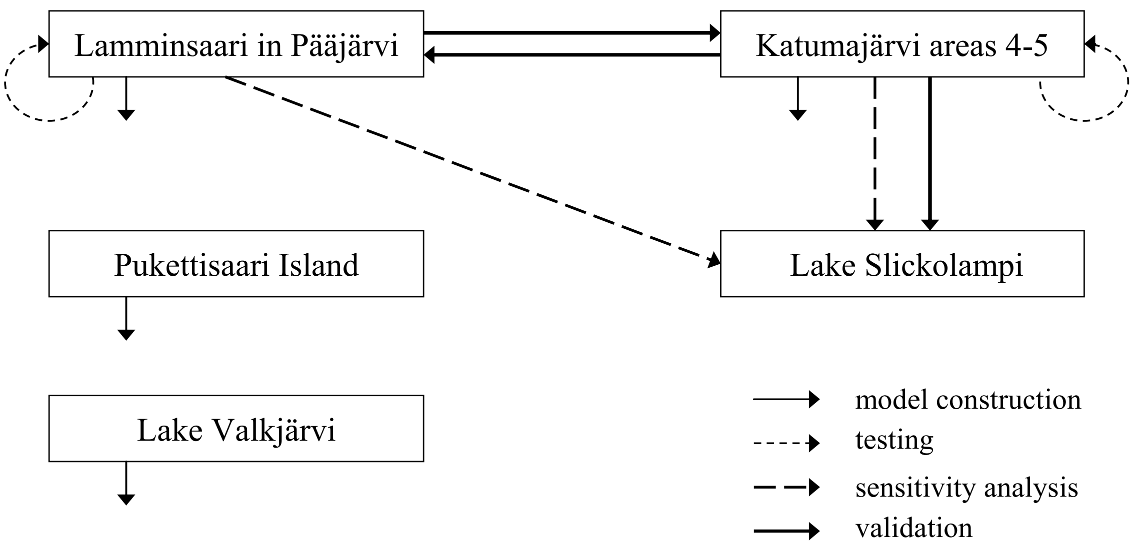


Figure 2.18 The construction, testing, sensitivity analysis and validation of the crayfish model in this work.

Descriptions of study areas

Lake Katumajärvi

Lake Katumajärvi is located near the town of Hämeenlinna in southern Finland at 6767266, 336529 in the KKJ coordinate system (Figure 2.19). The catchment area is about 51 km^2. The mean retention time is about 21 months. The size of the lake is 3.75 km^2 and the greatest depth 18 metres. It is classified as slightly eutrophicated (Anon 2. 2003).

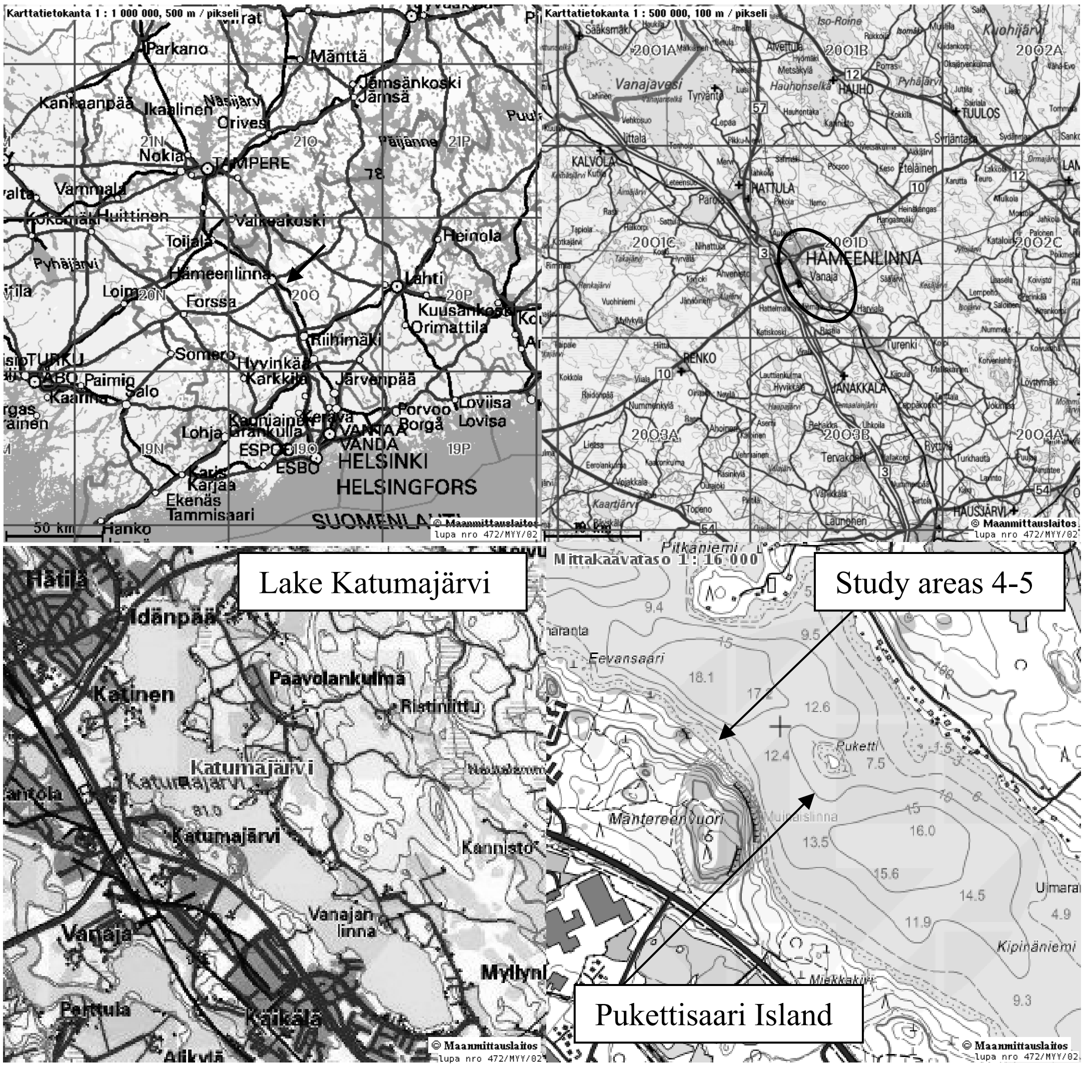


Figure 2.19 The location of Lake Katumajärvi and the study areas in the lake.

Lamminsaari Island in Lake Pääjärvi

The Lamminsaari study area is located in Lake Pääjärvi near the town of Hämeenlinna in Southern Finland at 61°4'N, 25°8'E (Figure 2.20). The catchment area is 244 km^2. The size of the lake is 13.4 km^2 and the mean depth is 14.8 metres. The lake is situated 100 metres above sea level. Its greatest length is nine kilometres in the SE-NW direction (Virta 2003). There are 25 rivers and brooks that drain into the lake. The area is situated in the Southern boreal vegetation zone. The annual mean air temperature is 3.6 ºC and the annual mean precipitation, according to the mean of the years 1961-1990, is 619 mm. Lake Pääjärvi is mesotrophic (Kuosa et al. 2006). In 2006, 62% of the watershed was forest, 16 % arable land, 12% pine bog, 1.5% swamp and 8% lakes (Stenberg 2007).

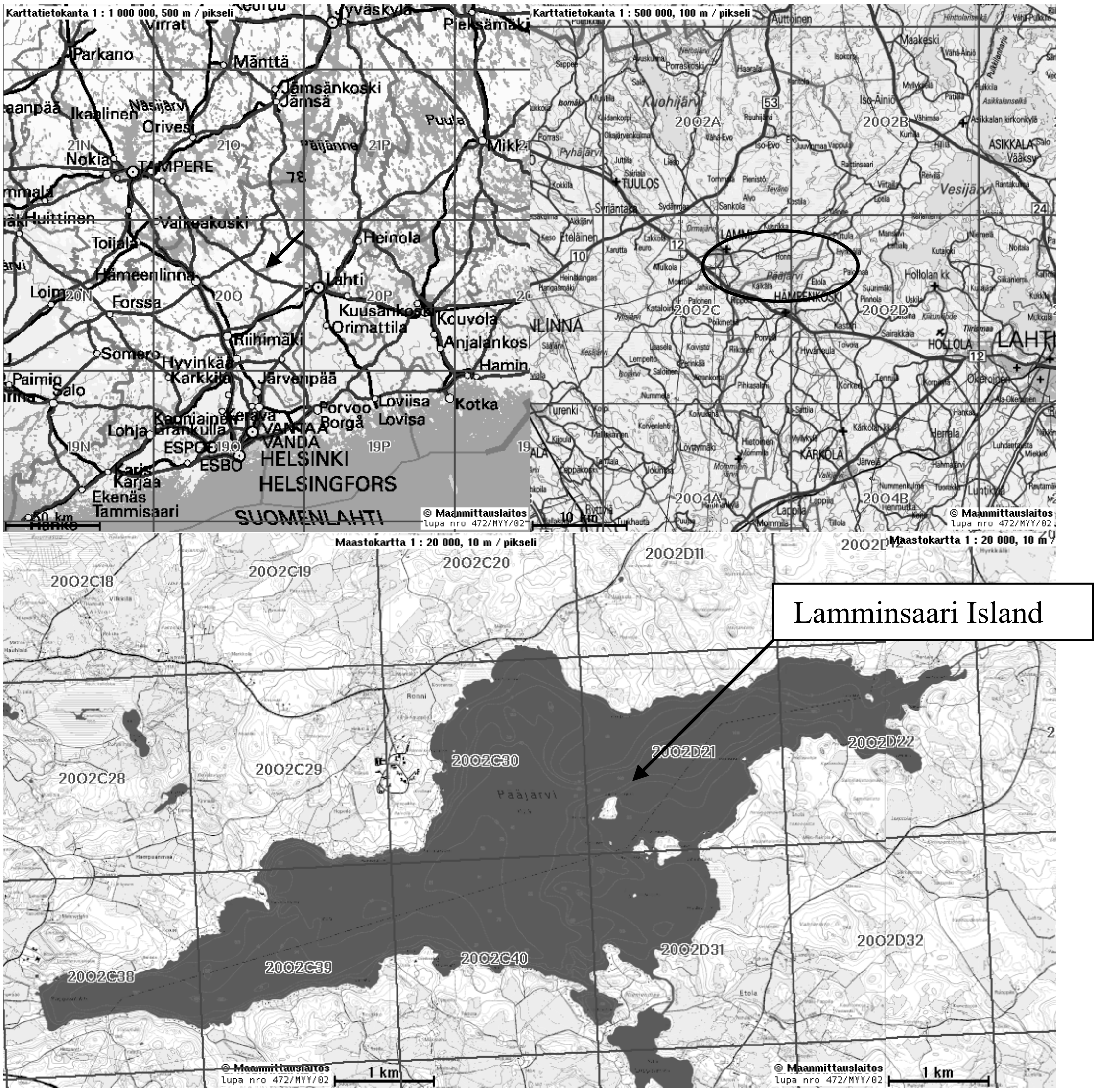


Figure 2.20 The location of Lake Pääjärvi and Lamminsaari Island.

Lake Slickolampi

Lake Slickolampi is located in Southern Finland at 60°9'N, 23°34'E (Figure 2.21). It is a smaller and shallower lake. The bed material is mostly soft, and cleaner near the shore. The greatest dimension of the lake is about 375 metres.

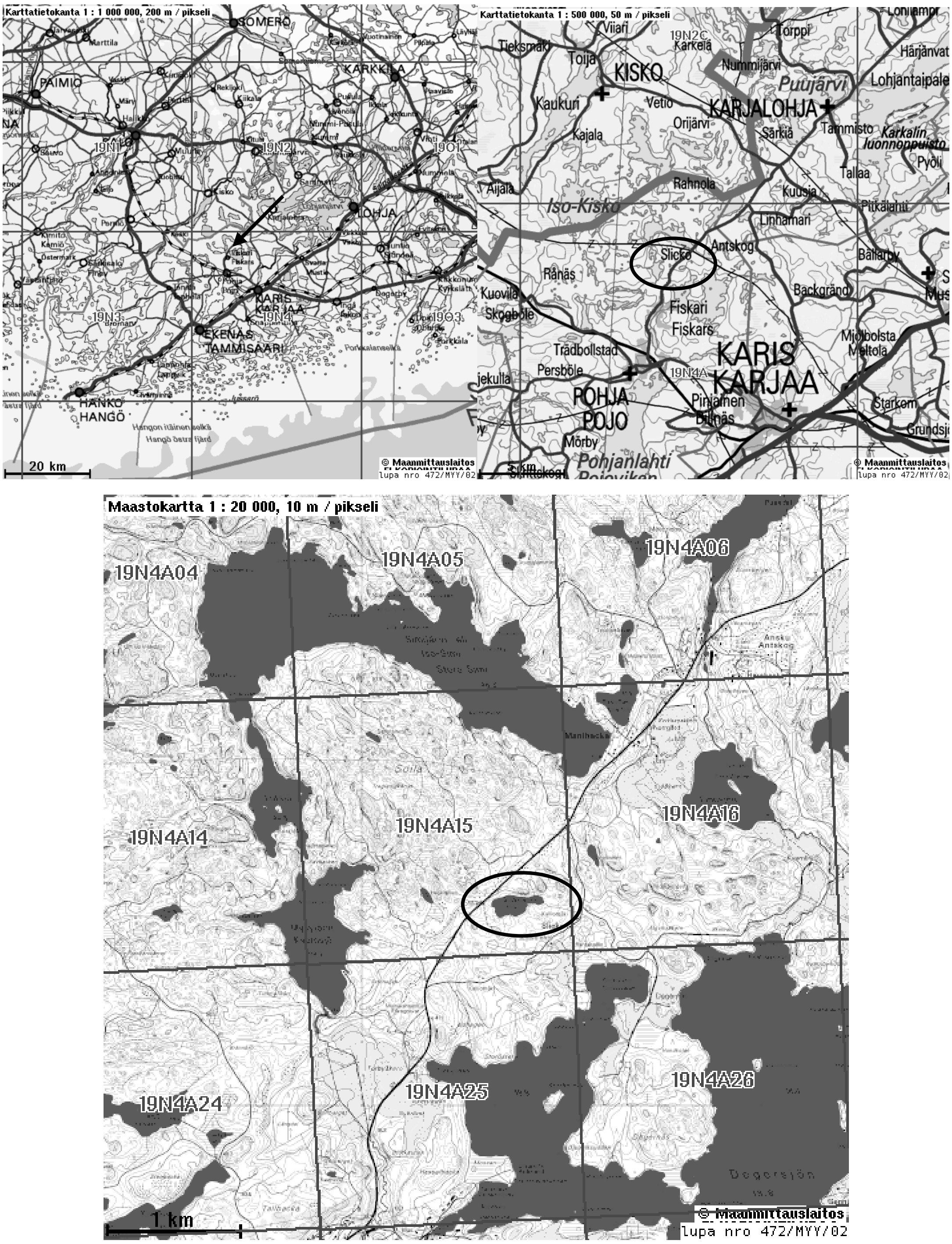


Figure 2.21 The location of Lake Slickolampi.

Lake Valkjärvi in the Lake Haarajärvi area

The positioning of Lake Valkjärvi is represented in Figure 2.22. Data from the lake are used only in studying the preference of crayfish for potential erosion, but not in modelling.

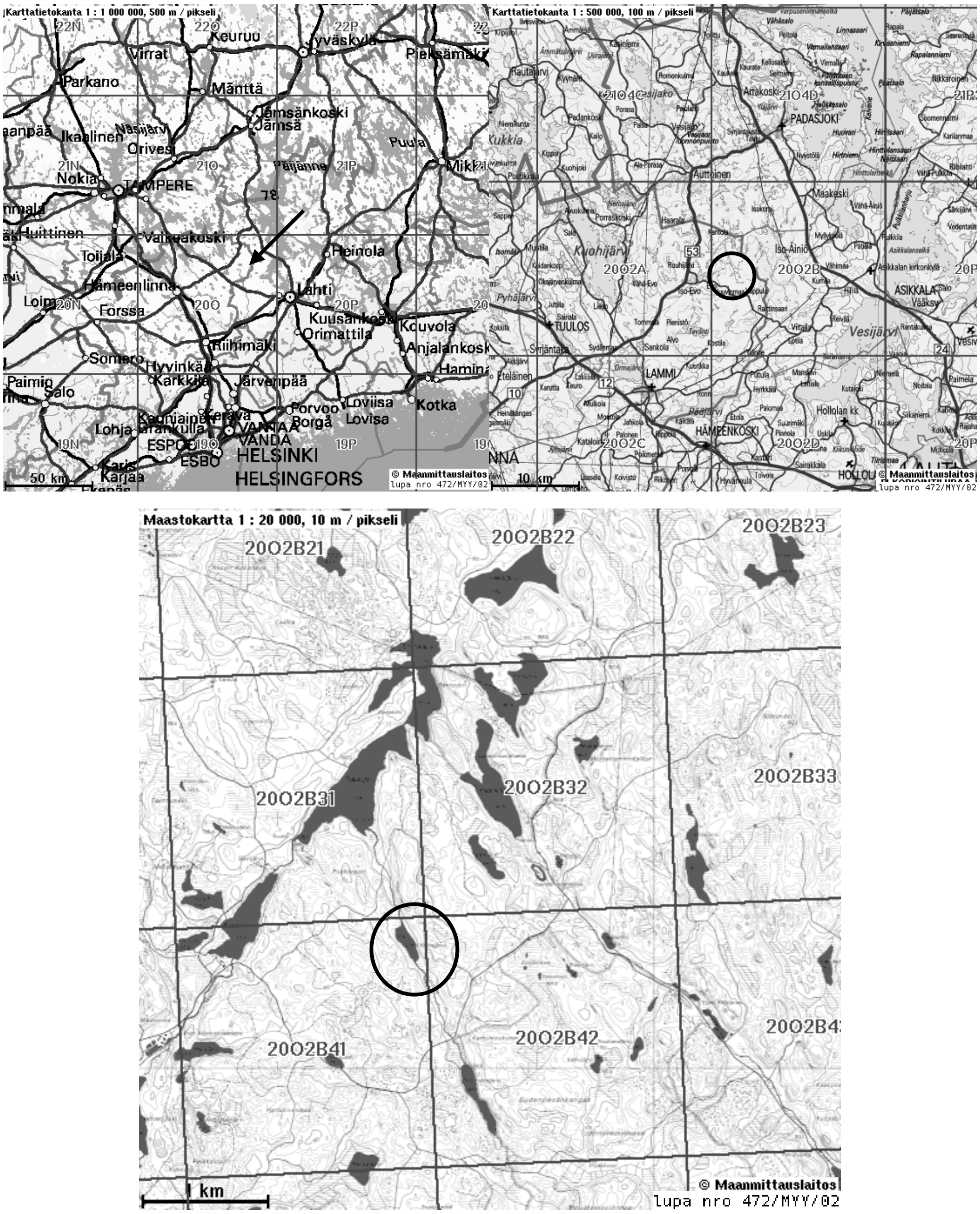


Figure 2.22 Lake Valkjärvi, near Lake Haarajärvi at the town of Lammi.

The organism studied and the biological data

The modelling of crayfish (*Pacifastacus leniusculus*) is based on the data from observations in the lakes mentioned above. Crayfish are known to favour clean, steady bed material in which they can find or build hiding places. It is assumed that water flow could keep the surfaces clean. The crayfish move mostly during the night-time, and they rest during the daytime. They are trapped mostly when moving, and they may move long distances, so the traps may catch crayfish which also prefer other areas to the area near the trap. So, the preference information obtained may include observations of crayfish in their resting and feeding habitats, but also observations of crayfish moving between these. Still, it is assumed that crayfish would be trapped more often in the more suitable habitats. Measurements were available from four lakes: Lake Slickolampi, Lake Valkjärvi, at the Lake Katumajärvi study areas 4-5 and at Pukettisaari Island, and from Lake Pääjärvi. The first two that are mentioned are much smaller than the others. Two-dimensional data were available from all the lakes but Lake Valkjärvi. Also, only the species *Astacus astacus* exists in Lake Valkjärvi, so the data were not used. Both the species *Pacifastacus leniusculus* and *Astacus astacus* were found at Lake Slickolampi. The data about the stronger competitor, *Pacifastacus leniusculus*, are used. The crayfish observation places were placed on a map afterwards on the basis of information on the beginning point of the rope to which the traps were attached, and on the average distance between two traps. The positions were checked at some known points. The maximum error in positioning the traps in relation to the habitat variable measurements was assumed to be 10 metres along the shoreline. This is considered to be good enough, because the lakes are large and the habitat characteristics change gradually.

Information at e.g. Lake Pääjärvi is available from the following variables: depth, potential erosion, water temperature, distance from the shore, slope, existence of stone, gravel, sand, or fine sand and soft underlaying bed material. Potential erosion the calculation formula for which was taken from work by Juntura and Hellsten (Juntura 2000, Hellsten & Juntura 2000) is used as a measure of water movement near the lake bed, where crayfish live. It is calculated from the water depth, free wind reach, and a given wind speed. The calculation formulae were applied from spreadsheet calculation formulae made by Juntura. As an example of variables, temperature as a function of depth at the Lake Katumajärvi study areas 4-5 during measurements in the summers of 2001 and 2002 is shown in Figure 2.23.

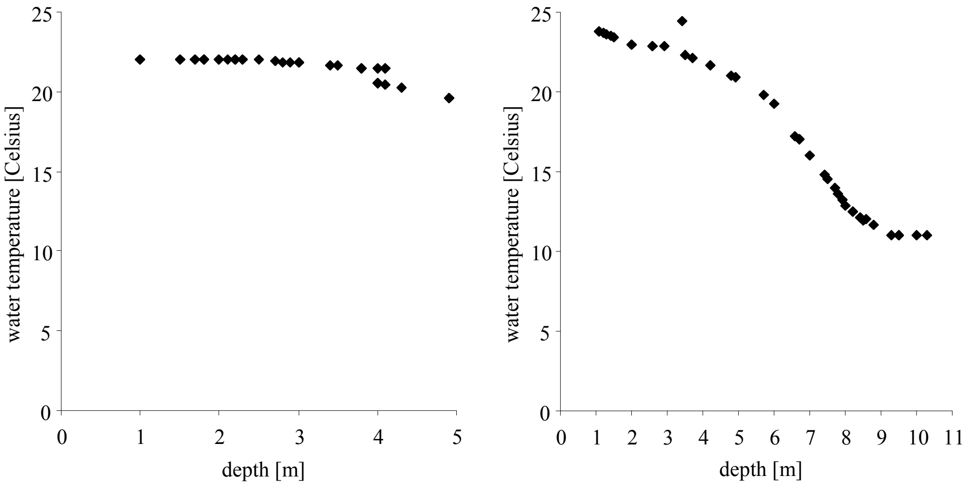


Figure 2.23 Temperature as a function of depth at Lake Katumajärvi study areas 4-5 during measurements in the summers of 2001 and 2002.

Data at different lakes

Lake Katumajärvi study areas 4-5

In Figure 2.24, catch/effort ratios are shown as a function of different variables at the Lake Katumajärvi study areas 4-5. From these figures it can be seen whether a relationship between catches and variables exists; e.g. catch/effort seems to have a top value at a potential erosion rate of about 700 g/(m^2*d). In Table 2.1, average catch/effort ratios according to the abundance of bed quality types at the Lake Katumajärvi study areas 4-5 are shown.

Preference curves for water depth, temperature, distance from shore, and erosion were made at study areas 4-5 (Figure 2.25). On the basis of data from other lakes, the curve for erosion could have been smoothed, but that was not done, because it would have been a subjective decision. Sand/fine sand was given a preference value of 0.72, if abundant; if not abundant, a value of 1 was given.

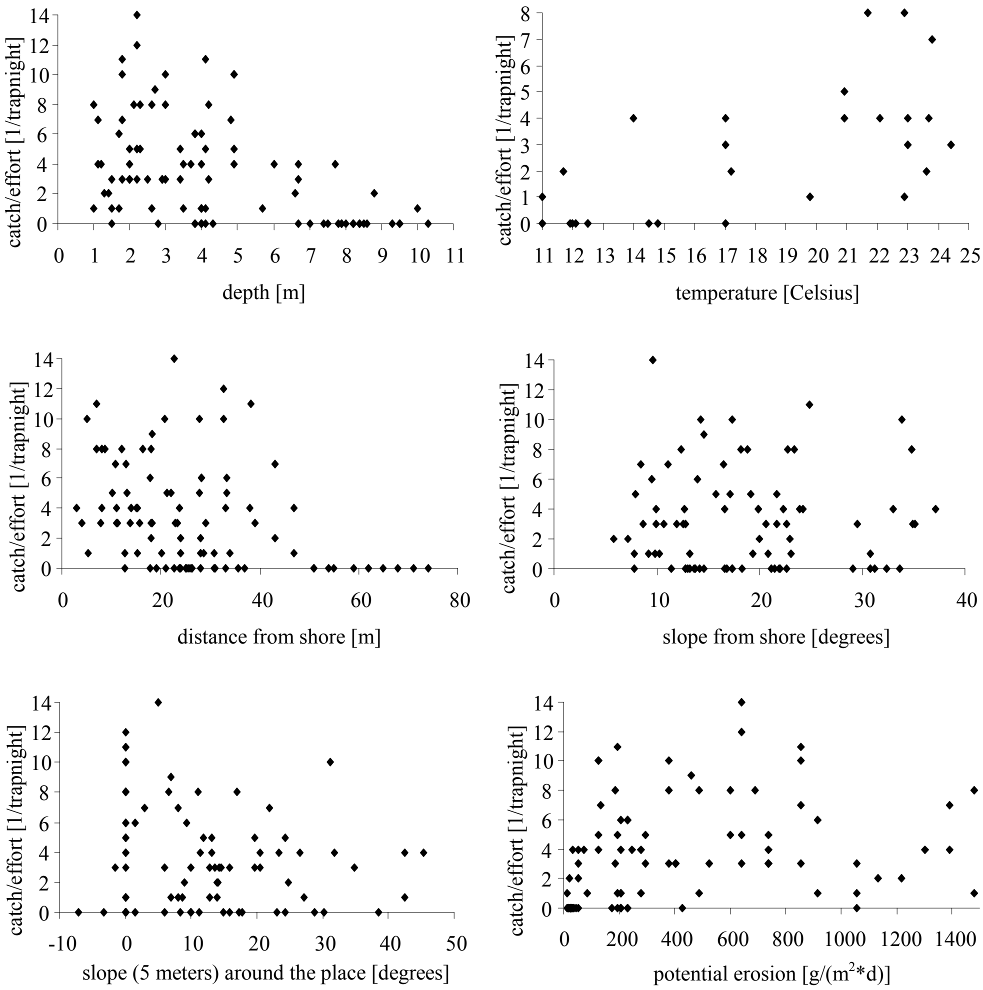


Figure 2.24 Catch/effort ratios as a function of different variables at Lake Katumajärvi study areas 4-5.

Table 2.1 Average catch/effort ratios according to abundance of bed quality types at Lake Katumajärvi study areas 4-5.

material	exists	does not exist
stone	4.65	3.98
gravel	4.25	4.24
sand/fine sand	3.98	5.55
soft material	4.40	3.72

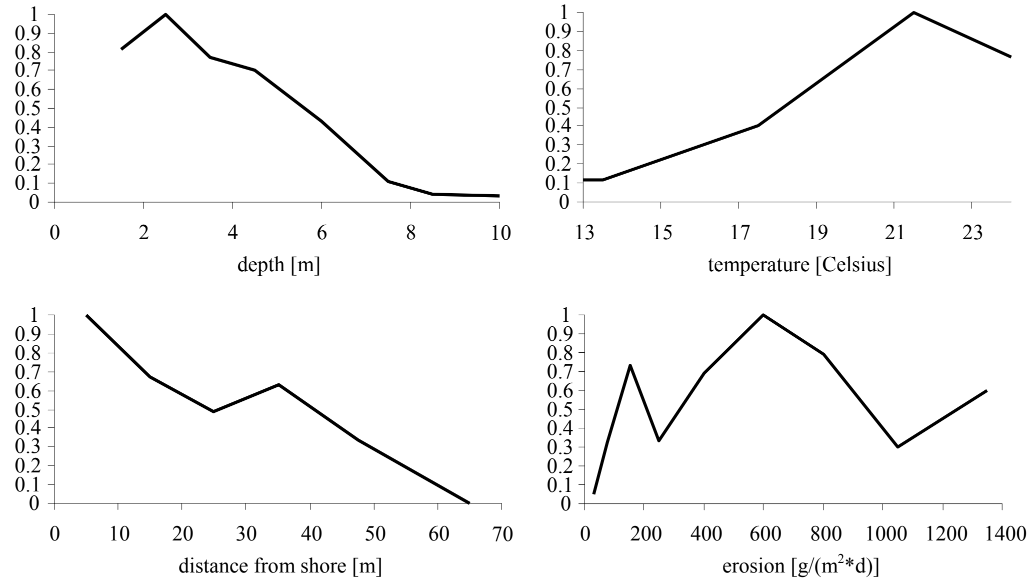


Figure 2.25 Preference curves for depth, temperature, distance from shore and erosion made at Lake Katumajärvi study areas 4-5.

Different habitat value calculation formulae were tested using preference curves made at the Lake Katumajärvi study areas 4-5 (Table 2.2). The product f(erosion)*f(water temperature), in which f is the preference function, had the highest correlation with catch/effort ratio and was chosen to the model. However, it must be remembered, that the real relationships are unlinear.

Table 2.2 Different habitat value calculation formulas tested at Lake Katumajärvi study areas 4-5, correlation with catch/effort ratios.

habitat value calculation formula	correlation
product (distance from shore, depth, erosion, water temp., sand/fine sand)	0.41
product (distance from shore, depth, erosion, water temperature)	0.55
product (depth, erosion, water temperature)	0.56
product (erosion, water temperature)	0.58
product (depth, erosion)	0.56
product (distance from shore, erosion)	0.57
product (distance from shore, depth)	0.50
sum (distance from shore, depth, erosion, water temperature)	0.55
sum (depth, erosion, water temperature)	0.54
sum (distance from shore, depth)	0.50
product (erosion, water temperature) + sum (distance from shore, depth)/2	0.57
product + sum (distance from shore, depth, erosion, water temperature)	0.56
max (distance from shore, depth, erosion, water temperature)	0.47

Lake Katumajärvi study area Pukettisaari Island

At Pukettisaari Island, strong currents hit the small island from both ends of the lake. This means that the formula used for the calculation of erosion based on depth and free wind reach may not work. This may also change the usefulness of other variables in predicting the bed material. So it is not expected that strong correlations could be found. From Figure 2.26 it can be seen that there are no strong correlations, and thus these data may have been affected by the currents and should not be used in choosing variables and making preference curves. Another explanation could be that the variables selected would not explain habitat selection there. Later in this case study, potential erosion rate is found to be among the two most important variables, perhaps the most important. Thus, the model could perhaps predict the abundance if flow velocities and potential erosion were calculated by a hydraulic model.

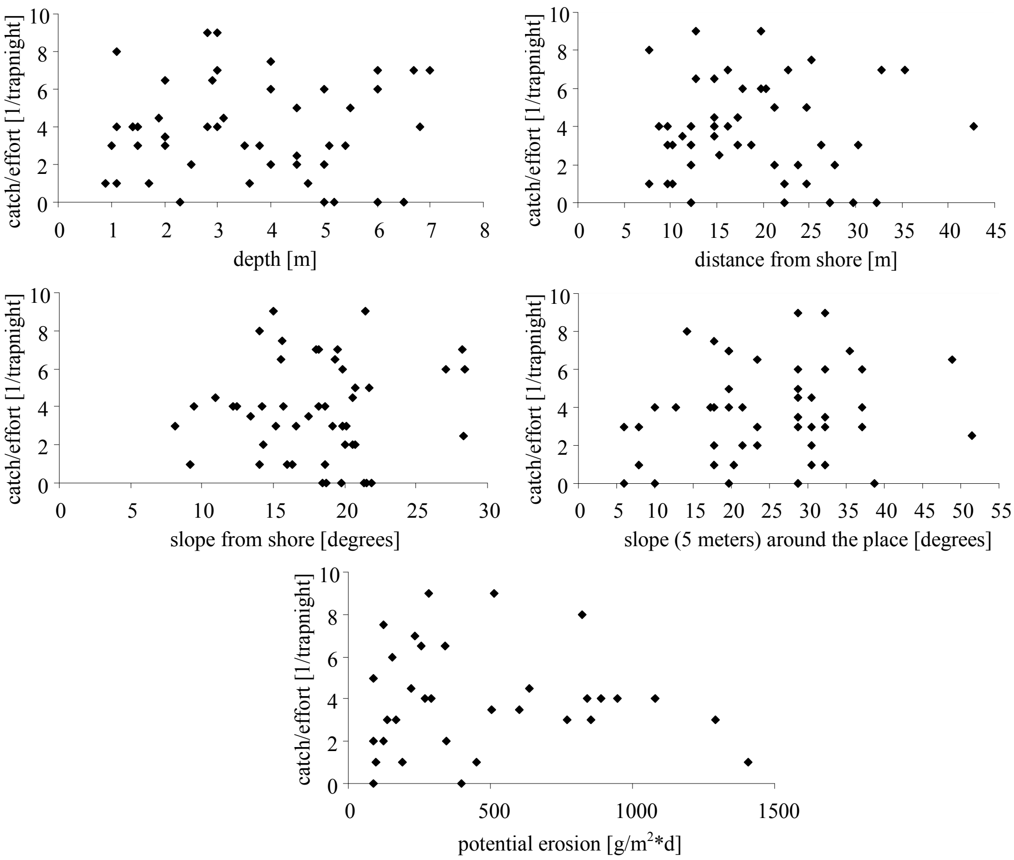


Figure 2.26 Catch/effort ratios as a function of different variables at the Lake Katumajärvi Pukettisaari study area.

But here the point is to develop a model for lakes, and at first the applicability of methods less laborious than hydraulic modelling should be studied. In Table 2.3, average catch/effort ratios according to abundance of bed quality types at the Lake Katumajärvi Pukettisaari study area are shown. Because there were only nine places with soft bed material at Pukettisaari, bed material quality must be studied at those lakes where there is more variation in it, namely at Lake Slickolampi and at Lake Valkjärvi.

Table 2.3 Average catch/effort ratios according to abundance of bed quality types at Lake Katumajärvi Pukettisaari study area.

material	exists	does not exist
stone	-	-
gravel	-	-
sand/fine sand	-	-
soft material	3.67	3.85

Lamminsaari Island at Lake Pääjärvi

The following variables were measured or calculated: water depth, water temperature, distance from shore, slope from shore, slope five meters around the place and potential erosion (Figure 2.27). In Table 2.4, average catch/effort ratios according to abundance of bed quality types at the Lamminsaari Island study area at Lake Pääjärvi are shown. Different variables were included in the model and the observed habitat value use distribution was compared with the expected distribution of even habitat use. It can be seen directly from Figure 2.27 that water depth and water temperature would be good variables. The erosion rate seems also to be a good alternative, so these three variables were chosen. The variable, existence of sand or fine sand were also chosen. The existence of gravel was not chosen. But information about these at the Lake Katumajärvi study areas 4-5 is missing in 27 traps out of 91. Still, the variables chosen will be depth, water temperature, erosion, the existence of sand or fine sand, and the existence of soft material.

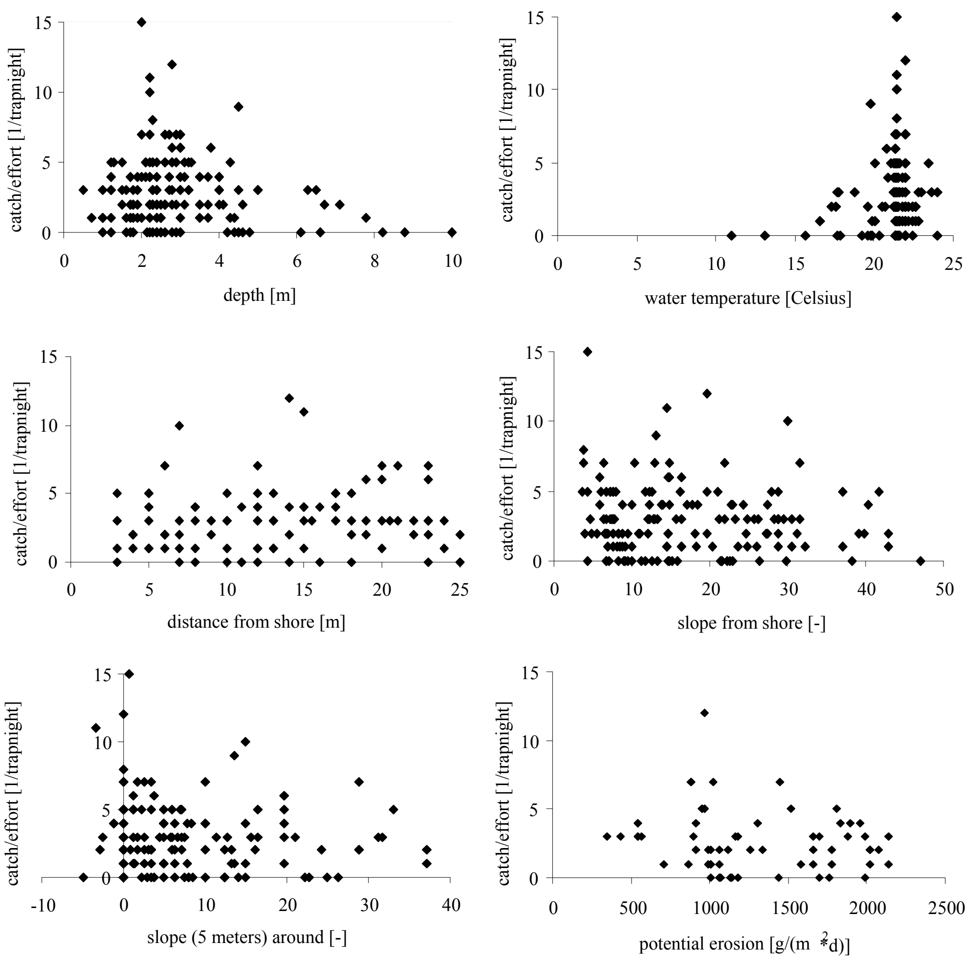


Figure 2.27 Lake Pääjärvi, some of the variables measured.

Table 2.4 Average catch/effort ratios according to abundance of bed quality types at the Lamminsaari Island study area at Lake Pääjärvi.

material	exists	does not exist
stones	2.89	2.95
gravel	3.34	2.80
sand/fine sand	3.18	2.25
soft material	2.00	3.03

Preference curves and preference values made at the Lamminsaari study area at Lake Pääjärvi are represented in Figure 2.28 and Table 2.5. Habitat value calculations with different combinations of variables were performed at Lake Pääjärvi. Correlations between habitat values and crayfish abundance are shown in Table 2.6. The product of preference values for the existence of sand or fine sand, the existence of soft material, erosion, and water temperature was chosen to be the habitat value calculation formula.

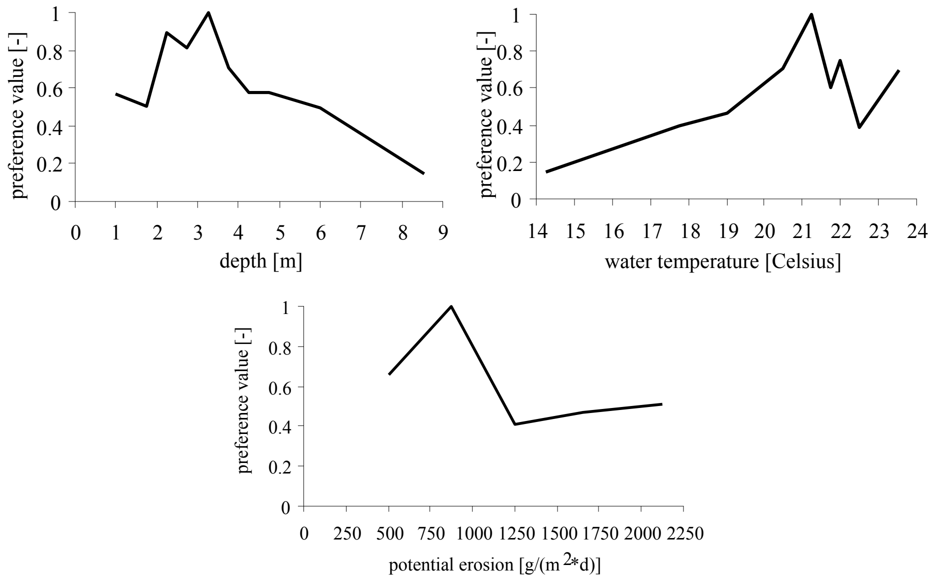


Figure 2.28 Preference curves made at the Lamminsaari study area at Lake Pääjärvi.

Table 2.5 Preference values for the abundance of lake bed quality types at the Lamminsaari study area at Lake Pääjärvi.

material	exists	does not exist
sand/fine sand	1	0.71
soft material	0.66	1

Table 2.6 Correlation of catch/effort ratios and habitat suitability values at the Lamminsaari study area at Lake Pääjärvi with different habitat value calculation formulae.

habitat value calculation formula	correlation
sand/fine sand	0.23
soft material	0.08
depth	0.23
erosion	0.27
water temperature	0.26
product of all	0.43
product (erosion, water temperature)	0.40
product (sand/fine sand, soft material, depth, erosion)	0.46
product (sand/fine sand, soft material, erosion, water temperature)	0.49
product (depth, erosion, water temperature)	0.36
product (sand/fine sand, soft material, depth, temperature)	0.29
sum of all	0.40
sum (sand/fine sand, soft material, erosion, water temperature)	0.44

Lake Slickolampi

At Lake Slickolampi, depth, water temperature, distance from shore, slope from shore, slope around the place and potential erosion were measured (Figure 2.29). These data were later used in validation, and a part of it in making the preference curves for potential erosion.

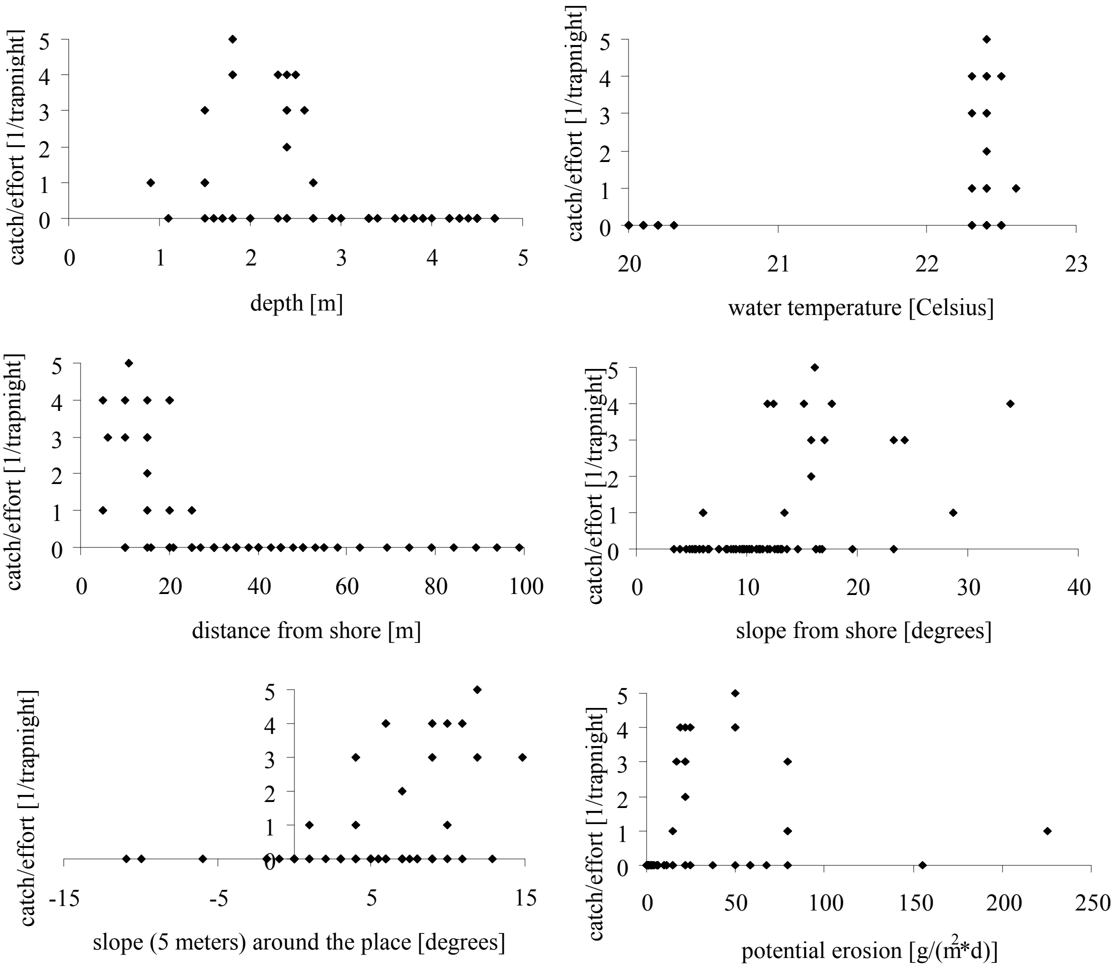


Figure 2.29 Catch/effort ratios as a function of different variables at Lake Slickolampi.

2.4 Vegetation model

In this section, the data used in building the model is represented, and the structure of the model is created.

Description of the area and the organism studied

The area is located in Northern Finland, next to the town of Oulu, located at a latitude of 65"01' north and a longitude of 25"30' east (Figures 2.30-2.31). The dimensions of the area in the study map are approximately 2.5*3 kilometres, one third of which is water (Figure 2.31). The water depth range is to 17.6 metres, and typical depths are 0-2 metres near the shoreline and 2-4 metres in the middle channels. The average discharge from the River Oulujoki is approximately 259 m^3/s. The flow velocities are low in most of the area; typical values are 0-0.5 m/s, 0-0.1 m/s being the most common.

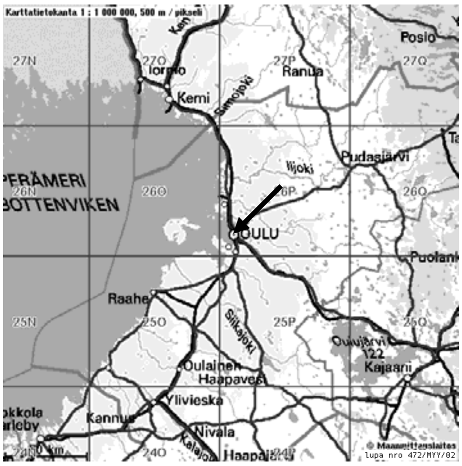


Figure 2.30 Location of the mouth of the River Oulujoki.

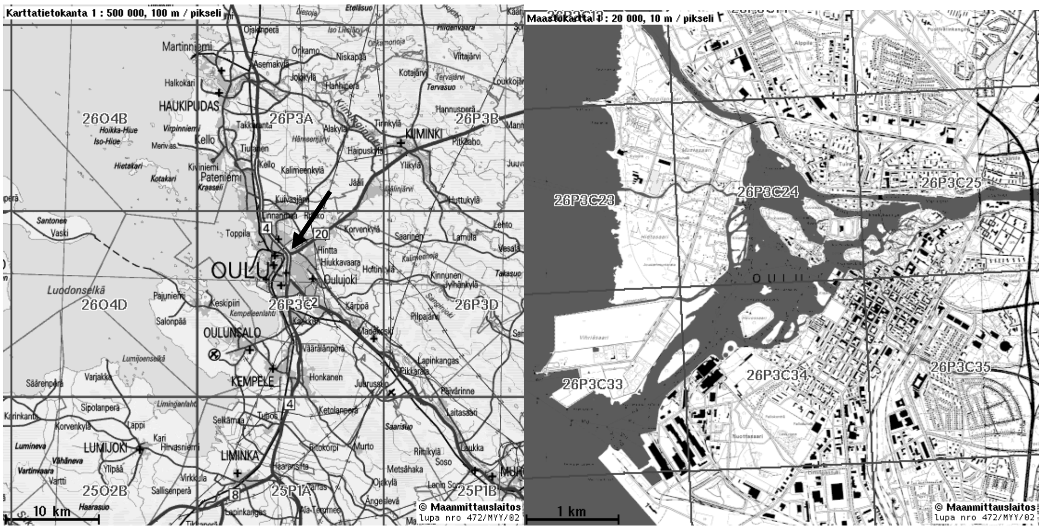


Figure 2.31 Location of the delta of the River Oulujoki and the study area.

Only in a small river-like section are the flow velocities higher. So, the water level fluctuations depend mostly on the sea water level. The fluctuations in the delta of the River Oulujoki during 1922-1999 are represented in Figure 2.32. The mean water level during June 1 to August 8 was MW2000 -15.8 cm and the standard deviation of the mean water level during the summer was +-7.06 centimetres during 1981-2000. The mean water level in the summer of 2000 was MW2000 -11.8 cm.

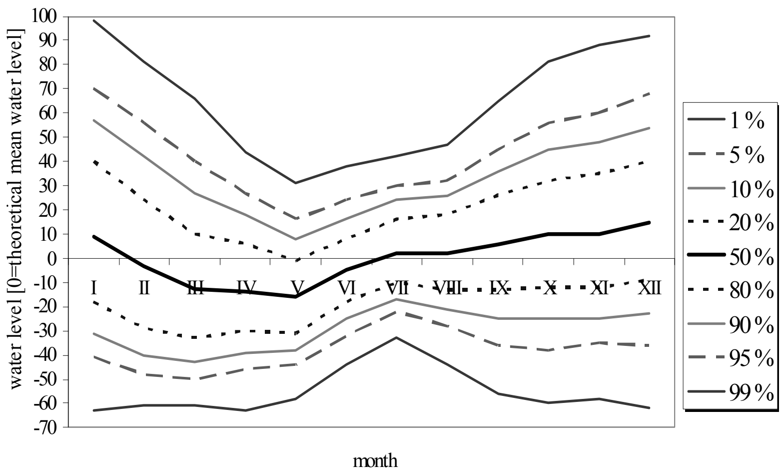


Figure 2.32 Water level fluctuations in the delta of the River Oulujoki 1922-1999. Based on data from the Finnish Institute of Marine Research.

The organism studied is a small water-spreading plant, *Persicaria foliosa* (H.Lindb.) Kitag. The organism prefers a position near the shoreline and a humus/mud bed quality. The habitat model was constructed with the principle normally used in fish habitat modelling: variables were chosen and the habitat suitability index values are multiplied together to get the total habitat suitability. The variables chosen were sea bed quality and the vertical distance downwards from the zero level of the water level system MW 2000 (Finnish Institute of Marine Research)

3 CALIBRATION OF THE MODEL

3.1 Fish model

3.1.1 Physical model

3.1.1.1 Field measurements and data models

Field measurement and topographic data interpolation methods were tested with measured field data.

Number of field measurement points

The effect of the number of field measurement points was tested with real case data from the River Ripatinkoski in Central Finland. The measurements of the waterline and upper bank were made with line measurements, i.e. they were measured only at every turning point of linear shapes and the lines were interpolated after that. The rest of the channel was measured as scatter points measured only at corner points in the form of the channel. The topographic model was created from the scatter point data added with the interpolated line data using Kriging (Figure 3.1). Every second field measurement point was removed from the data, and the resulting interpolated topographic model is shown in Figure 3.2. A comparison between these shows clear differences, but the larger-scale topography of the river remains about the same. The removal of points from the densely interpolated lines on the shore naturally does not change them much; it affects the scatter points more.

Choosing measurement points in the field

The difference caused by the amount of measurement points and by using different measurement groups was studied using data measured during the summers of 2003 and 2005 at the Tolpankoski Rapids on the River Kiiminkijoki. The river is a typical good trout river with large amounts of stones and boulders. The measurement data were interpolated with Kriging and the results are shown in Figures 3.3 and 3.4. This comparison shows the importance of the careful measurement of geometry. In the summer of 2005 boulders were measured more exactly. When boulders are being measured, points not only on the boulders but also around them should be measured. This comparison shows that the methods of choosing measurement points should be well planned and be clear, and that when analysing the effects of habitat rehabilitations with measurements and modelling, care should be taken to ensure the comparativity of measurement data. Using the same measurement group before and after rehabilitation would be beneficial.

The effects of using curvilinear anisotropic interpolation with Kriging compared with triangulation and only Kriging are studied in a real case. In Figure 3.5 the raw data used and a comparison between normal interpolation with triangulation, Kriging and curvilinear anisotropic interpolation in the Ahmaskoski area of the River Oulujoki are shown. These results imply that out of the standard methods, triangulation works well in regular channels formed linearly between amenably measured points, whereas the use of Kriging should be suggested in other cases, i.e. when trends in the data have to be guessed and the rate of change varies. The best interpolation method for a set of data should be selected by trying different methods (Golden Software 1999). Methods can be tested e.g. by removing points from the data and comparing the predictions of the values of these removed points produced by different methods. Results can also be compared at an area measured or known more exactly. Often the recommended method is Kriging. Interpolation with it may further be improved by using a customised variogram. Analysis of the variogram can be performed with special software that analyses spatial variation in the data and fits the parameter values of the variogram accordingly. From methods used in addition to the previous standard interpolations, curvilinear anisotropic interpolation is often beneficial. The test at Ahmaskoski area suggests that curvilinear anisotropic interpolation could be an effective method. The method can be used e.g. with Kriging and triangulation. In many cases, curvilinear anisotropic interpolation enhances model quality, especially if the river section studied is curved. If the amount of field measurement data is very high, moving the points into the grid in the method may cause a loss of detail if comparably rough grid densities are used. The number of interpolations should be kept small. However, the topographic model can often be improved so remarkably with anisotropic interpolation that the model is first interpolated in another program and after that the model is interpolated to the hydraulic model grid. The precision should be kept as high as practically possible so that the smoothening of the model is minimised.

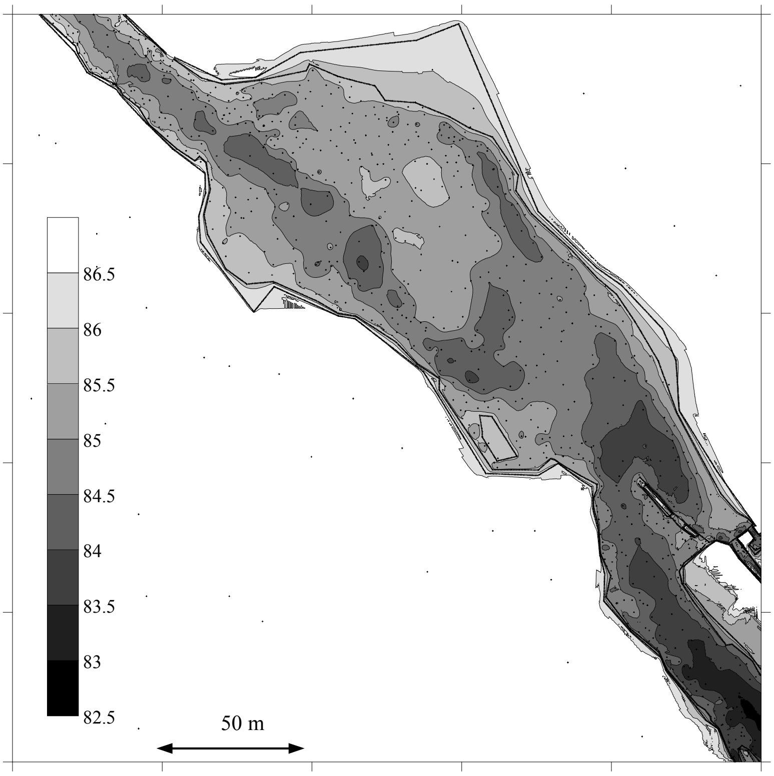


Figure 3.1 The topographic model and measured and line interpolated data points interpolated with a grid size of 0.25*0.25 (x,y) metres in the River Ripatinkoski.

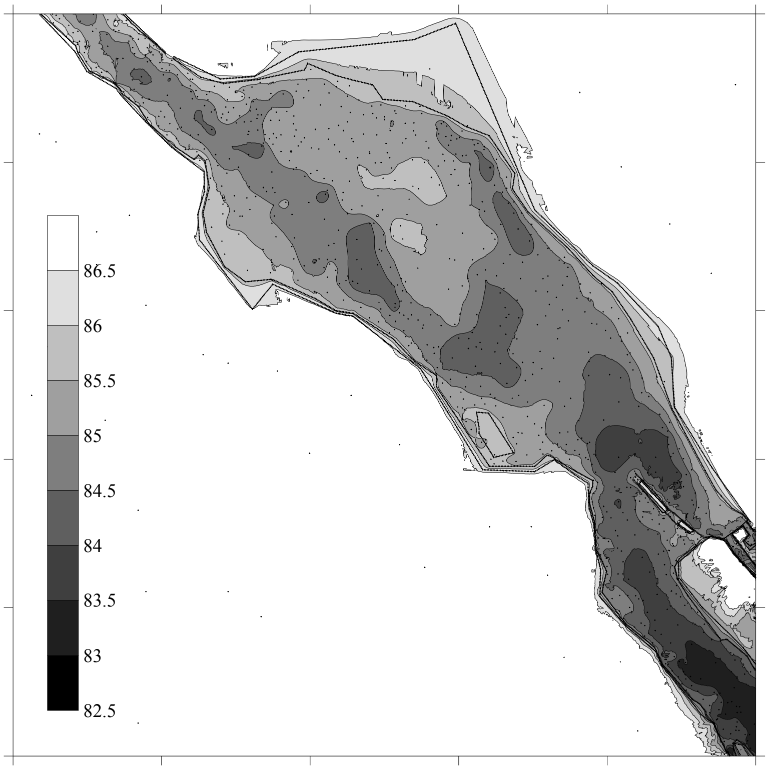


Figure 3.2 The topographic model and measured and line interpolated data points interpolated with a grid size of 0.25 metres, with every second measurement point deleted.

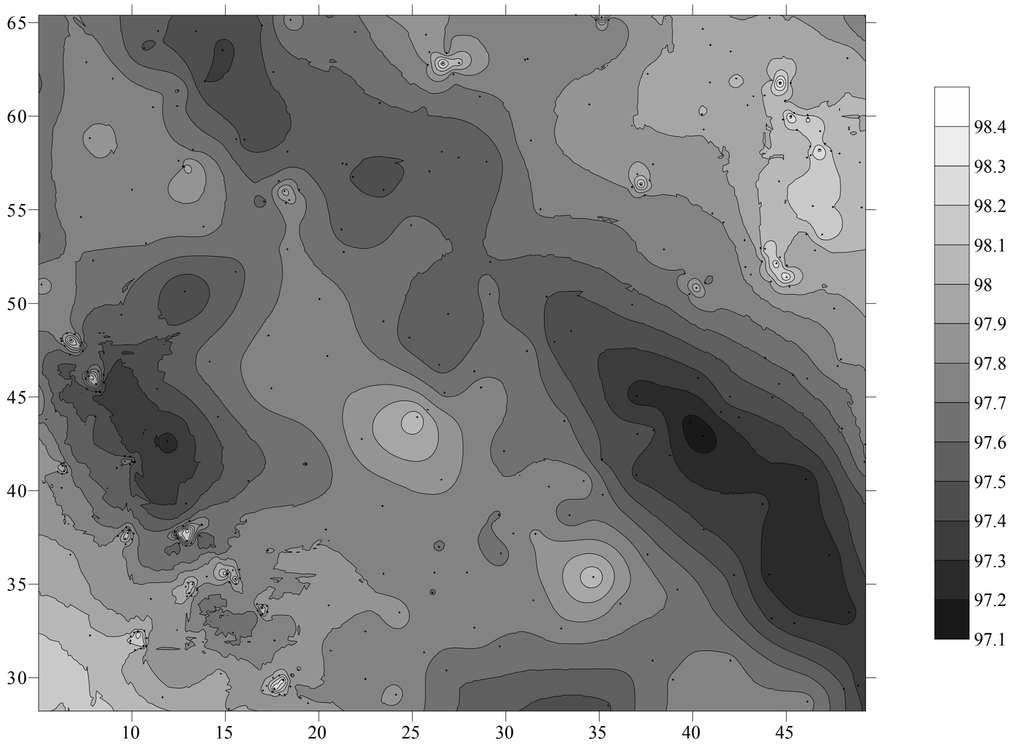


Figure 3.3 A topographic model interpolated from the coarser density measurements made 2003 at the Tolpankoski Rapids.

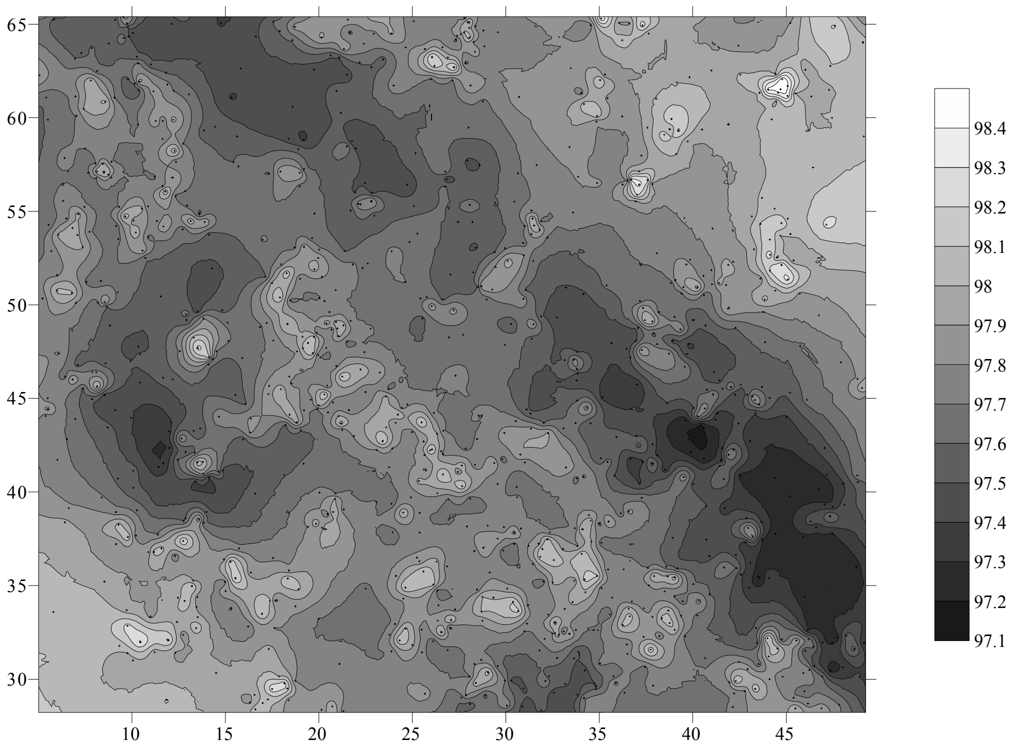


Figure 3.4 A topographic model interpolated from the finer density measurements made 2005 at the Tolpankoski Rapids.

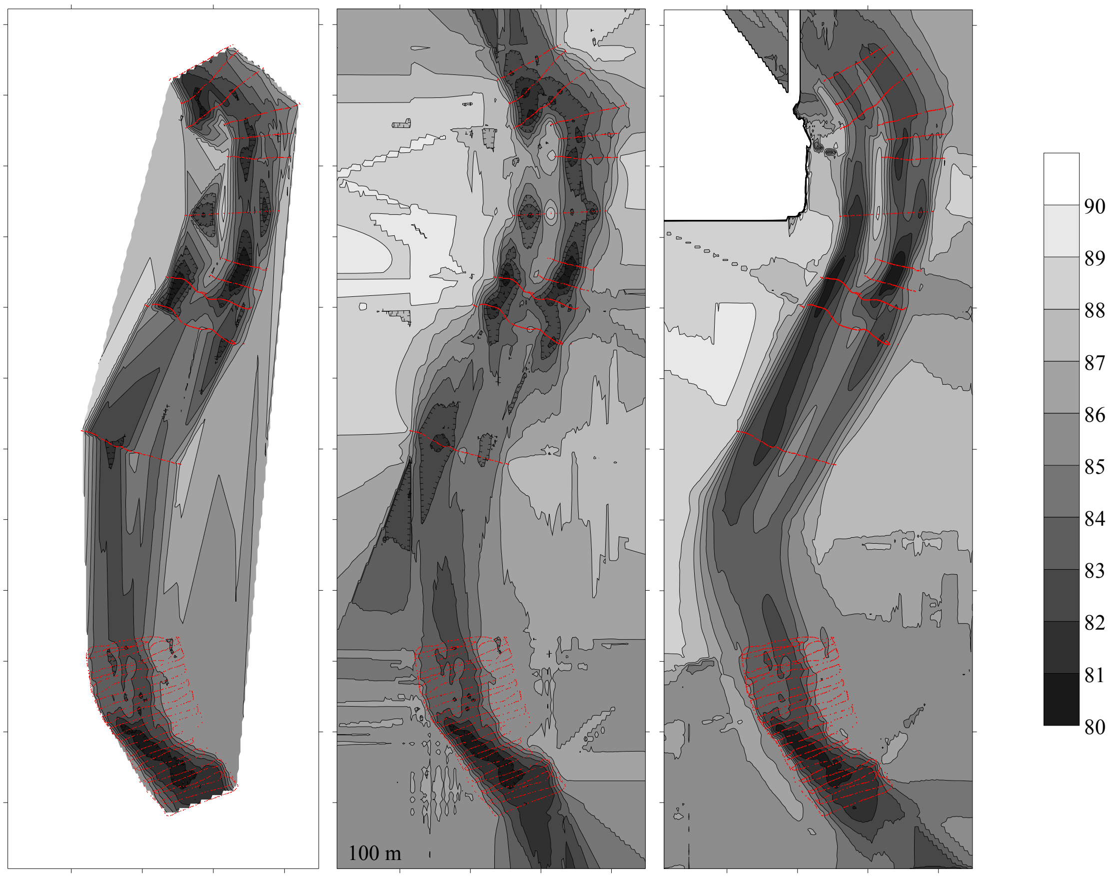


Figure 3.5 Cross-section and scatter point measurements marked with red, and a comparison between interpolation with triangulation, normal Kriging, and curvilinear anisotropic interpolation in the Ahmaskoski area of the Oulujoki River. The points show the measurements.

Using the modules of the method takes some time. The results with very large and dense sets of data could still be improved with the method by giving time for computation or by dividing the grid into smaller pieces. The benefit of increased accuracy should be compared with the cost of labour. However, in practice, the measurements made by an inclined echo sounder with large amounts of data could be such a large bulk of field material that the quality could not be improved remarkably or even at all. Shoreline interpolation can usually be used to improve the topography. Using it requires measuring the shoreline points and often putting them in an order afterwards, which may require additional work, in the office or in the field or both. On the other hand, the number of measurement points can be reduced.

The smoothening effect of interpolations on the topographic model

The smoothening effect of consecutive interpolations was studied by making interpolations with data from the Konnuskoski Rapids (Figure 3.6). Some smoothness is observed in the double-interpolated topography. The interpolation methods of topography presented here are exact, i.e. the interpolated surface goes through the original points. Instead, the values between calculation nodes may be different from measured values, and subsequent interpolations may smooth the surface.

To study the smoothening effect of subsequent interpolations and the effect of the hydraulic model element size, a topographic map from a hydraulic model from the River Kuusinkijoki in Northern Finland was compared with the original elevation measurements. The topographic model was created with shoreline interpolation and Kriging before it was interpolated in the nodes of the hydraulic model. The values picked along a cross-section from the topographic model are shown in Figure 3.7. The average and largest differences were 4.5 and 14 centimetres, the standard deviation for a sample being 3.3 centimetres, and the 95% confidence interval value was 10 centimetres. There were 30 elements across the river, 16 of which were in the water. The large number of dry elements is explained by the fact that the model was aimed for use with much higher discharges. When the shoreline is initially digitised, some dry area is included to ensure that all watered areas are included, because before calculations the water level is not known everywhere. Often, when longer river sections are modelled, e.g. 20 elements are used in a cross-section.

The effect of grid cell size

The effect of grid density on the accuracy of the topographic model was studied with real case data in the River Ripatinkoski. The topographic models interpolated with grid densities of 0.25, 1*2 metres, and 2*4 metres (x,y) are shown in Figures 3.8-3.10. Different precisions, 1 and 2 metres in the x- and y-directions, were used in the original modelling, because the river flows more from the north to the south, especially outside the figure. The model with the coarsest grid differs from the others in small details. No large differences were noticed, because the field measurements were made for habitat assessments of a reach 1.5 kilometres long. The most suitable grid density depends on the accuracy of field measurements and the accuracy required of the results.

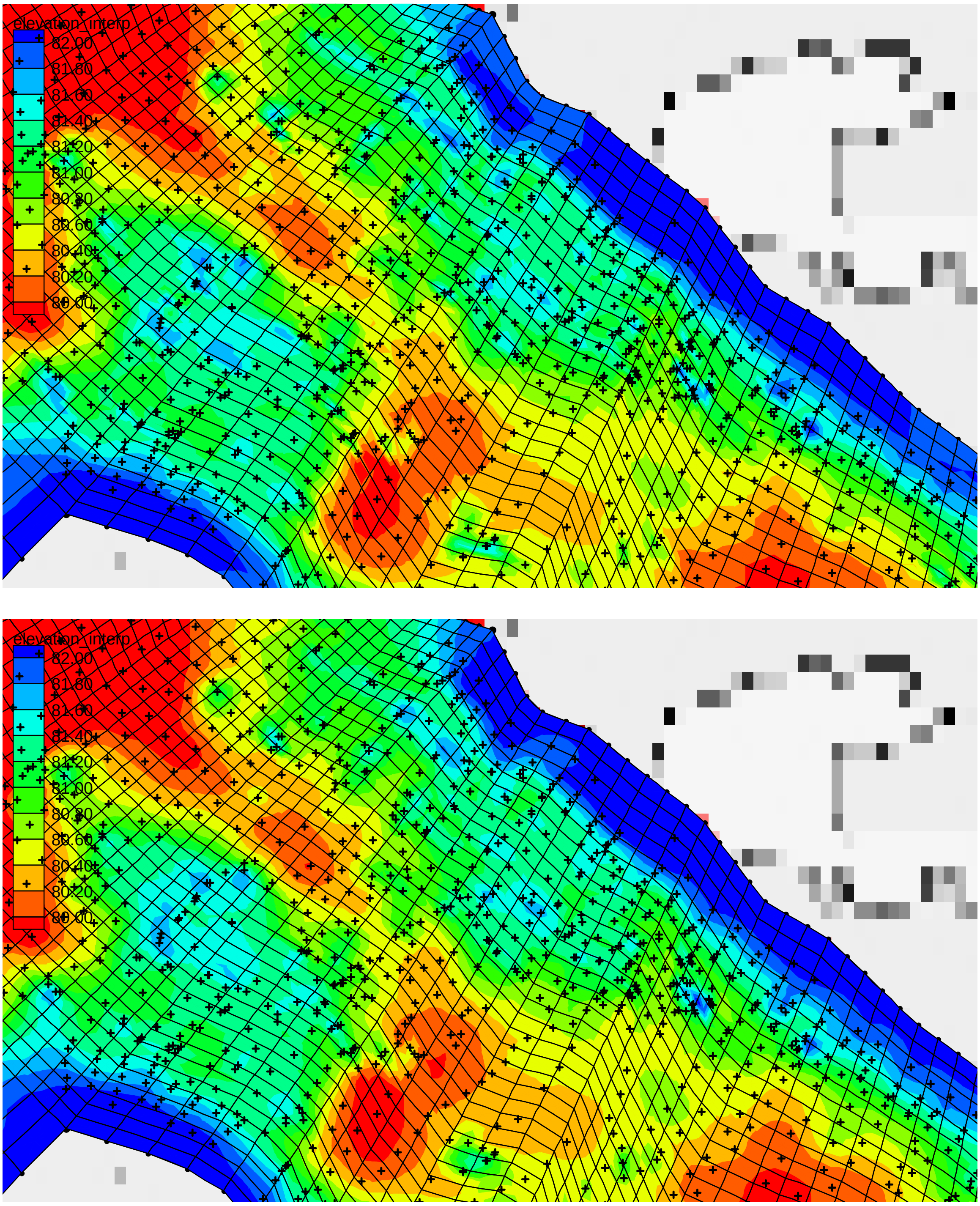


Figure 3.6 A topographic model interpolated with linear interpolation at the user interface of SMS and with an extra interpolation with Kriging to a 1*1-metre grid at the Konnuskoski Rapids before it. The element length in the middle of the figure is e.g. 5.7 metres. Field measurement points are marked with crosses.

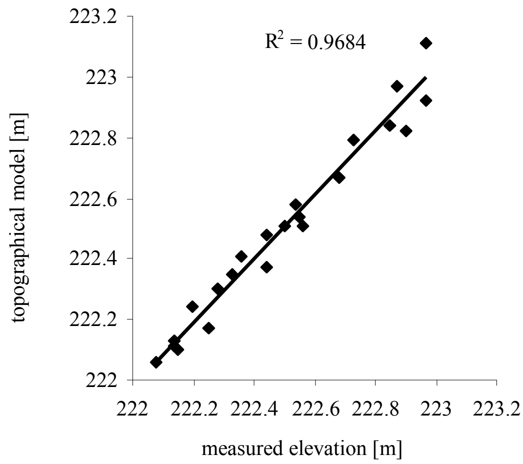


Figure 3.7 Measured elevation and topographic model of hydraulic model in the River Kuusinkijoki.

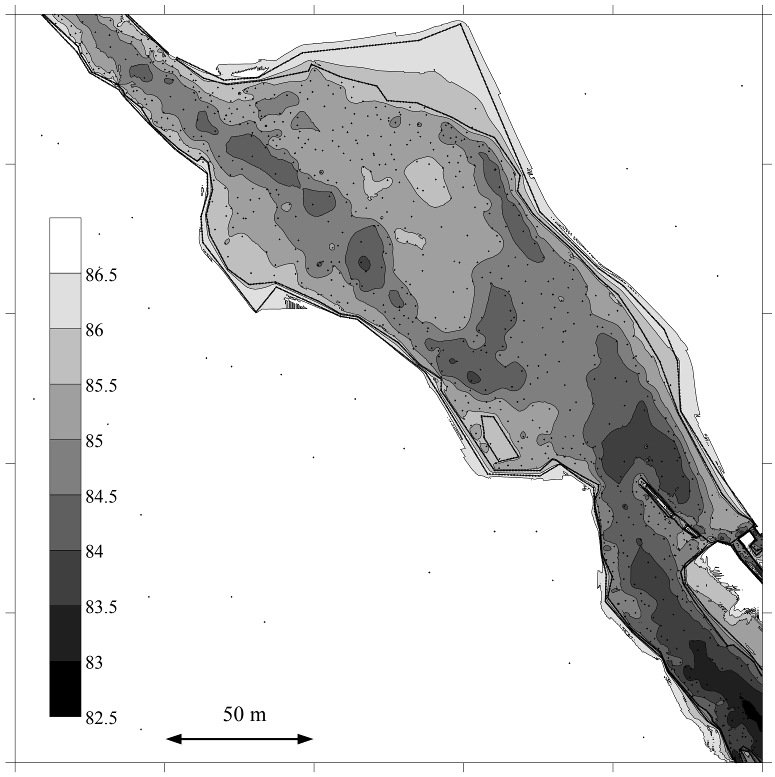


Figure 3.8 The topographic model and measured and line interpolated data points interpolated with a grid size of 0.25*0.25 (x,y) metres in the River Ripatinkoski.

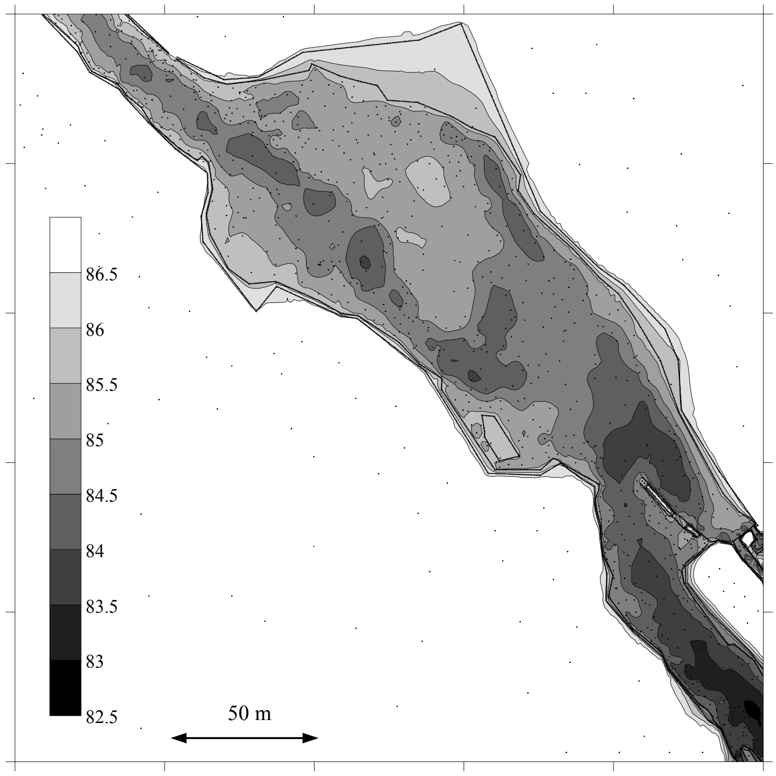


Figure 3.9 The topographic model and measured and line interpolated data points interpolated with a grid size of 1*2 (x,y) metres in the River Ripatinkoski.

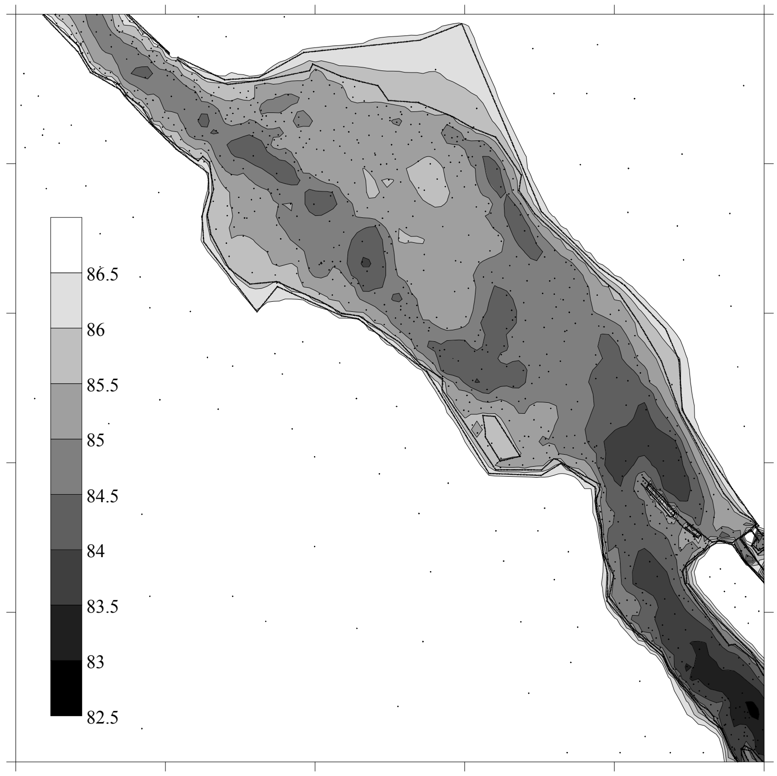


Figure 3.10 The topographic model and measured and line interpolated data points interpolated with a grid size of 2*4 (x,y) metres in the River Ripatinkoski.

3.1.1.2 Hydraulic model

Hydraulic modelling was performed at Pyhäkoski impoundment and the results were compared with measurements. The study site was the whole impoundment between the hydro power plants, where the fish moved. Measurements of topography were made by echo sounding combined with DGPS (Kylmänen 1999). The number of measurement points was 32,814. The high banks and forest in the upper part of the river section inhibited measurements from some of the shallow areas, but that did not cause too much harm, because the fish were known to live in deeper waters. The flow rates at each moment were modelled with a dynamic one-dimensional hydraulic model originally set up by Forsius (1984). The modelled and measured water levels at the Pälli hydro power plant are shown in Figure 3.11. The flow velocities and water depth were obtained from two-dimensional hydraulic modelling with SMS/RMA2. The number of elements was 19,698, and the number of calculation points in the hydraulic model was 60,215. There were 29 elements across the river. With this resolution, there are on average one element every five metres across the river. The accuracy of the topography and hydraulic modelling was assessed by comparing the measured and modelled water depths and flow velocities (Figure 3.12). The water depths and flow velocities coincided relatively well, but some values of water depths and flow velocities may be erroneous because of a lack of topography measurements near the shoreline. The correlation coefficient between the field and model data was 0.8 and $p<0.001$ (Vehanen & Lahti 2003). A grid cell size of 5*5 metres was used in the habitat modelling.

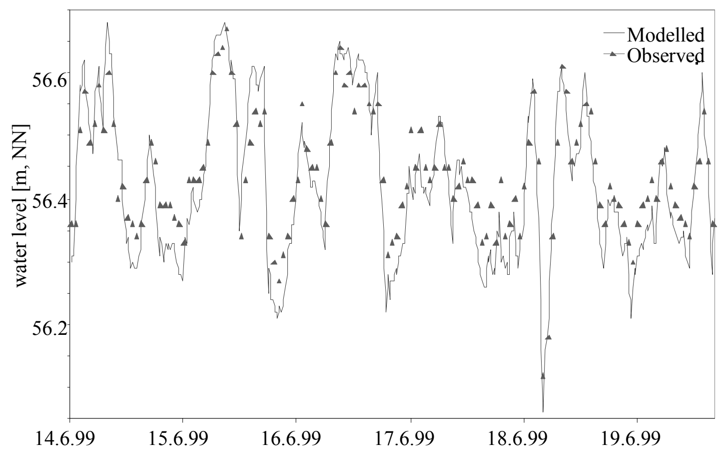


Figure 3.11 The modelled and observed water level below the Pälli hydro power plant.

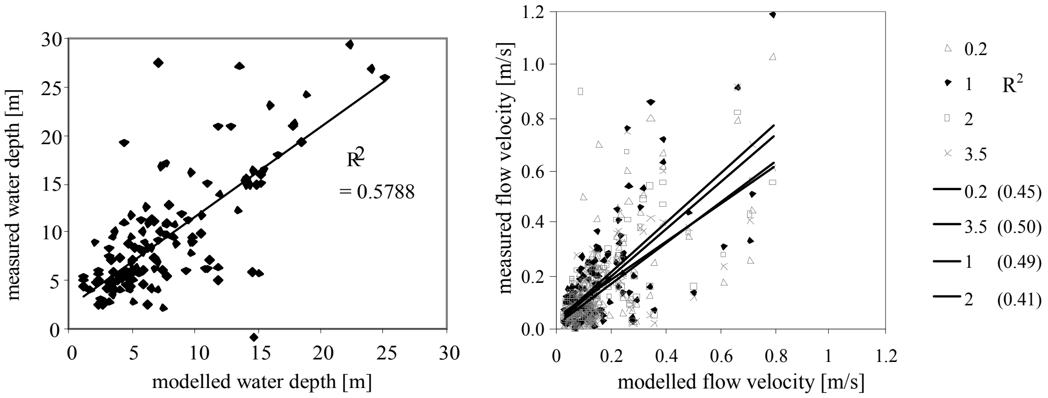


Figure 3.12 Modelled and observed water depths and mean column flow velocities and the observed flow velocities at different depths (0.2, 1, 2, and 3.5 metres) at fish observation places at the Pyhäkoski impoundment. Modelled R^2-values of linear regression fits shown in legend.

In order to test the hydraulic model and to test the effect of not including the shallow areas in the hydraulic model, a case with real field measurements at the Valajaskoski Rapids on the River Kemijoki was studied. The flow velocity measurements were originally made for the calibration and validation of ADCP measurements. Thus the data are of high quality. The hydraulic model and the grid used here were originally made by Kemijoki Oy for flow measurement purposes and may not include all the shallowest shore areas; the depth is 0.61 metres on the right bank side of the grid and 0.48 on the left bank side. These may cause too-high flow velocities near the banks. There were no water level measurements in the river between the power plants, and the water level at the upper power plant was known. Thus a typical value of 0.025 was used for Manning's coefficient. The effect of wall friction was estimated by calculating wall and element area at another bank of the current velocity profile. The area of the element was 372.6 m^2 and of the wall only 22.1 m^2, which means the effect of wall friction is small. But the vertical friction is left out of all elements, which means a greater overall reduction of friction. The modelled flow velocity distribution was noticed to be smoother and more uniform than the measured (Figures 3.14 and 3.15). Possible reasons may be inaccuracies in topographic models, which are deeper near banks, the fact that some shallow areas are probably excluded, also the fact that vertical friction is not included in the hydraulic model and temporal variations and inaccuracy in measurements. This phenomenon coincides with the findings with the figurative test reach (Figure 4.14). The effect of using a constant calculational value of kinematic viscosity, which neither takes the effect of varying element sizes nor flow velocities into account, was tested (Figure 3.15). The test showed that the flow velocity distribution got smoother than with an appropriate assignment of kinematic viscosity. To test whether element size had an effect on the results, the hydraulic modelling grid was refined from a distance double the length of both ADCP lines up- and downstream from the lines (Figure 3.16). The whole grid was not refined, because the number of elements would have got so much larger that the computation time would have increased and the hydraulic calculation program would have had to be compiled with new settings. New topography points were not included. Refining the grid had rather a small effect.

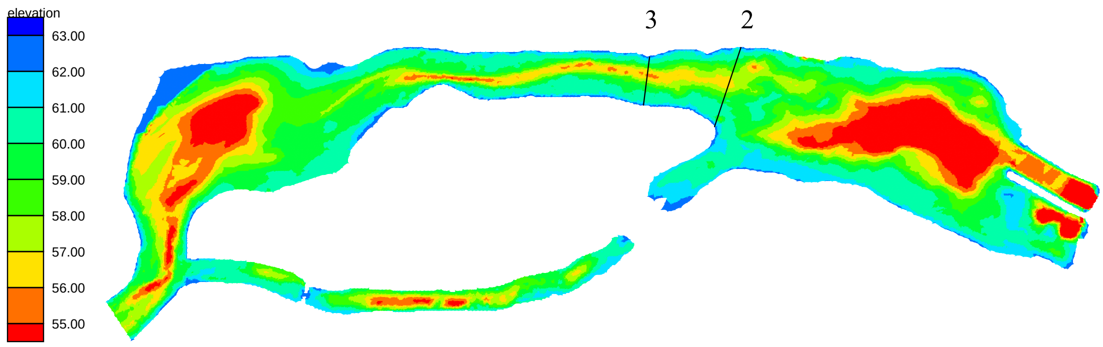


Figure 3.13 The topographic model and the location of ADCP measurement lines at the Valajaskoski Rapids.

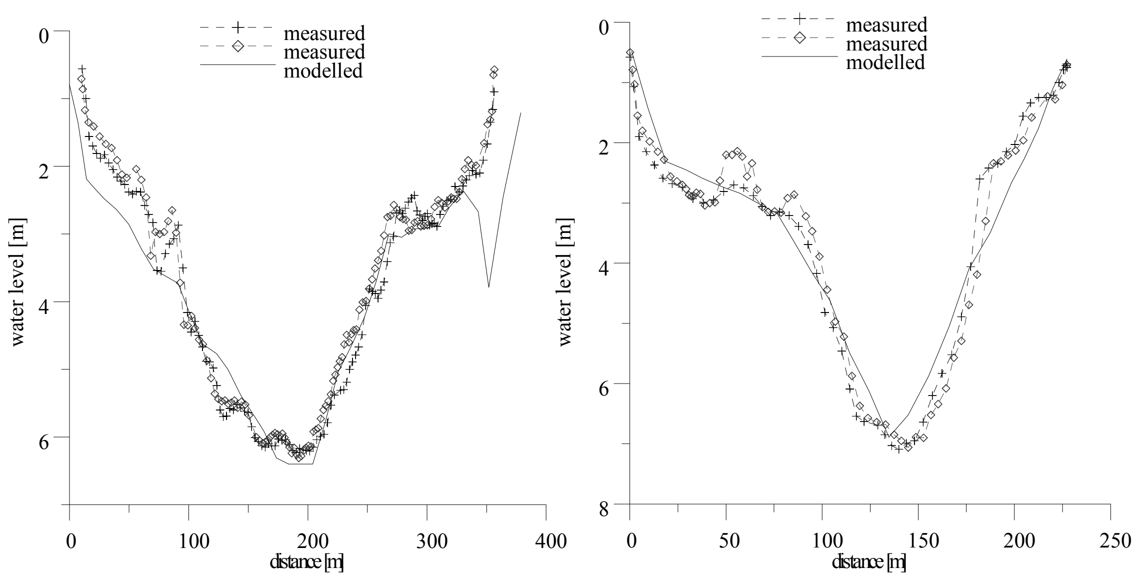


Figure 3.14 Modelled and two measured water depth profiles at Valajaskoski measurement lines 2 and 3. Hydraulic model not calibrated across the river.

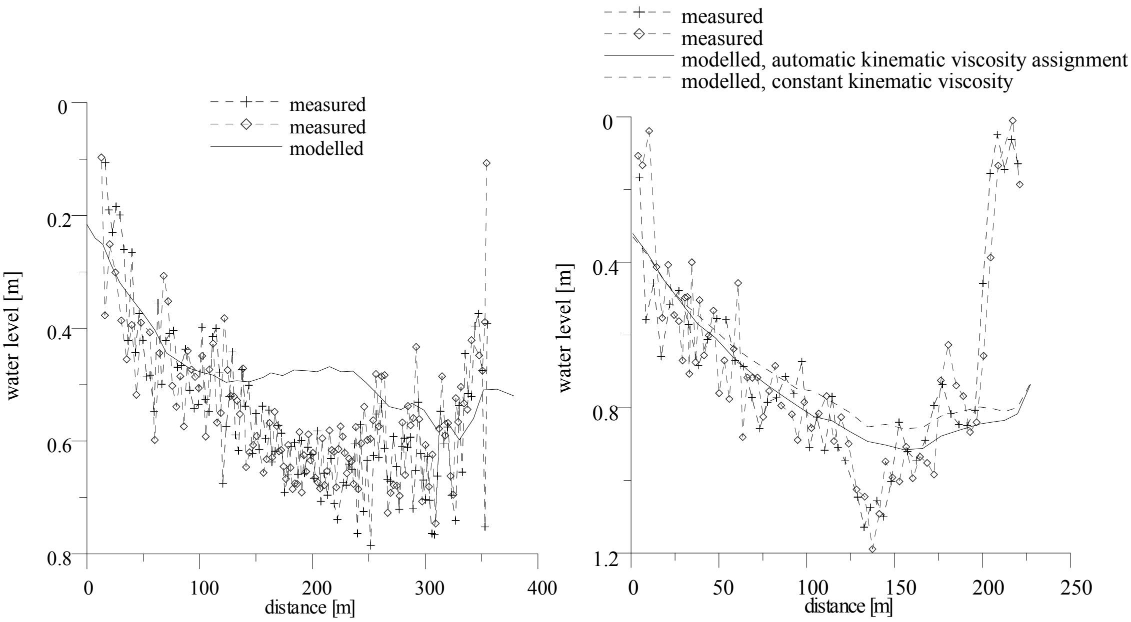


Figure 3.15 Modelled and two measured flow velocity profiles at Valajaskoski measurement lines 2 and 3. Hydraulic model not calibrated along or across the river.

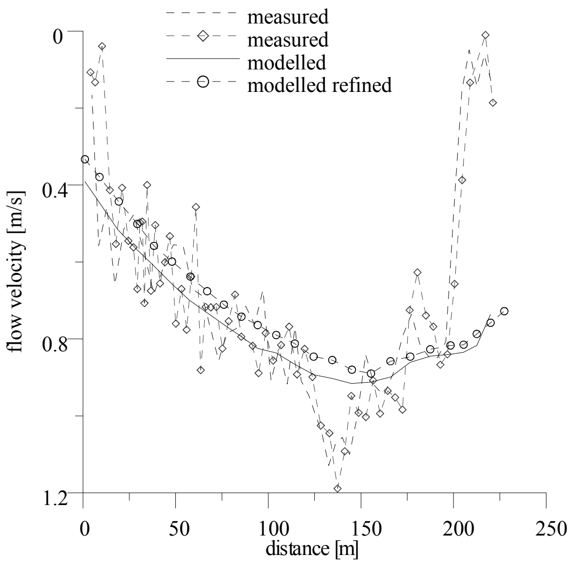


Figure 3.16 Modelled flow velocity with a refined grid with 24 rows of triangular elements in cross-section, and with an unrefined grid with 12 rows of elements, and the measured lines at the ADCP measurement line 3.

3.1.1.3 The effect of habitat modelling grid density

The effect of the spatial precision of habitat value calculation grids was tested by calculating two cases with different habitat modelling grid densities. At the Ripatinkoski Rapids, a total of approximately 1.5 kilometres was modelled for large area habitat assessments, and because of that the field measurement material was not very densely measured (Figure 3.17). The habitat maps calculated with grids of varying sizes in the upper and lower fish-locating areas are shown in Figures 3.18-3.19. It can be seen that the amount and position of habitats did not change greatly for habitat assessments, even if the shoreline gained a saw edge with the roughest grid. One reason for this is that with a coarser density of field measurements less fine details that could be flattened away with a coarser grid are included in the data. Even the roughest grid was found to be satisfactory for habitat assessments of the long reach studied.

Next, it is studied, which kind of a modelling grid size is sufficient when measurements are dense and a higher spatial resolution is needed, e.g. for fish habitat preference studies. A fish study area with dense field measurements was selected: Siltapuro B, in the Siltapuro brook, a tributary of the River Oulujoki. Habitat value calculations were carried out and habitat values at fish observation points were distributed into classes, as is also done in preference studies. It is better to compare habitat values at certain points rather than to compare distributions, because the fine structure of the river bed may cause differences in point values with different grid sizes but not possibly so much in habitat value distributions. The average width of the river is 5-7 metres. The maps calculated with grids with 20- and 40-centimetre cell widths look moderately similar (Figure 3.20). In the maps with other grid cell sizes, much detail is missing.

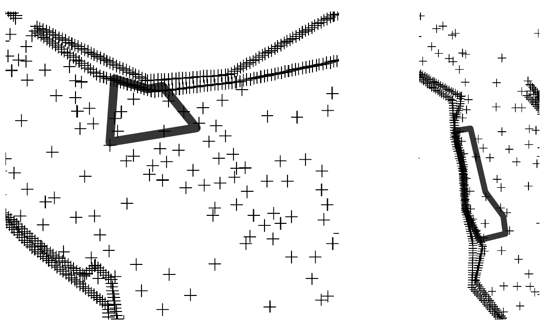


Figure 3.17 Field measurements from the modelled upper and lower areas. Shore lines were interpolated and the electric fishing areas studied are shown with continuous lines.

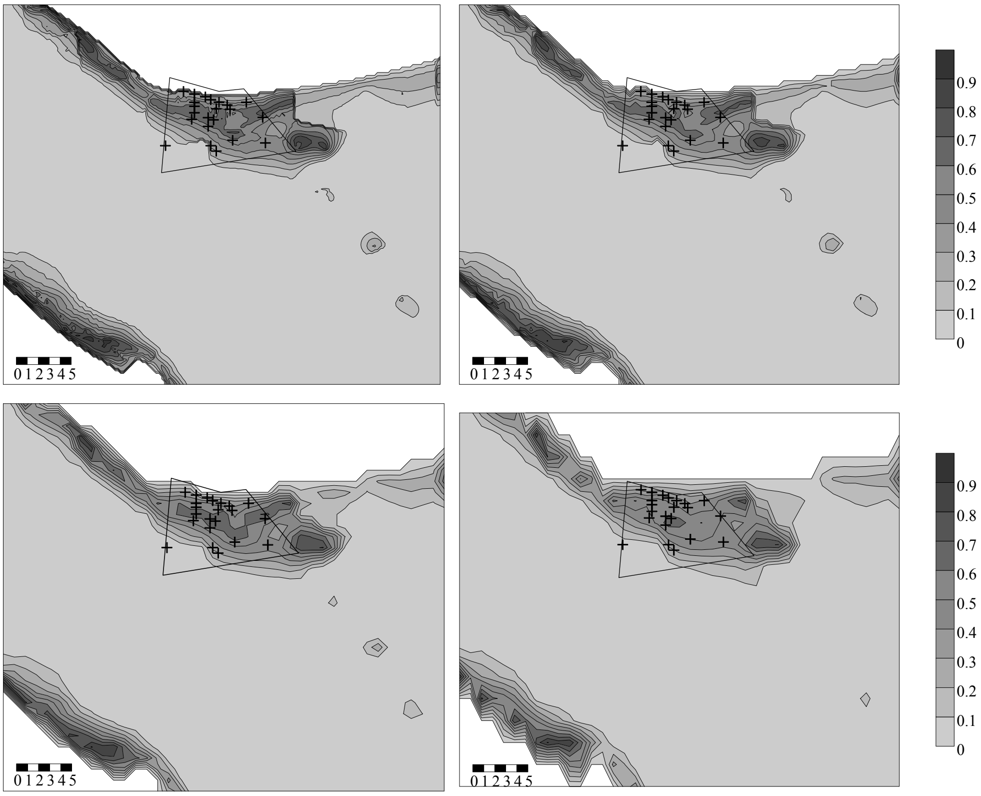


Figure 3.18 Habitat value maps calculated in the upper fish-locating area with the preference curves of Mäki-Petäys & Huusko (2001) with habitat calculation grid cell sizes 0.25*0.25, 0,5*0,5, 1*1, and 1*2 metres (x,y) and fish observations.

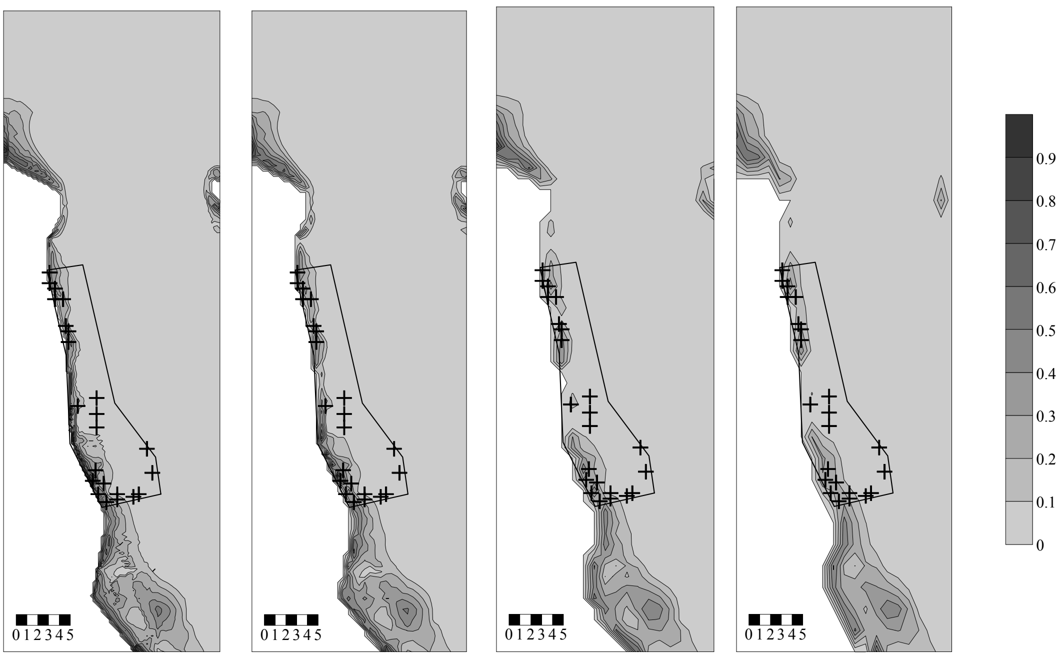


Figure 3.19 Habitat value maps calculated in the lower fish-locating area with the preference curves of Mäki-Petäys & Huusko (2001) with habitat calculation grid cell sizes 0.25*0.25, 0,5*0,5, 1*1, and 1*2 metres (x,y) and fish observations.

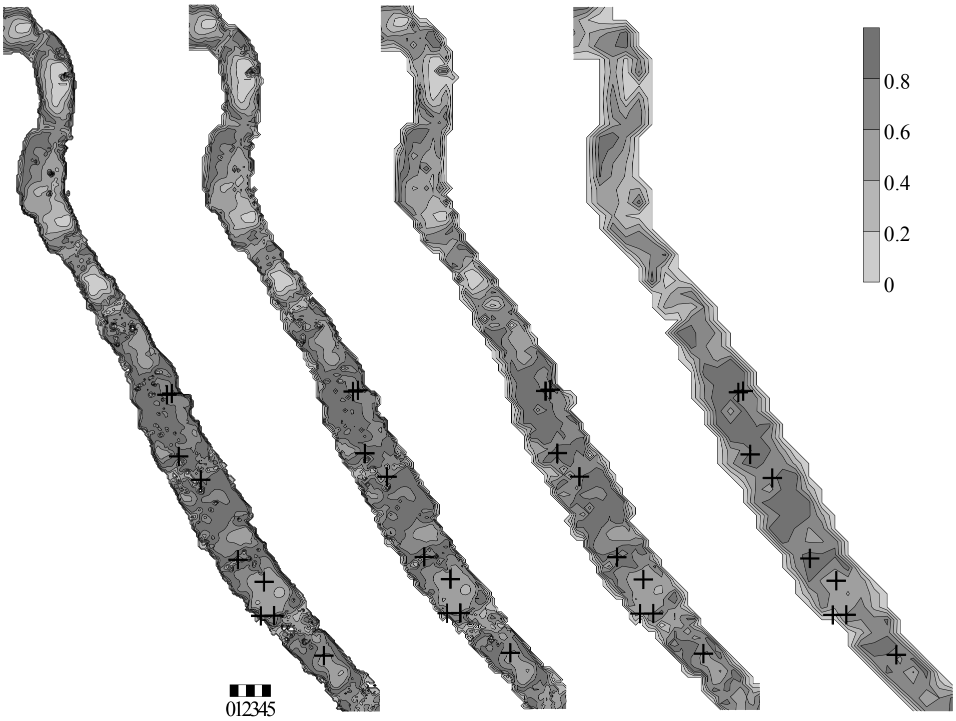


Figure 3.20 Habitat value maps for 4-9-cm trout in summer in a tributary of the River Oulujoki, the Siltapuro, study area B, with grid sizes of 20, 40, 80, and 160 centimetres in both directions and fish observations.

The grid size with a 20-centimetre distance is 436*233, which is still easily calculable with computers. The results of the test can be seen in Figure 3.21. The habitat value classes are similar with grid sizes of 20 and 40 centimetres. For the habitat assessment of a long reach of the River Ripatinkoski, a grid cell size of 1*2 metres was found to be sufficient as a size of 20-40 centimetres was the value for fish preference studies in the Siltapuro B reach. The grid density needed depends on the density of field measurements and the accuracy desired.

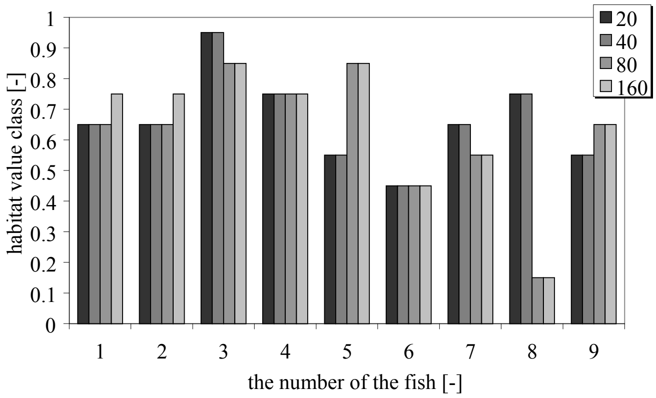


Figure 3.21 The habitat value class of the calculated habitat at fish observation points with grid sizes of 20, 40, 80, and 160 centimetres in both directions.

3.1.2 Habitat preference model

In this section, it is studied, with which kind of preference material the model should be calibrated with. The origin of the fish observation data and the methods of processing the data for the model are studied. Fish observation data can be local, foreign, multi-site, from different sizes of rivers, etc. The preference information can be input as curves or surfaces. These can be constructed in many different ways. Different preference curves that are used in modellings at Rivers Simojoki and Ala-Koitajoki, are represented and compared visually. Laukka area and Pyhäkoski impoundment data are used in testing different methods of calibration, the original fish observation data being available.

3.1.2.1 Rivers Simojoki and Ala-Koitajoki

The biological habitat preference model was calibrated with material from fish preference studies carried out in northern Finland. No calculations for testing were carried out, because the observation data of Rivers Simojoki and Ala-Koitajoki was water depths, flow velocities and substrate from which habitat suitability index values are calculated directly in the model validation. In habitat suitability index value calculation, typically no parameters are calibrated. The physical model contains a hydraulic model that needs to be calibrated. The Finnish preference curves for salmon were calculated as averages of the curves of the rivers in the data of Mäki-Petäys (2000). Whilst the habitat preferences of salmon and trout have been the subject of intensive studies worldwide, some preference curves exist for grayling, but for stone loach and bullhead no curves were found except the data of Lamouroux et al. (1999). Preference curves for size classes in the data of this study for salmon (*Salmo salar*), brown trout (*Salmo trutta*), and grayling (*Thymallus thymallus*) for water depth, flow velocity, and substrate are shown in Figures 3.22-3.26. The Finnish and Norwegian curves are very similar to each other. Preference curves for stone loach and bullhead are shown in Figures 3.27-3.30. The preference for flow velocity curve with multiple optima for stone loach doesn’t seem biologically sound. The curves are made with Jacobs's method from small sets of data, n=31 and 42, respectively, at the Harrikoski and Iso Tainikoski Rapids and directly based on French data of observed log-densities (Lamouroux et al. 1999).

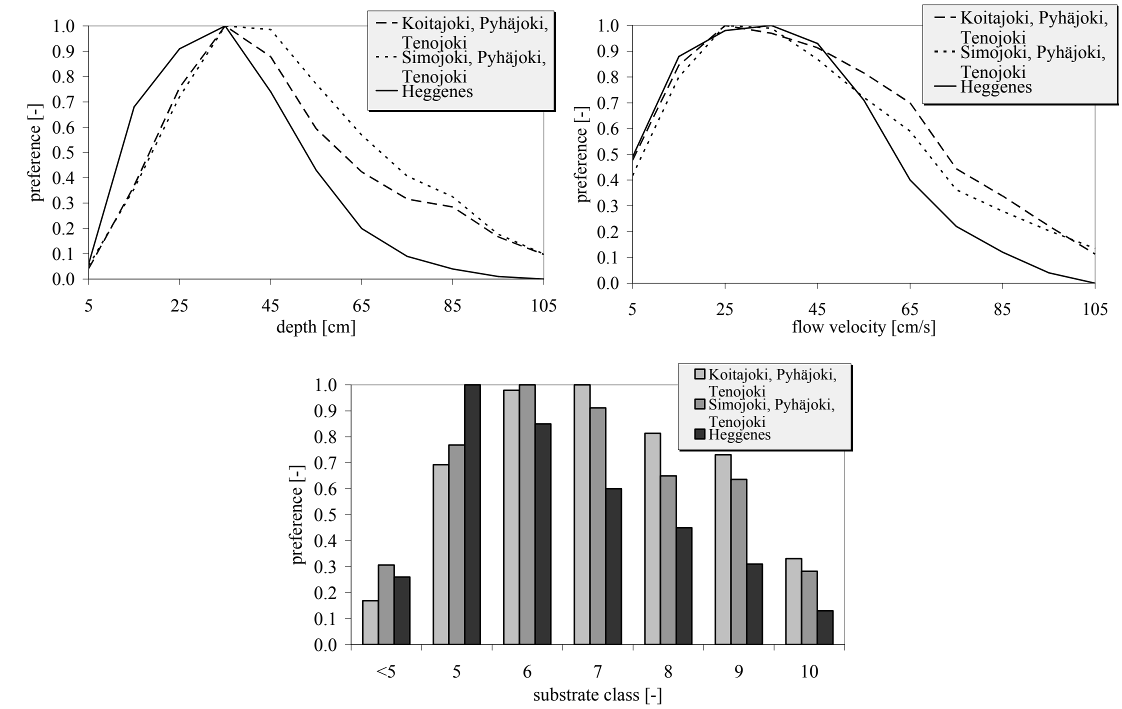


Figure 3.22 Preference of salmon <10 cm (*Salmo salar*) for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock). Mäki-Petäys (2000), Heggenes (1990).

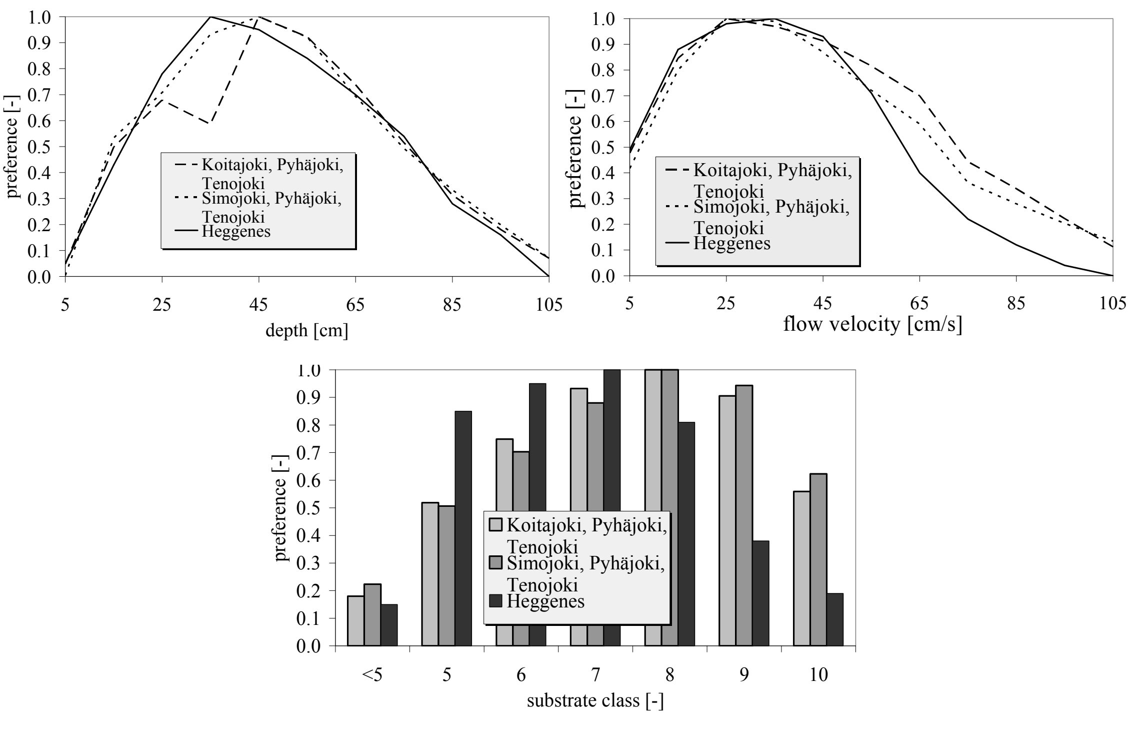


Figure 3.23 Preference of salmon >10 cm (*Salmo salar*) for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock). Mäki-Petäys (2000), Heggenes (1990).

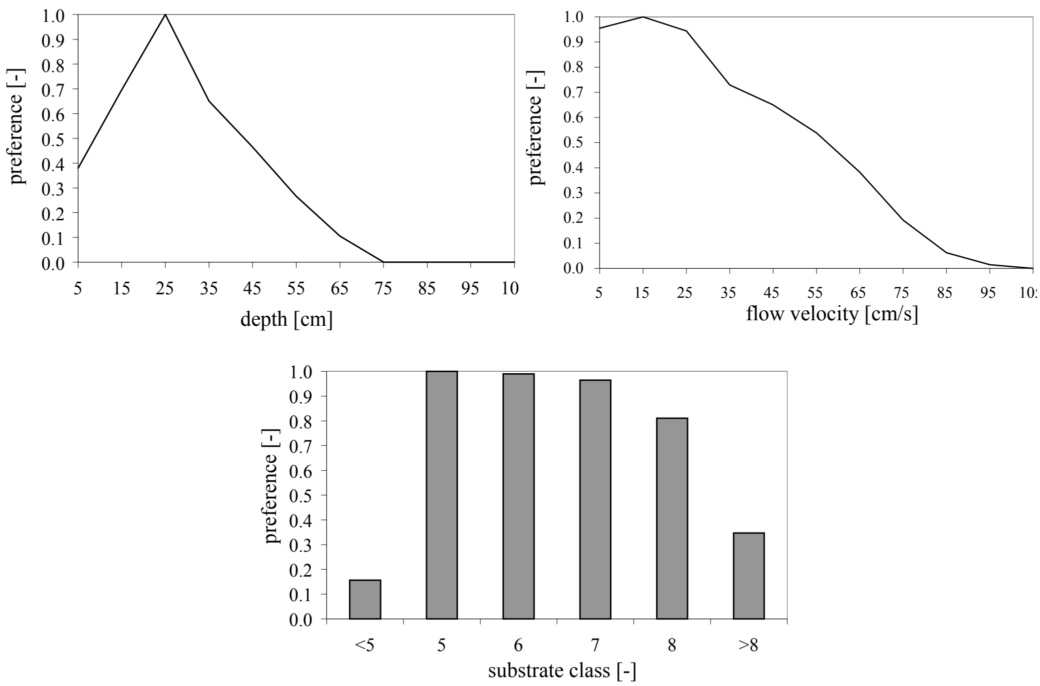


Figure 3.24 Preference of brown trout <10 cm (*Salmo trutta*) for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; >8 >512.1 mm) from Rivers Kuusinkijoki, Rutajoki, and Varisjoki. Mäki-Petäys (2000).

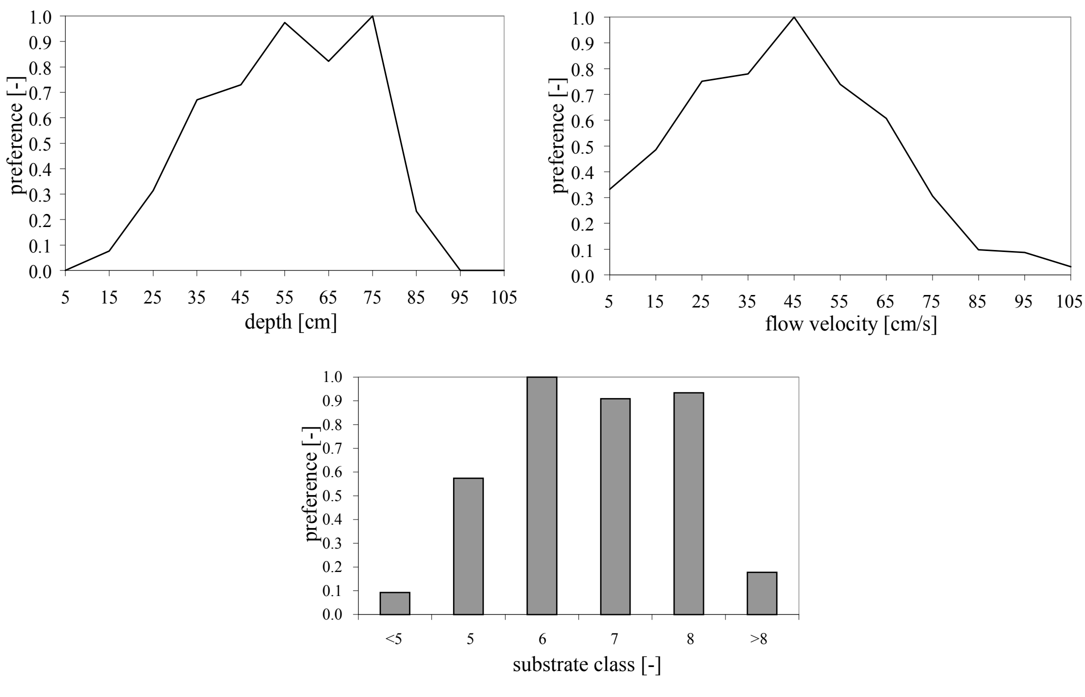


Figure 3.25 Preference of brown trout >15 cm (*Salmo trutta*) for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; >8 >512.1 mm) from Rivers Kuusinkijoki, Rutajoki, and Varisjoki. Mäki-Petäys (2000).

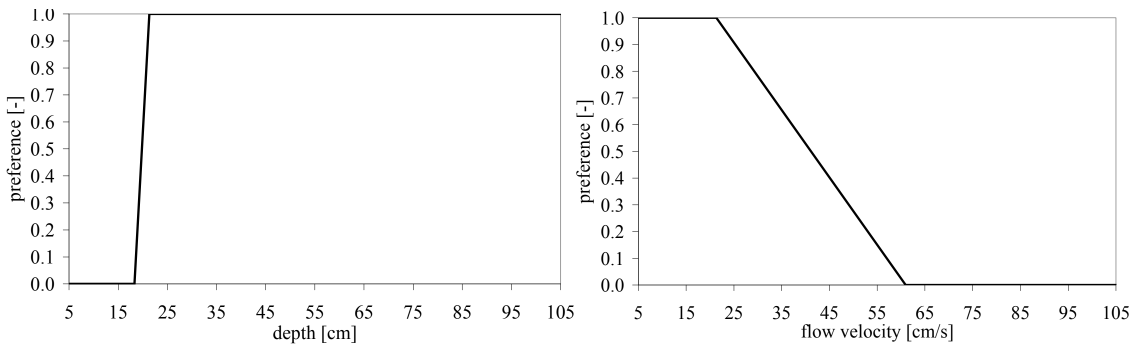


Figure 3.26 Preference of grayling of 5.1-25.4 cm (*Thymallus thymallus*) for water depth and flow velocity by Hubert et al. (1985). The preference for substrate is uniform. Hubert et al. (1995).

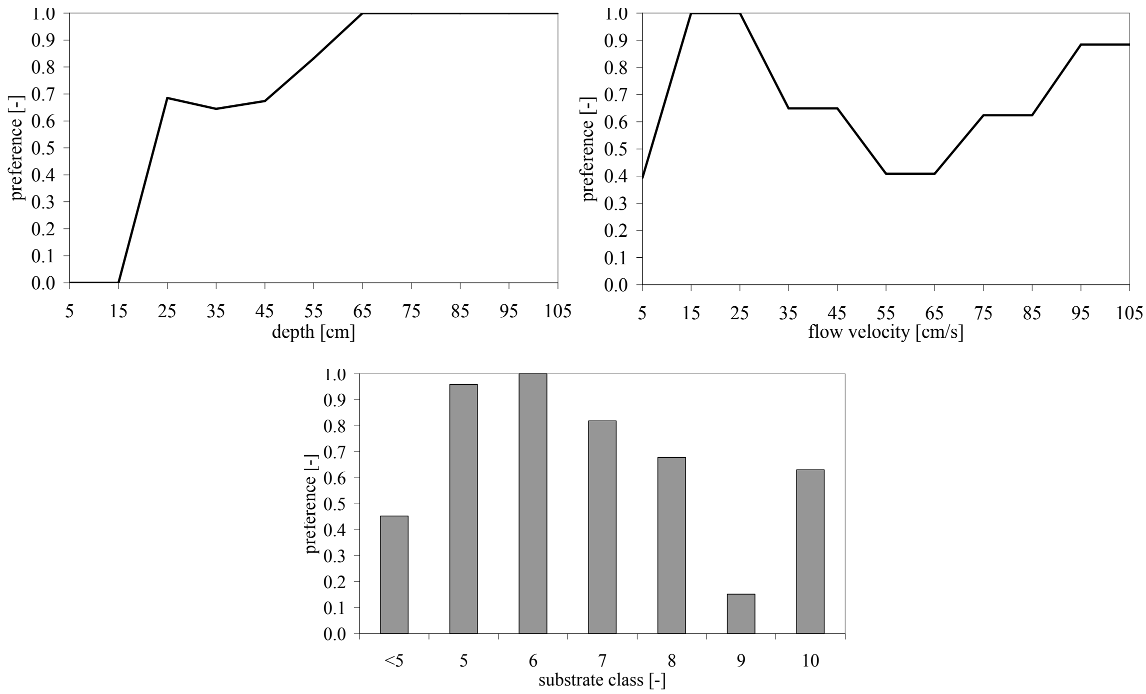


Figure 3.27 Preference of stone loach (*Noemacheilus barbatulus*) of 5-13 cm for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock) at Harrikoski Rapids. Lamouroux et al. (1999).

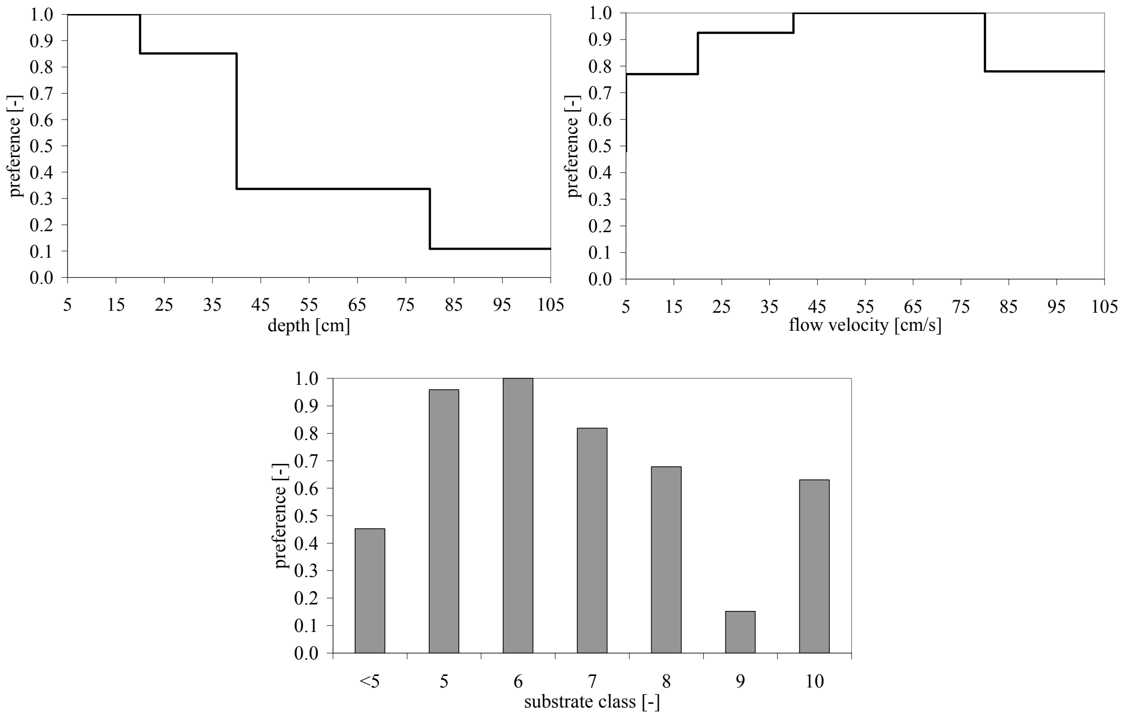


Figure 3.28 Preference curves based on data for stone loach (*Barbatula barbatula*) of all sizes in the preference study for water depth, flow velocity, and substrate (<4, <16 mm; 4, 16-32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock) based on data of Lamouroux et al. (1999).

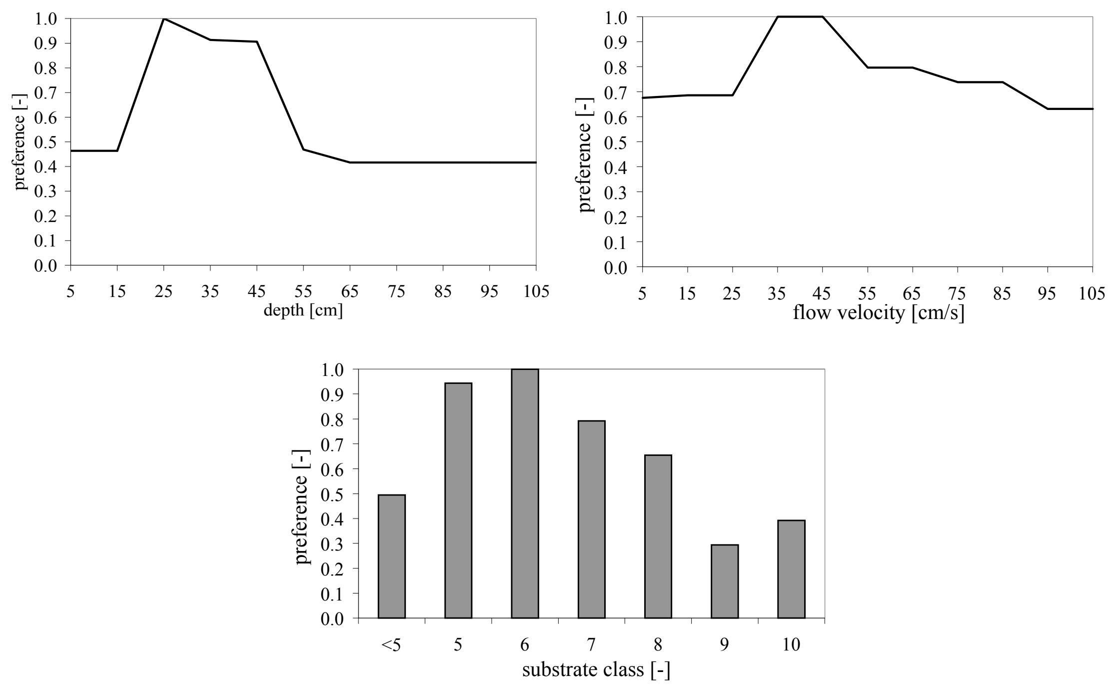


Figure 3.29 Preference of bullhead (*Cottus gobio*) of 2-7 cm for water depth, flow velocity, and substrate (<5, <32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock) at Harrikoski Rapids. Lamouroux et al. (1999).

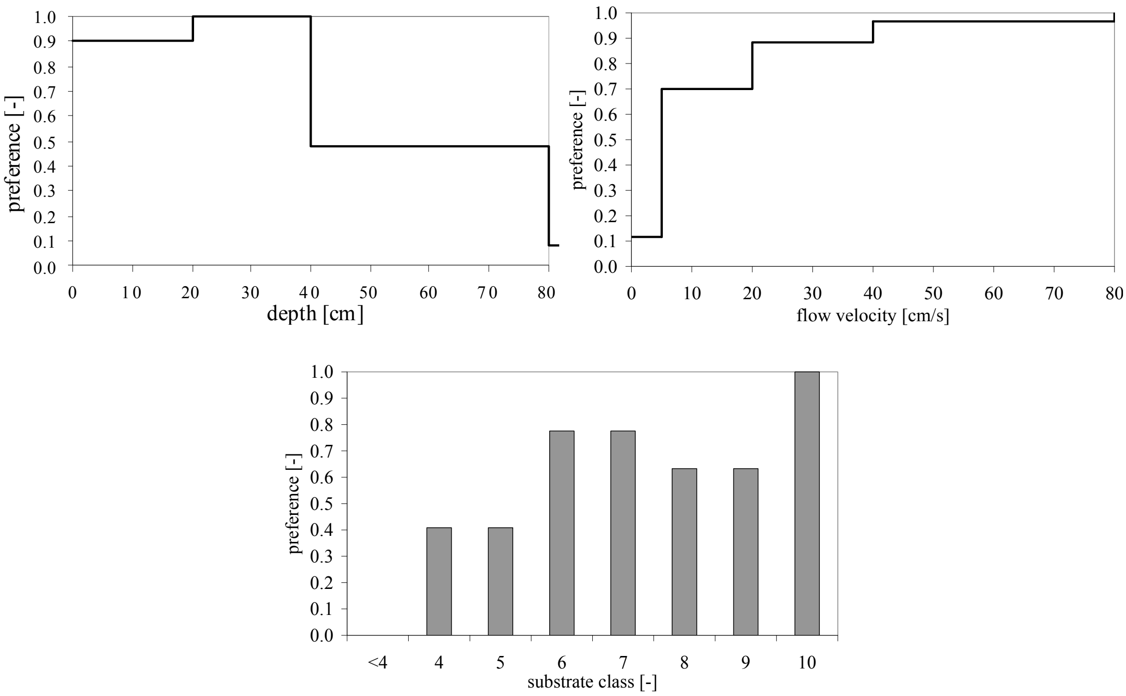


Figure 3.30 Preference of bullhead (*Cottus gobio*) of all sizes in the study for water depth, flow velocity, and substrate (<4, <16 mm; 4, 16-32.1 mm; 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9, 512.1-1024 mm; 10, bedrock) based on French data (Lamouroux et al. 1999).

3.1.2.2 Laukka area

As mentioned earlier, calibration of habitat preference models means using some data to get models applicable at some areas or universally. In the case of fish models, the most important calibration data is the fish study data that was used in making the habitat suitability index curves. The calibration of the biological model is carried out by the selection of variables used, and by the making or selection of the preference curves, and the calibration of the physical model is carried out by calibrating the hydraulic model. At Laukka area of Oulujoki River, river topography was measured, which means that calibration of the whole of the model including the physical model could be tested. Original fish observation data was available for testing the effect of using different types of data and of different methods of making preference curves. Telemetry data and log book markings of fish positions were available (Figures 3.32-3.36). The most suitable set of data of Vehanen et al. (1998, 2003), from telemetry, was left for model validation, because the data is the set that normally would be selected as calibration material. The model was validated in Chapter “Validation of the model”.

Description of the area and the organism studied

The area is located on the River Oulujoki in Northern Finland at latitude 64°51' north and longitude 25°55' east, between the Montta and Merikoski hydro power plants (Figure 3.34). The average discharge is about 254 m^3/s, MHQ 508 m^3/s, HQ 779 m^3/s, MNQ 61 m^3/s, and NQ 18 m^3/s. The river is short-term regulated; the discharge is highest during the daytime, normally 150-450 m^3/s, and at least 50 m^3/s during the night. The catchment area of the river is 22925 km^2 and the lake percentage is 11.4%. The modelled area is about 550 metres long, and the width of the river is about 150 metres. The river section was dredged earlier for log transport. A habitat rehabilitation (Yrjänä et al. 1999) was carried out in the early summer of 1997. In the rehabilitation, e.g. the south bank and the artificial island (Figure 3.31) in the middle of the channel were converted to shallow reefs. The average depths before rehabilitation were 1.76 and 2.17 m and the average flow velocities were 0.32 and 0.58 m/s for discharges of 110 and 300 m^3/s respectively. The organism modelled was adult grayling *(Thymallus thymallus)*. It prefers mild to moderate flow velocities, especially the borderlines of slow and fast flow velocities. The substrate does not play a very significant role in its habitat selection.

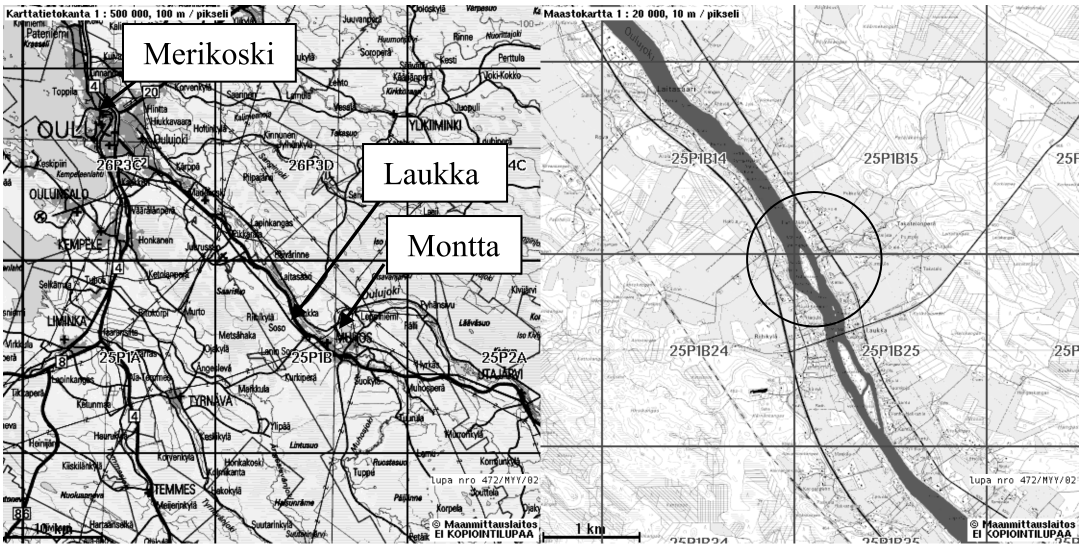


Figure 3.31 The location of the Laukka area.

Preference curves

Adult grayling *(Thymallus thymallus)* was modelled with two different types of preference curves (Figures 3.34-3.36): 1) curves from much smaller rivers (Greenberg et al. 1994), and 2) physiological, universal-type curves (Hubert et al. 1985) from another continent, using observation data from both rivers and lakes to see how each of them can be applied.

The preference curves of Hubert et al. (1985) are based on data from North America and there are also some data from the Eurasian continent. They were made for a sister species of *Thymallus Thymallus,* namely *Thymallus arcticus*. The environmental demands of these two species are thought to be quite similar Northcote (1995). The curves were made with knowledge of habitat use in rivers and lakes. The preference curves of Hubert et al. may be too general for predictions of fish habitat selection in rivers, because zero velocities are assumed to be suitable, because in lakes, grayling may use this kind of habitats. If the curves had been made from information from rivers only, in the source text it was said that the average flow velocity used in rivers was 0.27 m/s (Hubert et al. 1985, Elliot 1980). In rivers, flowing water is known to carry nourishment to fish, and therefore, there exists an optimal flow velocity range that does not include the value zero. Thus, the flow velocity suitability curve may not be suitable for use in rivers.

The curves of Greenberg et al. (1994) are made on the basis of data from small rivers, in which only shallow water depths were found, where the average flow velocities used by the fish were lower. Grayling have been noticed in literature to favour also and often prefer relatively fast flowing sections (Nykänen & Huusko 1999), and in a study in northern Finland during spring and summer (Nykänen 2004). In both curves, relatively low flow velocities are preferred, in the case of the curves of Hubert, because of the lake data, and in the case of the curves of Greenberg, because of the shallow river.

Preference curves made on the basis of the observations, the log book fishing data classified in Figure 3.32, are represented in Figure 3.33. The use of different water depths did not change very much from May to July. Probably because grayling use lower flow velocities during winter (Hubert et al. 1985), the flow velocities used after rehabilitation in June were higher. The samples were relatively small – before rehabilitation 31 fish and after rehabilitation 14 – thus the flow velocity curve produced is rather coarse. The suitable area seems to be from 0.1 to 0.8 m/s, which coincides well with the curves of Vehanen et al. (1998, 2003), but not with the curves of Hubert et al. (1985). The activity of the fish, e.g. feeding vs. resting, affects the preferences. The preference curves of Greenberg et al. are based on diving, the curves of Vehanen et al., used later in model validation, are based on fish telemetry, and the curves of Hubert et al. on the literature, i.e. they all mostly present average living habitats, whilst the observed values may represent more feeding habitats.

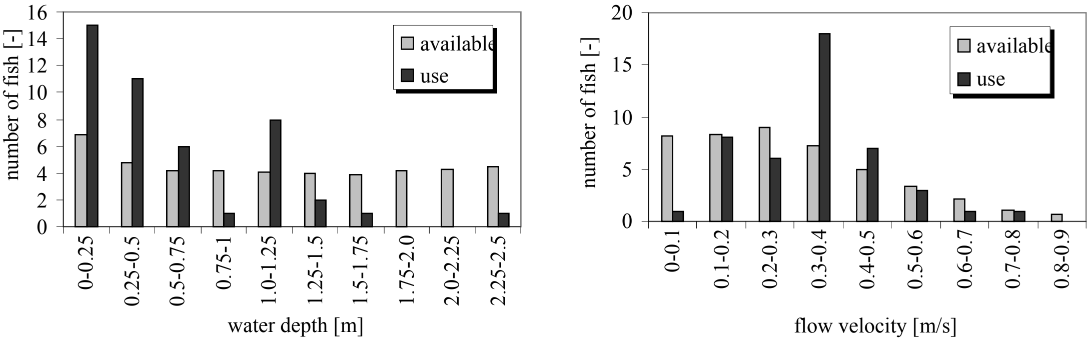


Figure 3.32 Available habitat and habitat use according to log book fishing in the Laukka area, water depth [m/s], and flow velocity [m/s].

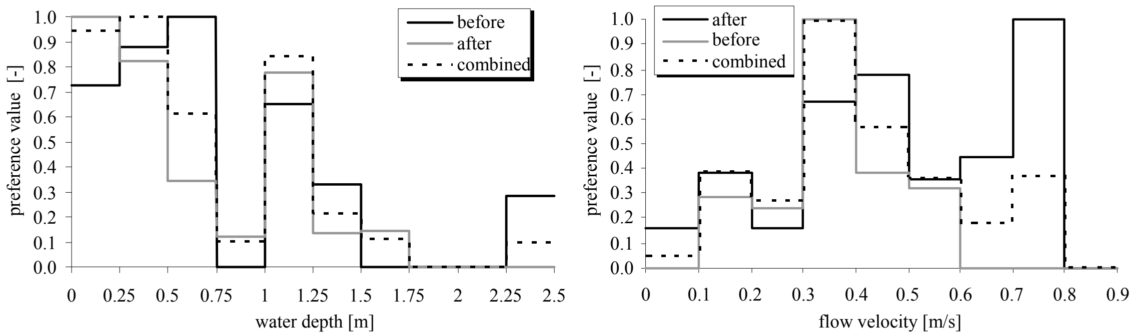


Figure 3.33 Preference curves for water depth and flow velocity, made on the basis of fish observations and the availability of habitats before rehabilitation (darker line), after rehabilitation (lighter line), and a combined curve (dashed line).

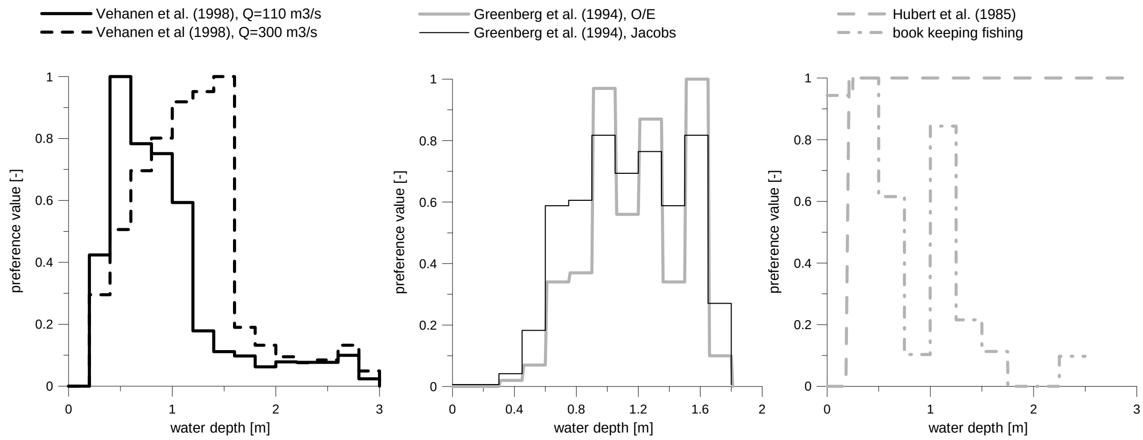


Figure 3.34 The preference curves for water depth (m) by Vehanen et al. (1998, 2003), Greenberg et al. (1994) with Jacobs's method, and the traditional method by Hubert et al. (1985) and from log book fishing.

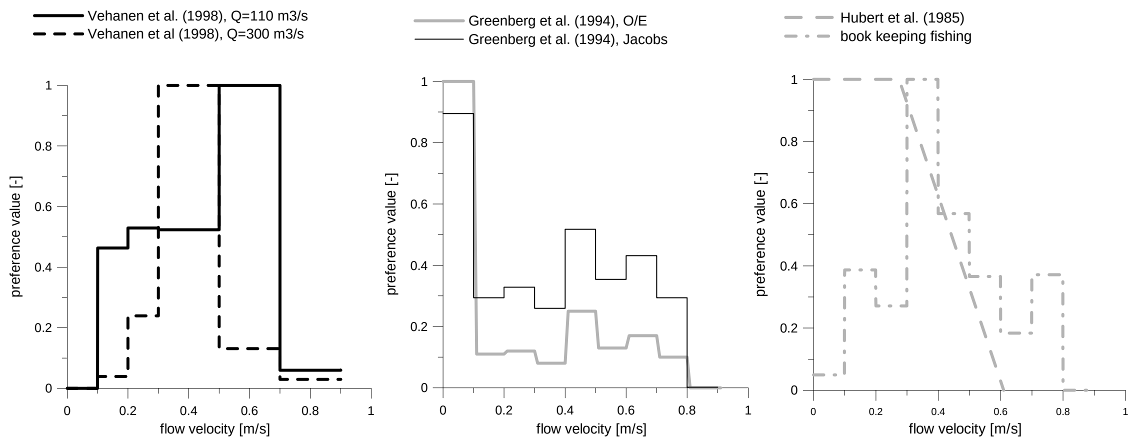


Figure 3.35 The preference curves for flow velocity (m/s) by Vehanen et al. (1998, 2003), Greenberg et al. (1994) with Jacobs's method and the traditional method, Hubert et al. (1985), and from log book fishing.

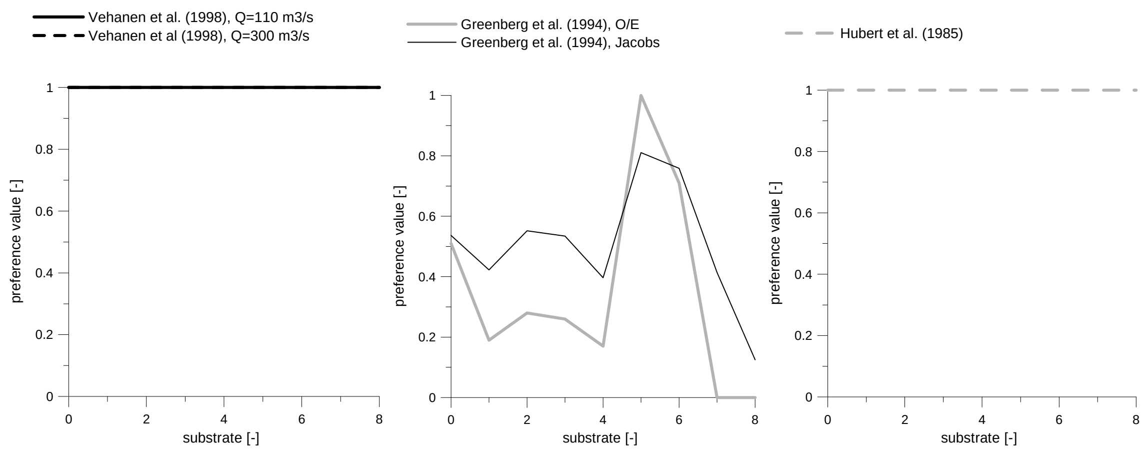


Figure 3.36 The preference curves for substrate (-) (classification in a numerical order: <2, 2.1-8, 8.1-16, 16.1-32, 32.1-64, 64.1-128,128.1-256, 256.1-512, and >512 mm) by Vehanen et al. (1998, 2003), Greenberg et al. (1994), and Hubert et al. (1985).

Measurements and modelling

Field measurements of the Laukka area had been carried out with echo sounding and tacheometer. Flow velocity cross-sections were also measured. The river bed topography was measured before the rehabilitation with line measurements with a tacheometer from the rehabilitated areas. After rehabilitation, the topography was measured over a larger area with echo sounding equipment, together with DGPS mapping equipment (Kemijoki Oy, Vehanen et al. 2000) from deeper areas and the shallow areas, and the reefs that had been constructed, the depths of which were 0.5-1.0 m, were measured with a tacheometer. In hydraulic modelling, a larger area was needed, so the measurements taken after rehabilitation outside the rehabilitated area were also used in the hydraulic model for the situation before rehabilitation. The substrate was classified according to a modified Wentworth scale using nine categories (<2, 2.1-8, 8.1-16, 16.1-32, 32.1-64, 64.1-128,128.1-256, 256.1-512, and >512 mm). The classification was made by using a glass viewing device (depth 0-1.2 m), or by probing with a long rod when water depths exceeded 1.2 m. In the latter cases the classification was checked at several measurement points by diving. In the modelling, weights of 0.2, 0.4, and 0.4 were used for the preference values of the coarsest, the most common, and the second most common substrate respectively. The hydraulic modelling was carried out with the hydraulic modelling interface SMS (Brigham Young University 1997) and the calculation program RMA2 (US Army Corps 1996). The calibration before restoration was performed using averaged current velocities of 300 measurement points originally measured with a Schiltknecht Mini Water flow meter at 0.2, 0.6, and 0.8 times the depth from the bottom at a flow of 66 m^3/s in June 1996 (Yrjänä et al. 1999). The calibration after restoration was performed by using data collected with Acoustic Doppler Current Profiler equipment in June 1997 at flows of 110 and 300 m^3/s. The flow situations modelled were 50, 110, 200, 300, and 450 m^3/s, covering the normal range at the site. Habitat values were calculated for these situations. Because fish observations were made at different flows, habitat values during the observations were interpolated from those calculated. The habitat model consisted of a grid of 100 * 100 calculation points. The dimensions of a cell were 5.46 * 3.46 metres.

Observations

The fish observations (Figure 3.32) were gained from fishermen's log book with a map while fishing (Leinonen 1999) during the summers of 1996, 1997, and 1998. The places and times of catching were marked on a map in situ. The fish were mapped from quite a high bridge and from the river bank, so the positions could not be marked very precisely on the map. The width of the river exceeds 100 metres and the estimated precision of mapping was 10 metres (Yrjänä 2002). The islands probably helped in positioning the places where fish were caught, so the precision may be somewhat higher on average. It may be that the fishermen prefer areas easily accessible which may reduce the effective sample size. The number of fish observations May 5 to 31, 1996 before the rehabilitation was 31, during the rehabilitation May 25 to June 20, 1997 12, which were not used, and after the rehabilitation July 2 to August 10, 1997 the number was 14.

Calculation of habitat use and availability

The discharge in the area for each fish-catching moment was calculated with a dynamic one-dimensional hydraulic model developed and set up by Forsius (1984). The habitat values for each flow situation were interpolated from habitat values calculated for those five flow situations modelled with the two-dimensional hydraulic model. Habitat availability was obtained by calculating distributions for each fish-catching moment and adding them together. This could be done, because e.g. the different situations can be thought to be like different types of river sections, i.e. to be parts of a longer river, whilst the phenomenon studied remains the same. Because of additivity in chi-square tests, e.g. Spiegel 1972, the distributions from the same phenomenon can be added together. Though, grayling take territories, it may also shoal, which may reduce the effective number of observations. Because the properties of the area before and after the rehabilitation are different, only the data before rehabilitation with a sufficient number of observations was used in testing.

Results

Greenberg et al. (1994)

To see whether preference curves from a much smaller river (mean flow 4 m^3/s) could be used in modelling a larger river (MQ 259 m^3/s), converted Swedish curves of Greenberg et al. (1994) were tested in the Laukka area. Problems in prediction may occur because of different water depths and vertical flow velocity distributions in the rivers. The curves were originally made with Jacobs's method and were converted to the traditional habitat use / habitat availability -scaling. The results are shown in Figure 3.37 and Table 3.1. As can be seen in Figure 3.37, the prediction of the fish positions is fairly good, although all habitat values are lower than usual. Tests of significance and available habitats and habitat use and proportion of use to availability are represented in Table 3.1 and Figure 3.38.

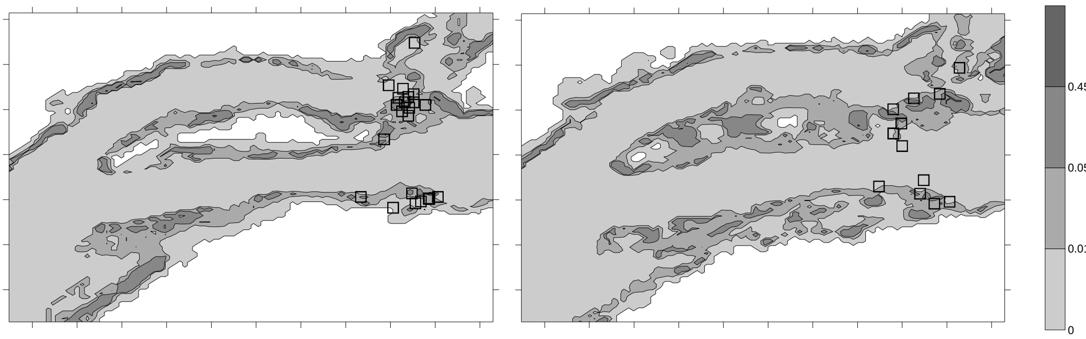


Figure 3.37 The habitat value map calculated with the preference curves of Greenberg et al. (1994) before rehabilitation when Q=110 m^3/s and fish observations during Q=56-242 m^3/s and after rehabilitation when Q=200 m^3/s, and fish observations during Q=70-257 m^3/s. The fish caught are shown with squares.

Table 3.1 Available habitat and habitat use calculated with the preference curves of Greenberg et al. (1994) before rehabilitation in the Laukka area and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0	23.98	6	0.25	13.48	12.74	-16.62	
0-1	7.02	25	3.56	46.01	43.49	63.48	
sum	31	31	high/low	59.49	56.23	46.86	46.11
			14.22	<0.0001	<0.0001	<0.0001	<0.0001

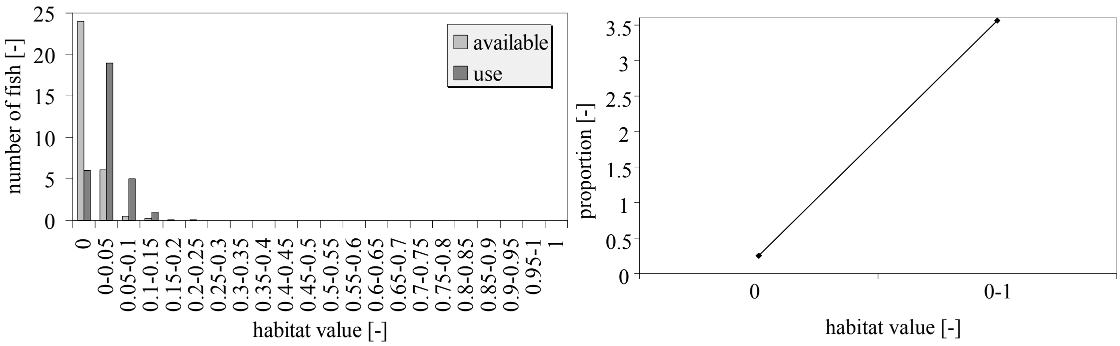


Figure 3.38 Distributions of available habitat and habitat use calculated with the preference curves of Greenberg et al. (1994) before rehabilitation in the Laukka area. On the right proportions of habitat use to available habitat.

Greenberg et al. (1994) with Jacobs's method

The same calculations were carried out with the original preference curves (Greenberg et al. 1994) made with Jacobs's method. The results are shown on the map in Figure 3.39. Tests of significance and available habitats and habitat use and proportion of use to availability are represented in Table 3.2 and Figure 3.40. The preference curves made with Jacobs's method produced more accurate estimations of habitat use than the curves made by traditionally dividing habitat use by habitat availability.

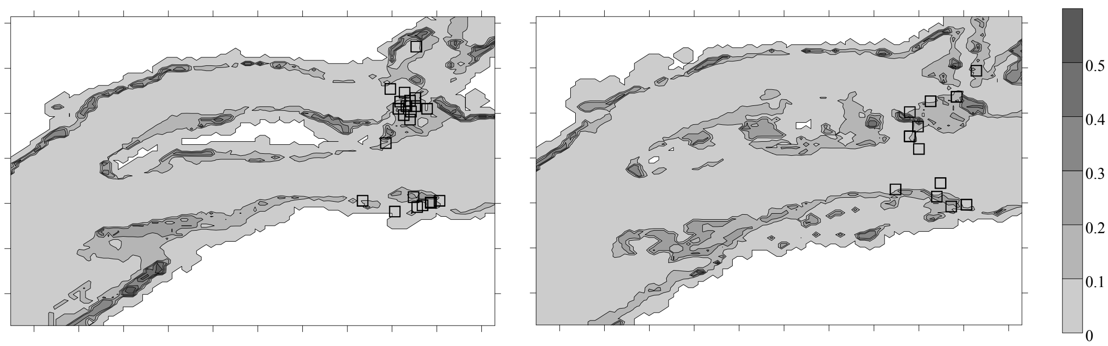


Figure 3.39 The habitat value map calculated with the preference curves of Greenberg et al. (1994) with Jacobs's method before rehabilitation when Q=110 m^3/s and fish observations during Q=56-242 m^3/s and after rehabilitation when Q=200 m^3/s and fish observations during Q=70-257 m^3/s. The fish caught are shown with squares.

Table 3.2 Available habitat and habitat use calculated with the preference curves of Greenberg et al. (1994) with Jacobs's method before rehabilitation in the Laukka area and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.002	15.83	2	0.13	12.08	11.23	-8.28	
0.002-1	15.17	29	1.91	12.61	11.72	37.59	
sum	31	31	high/low	24.70	22.94	29.31	28.85
			15.13	<0.0001	<0.0001	<0.0001	<0.0001

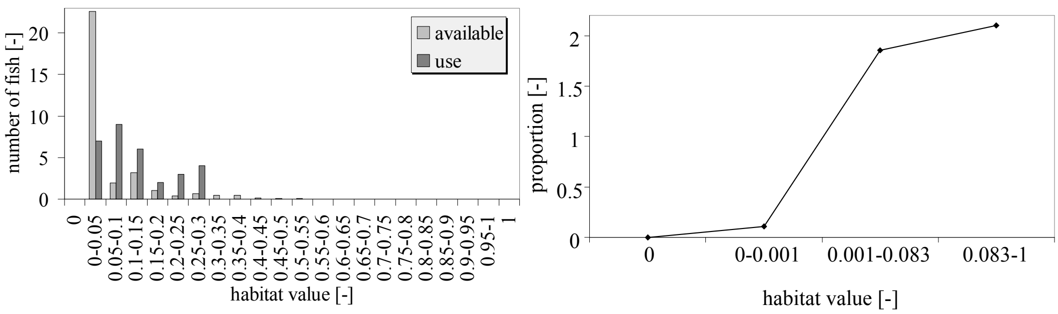


Figure 3.40 Distributions of available habitat and habitat use calculated with the preference curves of Greenberg et al. (1994) with Jacobs's method before rehabilitation in the Laukka area. On the right proportions of habitat use to available habitat.

Hubert et al. (1985)

American general literature-based physiological-type curves were also tested. The fish observations and the habitat value map at a flow rate of 110 m^3/s are shown in Figure 3.41. Visually, the fish seem to prefer any other habitat values than the highest and the lowest. The results are shown in Table 3.3 and Figure 3.42.

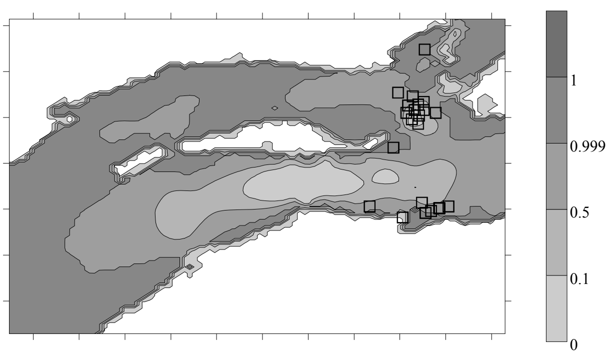


Figure 3.41 The habitat value map calculated with the preference curves of Hubert et al. (1985) before rehabilitation when Q=110 m^3/s and the fish observations during Q=56-242 m^3/s. The fish caught are shown with squares.

Table 3.3 Available habitat and habitat use calculated with the preference curves of Hubert et al. (1985) before rehabilitation in the Laukka area and goodness of fit tests.

habitat value	available	use	Proportion	Pearson	Yates	log-likelihood	Williams
0-1	15.33	28	1.83	10.47	9.66	33.73	
1	15.67	3	0.19	10.24	9.45	-9.92	
sum	31	31	high/low	20.71	19.11	23.81	23.43
			0.10	-<0.0001	-<0.0001	-<0.0001	-<0.0001

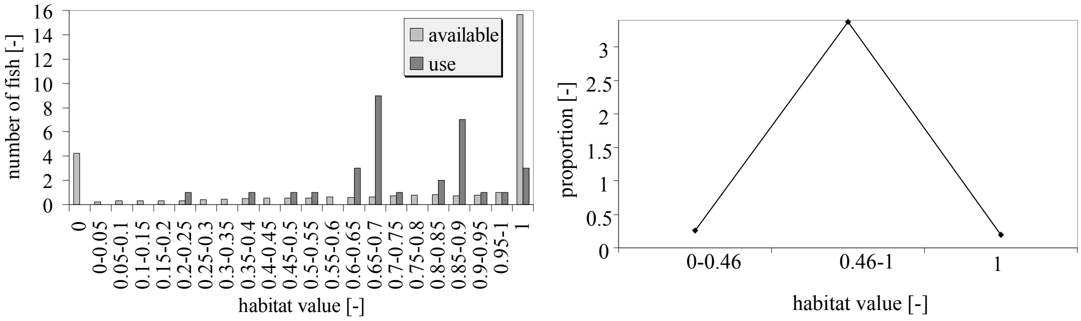


Figure 3.42 Distributions of habitat use and habitat availability calculated with the preference curves of Hubert et al. (1985) before rehabilitation in the Laukka area. On the right proportions of habitat use to available habitat.

Summary

The curves of Greenberg et al. from a much smaller river yielded a good prediction of suitable and unsuitable habitats; also visually analysing from the map, the prediction with the curves from Greenberg et al. was again good. The curves of Hubert et al. were too general for predictions of habitat selection in rivers, as was supposed. It still seemed that totally unsuitable habitats could be assessed with preference curves that were also in some sense unsuitable, even if the most suitable habitats could not be told apart from the suitable. There is a remarkable difference between the preference curves for flow velocities of Greenberg et al. (1994) and the locally determined telemetry curves of Vehanen et al. (1998, 2003). In the shallow brooks of the River Vojmån in Sweden, fish were found in places with small mean column velocities, but in the deep Laukka area, faster-flowing places could be preferred, perhaps because the greater depth could allow the fish to select places with smaller nose velocities with the same mean column values (Yrjänä 2001). In Figure 3.35, the preference curves for flow velocity of Vehanen et al. (1998, 2003), Greenberg et al. (1994), and Hubert et al. (1985) are shown. As can be seen, in larger rivers, higher mean column velocities are used, which means that the flow velocity values in the preference curves from the study from the small brooks might be too low to be used in the Laukka area. Although the Swedish river was much smaller, e.g. its average discharge was 60 times smaller it was possible to predict the differences between unsuitable and suitable habitats with the curves.

3.1.2.3 Pyhäkoski impoundment

Original fish observation data was available. A set of data from early winter was used in making habitat suitability indices. There was also a set of data from summer available, but it was left for use in the model validation, because it consisted of a larger amount of observations. Seven different methods of calibrating the model with biological data were studied; five of these were different methods of making preference curves and two of making preference surfaces. Habitat value calculations were carried out with two of these: preference curves made with dividing habitat use by habitat availability and a preference surface was constructed with Jacobs's method.

Description of the area

The Pyhäkoski impoundment is located on the River Oulujoki near the town of Muhos in Northern Finland at 64°51N, 26°07E (Figure 3.43). The catchment area is about 20000 km^2 and the lake percentage about 12. The length of the impoundment between the Pyhäkoski and Pälli hydro power plants is 8680 metres. The width of the river in the more river-like upper part is about 50 metres, but in the deeper downstream part, the width is a maximum of about 300 metres. The average depth at a discharge of 400 m^3/s is 6.1 metres in the upper part, the maximum being 12.3, in the middle part 9.7, the maximum being 20.6, and in the lower part 15.1 metres, the maximum being 34.8. The daily average discharges at the upper power plant varied between 58 and 479 m^3/s during October 6, 1999 to June 20, 2000, the average being 250 m^3/s. The 10 and 90% fractiles of water levels were NN+ 56.20 m and NN+ 56.40 m, so the fluctuations in water levels were small. Short-term regulation changes the discharge daily so that it is at its highest during the day. At a discharge of 400 m^3/s, the flow velocities are a maximum of 1.4 m/s in the upper part, but in the lowest part, the flow velocity is mostly between 0.1 and 0.2 m/s. In the middle part, the flow velocity is between 0.3-0.7 m/s.

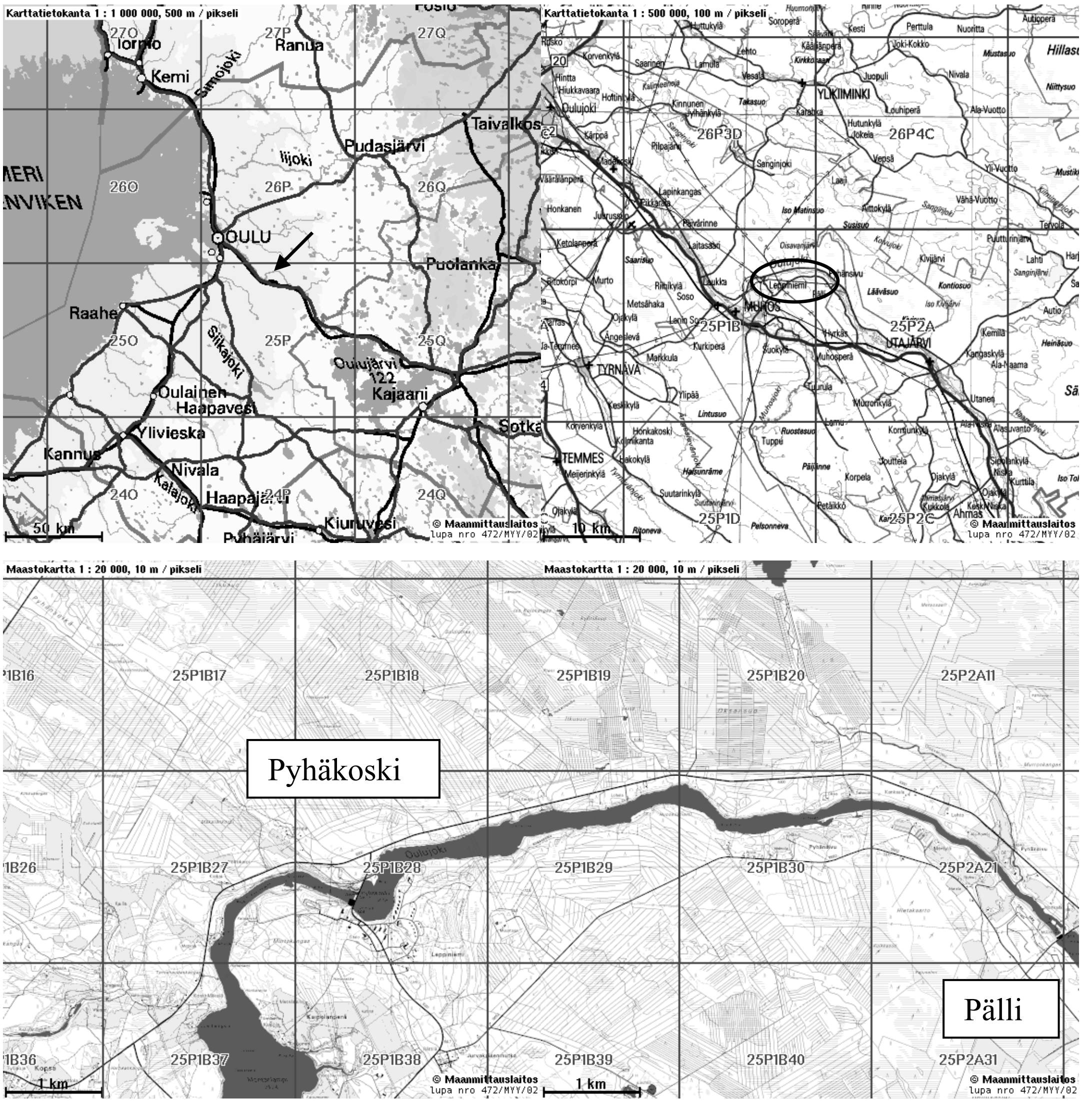


Figure 3.43 Location of Pyhäkoski impoundment.

The organism studied and the biological data

Pikeperch (*Stizostedion lucioperca*) was observed using telemetry. The pikeperch were caught from Lake Oulujärvi and moved to the Pyhäkoski impoundment in June 1999 (Vehanen & Lahti 2003). Five of the 20 fish were left in the impoundment in the winter. The others had e.g. moved to other impoundments. The locations of fish were observed from a boat with the telemetry equipment. The observations continued through the winter. Habitat value calculations were carried out for winter habitats. Observations from November 5, 1999 to January 27, 2000 were used to test winter habitat modelling. No shoaling was observed.

Testing the model

The fish telemetry observations of pikeperch were divided into two parts of equal size. The first observations were used for habitat preference curves, the latter for comparison with modelled habitats. Winter preference curves are shown in Figures 3.48-3.50. The observations during January 27, 2000 to April 10, 2000 were used as test data. The mean discharge during the observations used for making preference curves was 289 m^3/s and during the observations of the test data 458 m^3/s. So this study can also be used to study whether a change in discharge or season affects the modelling. Because the observations in the preference and test sets of data were of the same fish individuals and some observations were temporally close to each other, the effective sample size was reduced. Variability induced by the individuality of the behaviour of fish individuals and by temporal independence of observations was reduced. However, the distances moved between observation places were studied by Vehanen & Lahti (2003) and the fish were observed to daily move long distances which add to the variability. Still, some serial correlation was found and because the effective number of observations was lower than the required, the set of data was not used in validation, but was used in testing in this section.

Results

The observations from which the preference curves were made and a habitat value map calculated with preference curves made from observations during the same, the first period (May 11, 1999 to January 27, 2000), at an average flow (289 m^3/s) are shown in Figure 3.44. The fish were almost exactly in the habitats with the highest calculated habitat suitability values. Because these data were not used in model validation; no statistical tests were carried out. A habitat value map calculated with preference curves made from observations during the first period (November 5, 1999 to January 27, 2000) at an average flow (289 m^3/s) for that period and fish observations during January 27, 2000 to April 10, 2000 with an average flow rate of 460 m^3/s are shown in Figure 3.45. The distributions and proportions are shown in Figure 3.46. The fish preferred selecting the habitats with the highest suitability index values quite well, but favoured greater depths as the winter went on and the discharge became larger than during the period when the preference curves were made. A change in discharge or season, or both, affects the preference of the fish. But the modelling still yielded a good prediction of habitat use. With these preference curves, the fish were found in areas with higher habitat values. This is despite the fact that the values preferred by the fish in the preference curves made in the early winter were somewhat different from those of late winter, when the fish switch to deeper habitats. By comparing Figures 3.44 and 3.45 with each other, a shift towards the deeper areas can be seen towards the end of the winter and as the discharge increases. The mean depth used by the fish during the first period was 7.62 metres and 14.06 metres during the latter one. The correlation between the date and depth was higher (0.48) than between the depth and discharge (0.45).

Because the fish moved to deeper areas a month after the discharge was increased, it could be assumed that it either took a month for the fish to find new places for the new flow situation or that the shift to deeper habitats was due to the seasonal changes, which is more probable. The discharge was high when the air temperature was low, because of the needs of electricity production. Pikeperch have been noticed to switch to deeper habitats in winter in many studies (Vehanen & Lahti 2003).

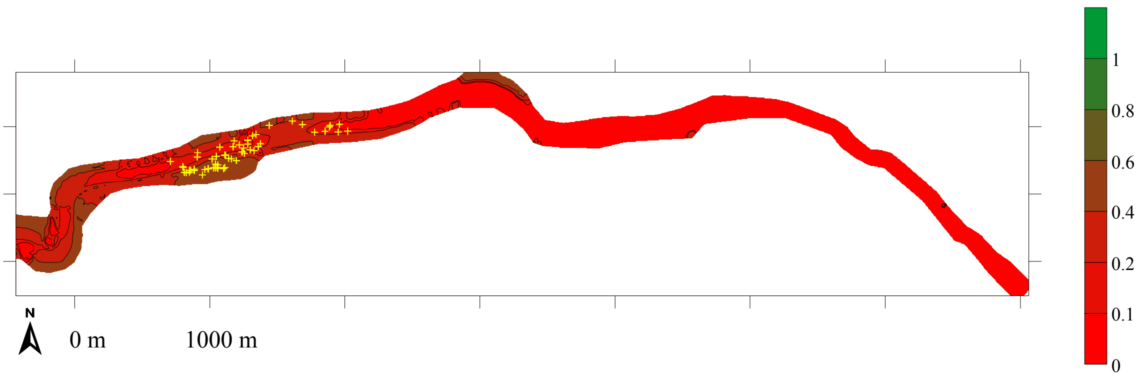


Figure 3.45 A habitat value map calculated with preference curves made from observations during November 5, 1999 to January 27, 2000 at an average flow (460 m^3/s) for the second period and fish observations during January 27, 2000 to April 10, 2000.

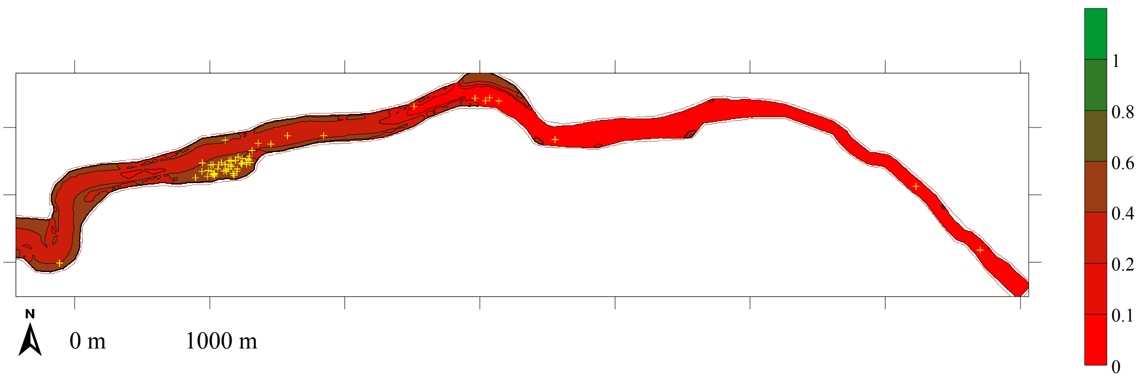


Figure 3.44 A habitat value map calculated with preference curves made from observations during November 5, 1999 to January 27, 2000 at an average flow during the first period (289 m^3/s) and fish observations during the same period.

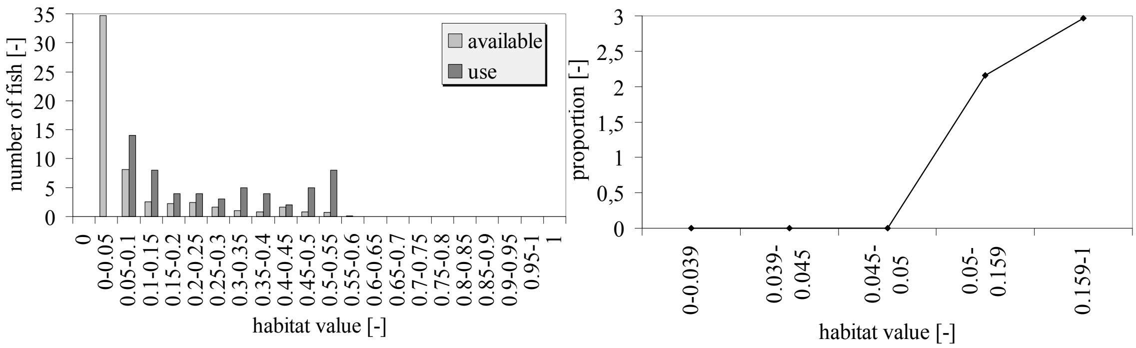


Figure 3.46 Distributions of available habitat and habitat use and proportions of available habitat to habitat use January 27, 2000 to April 10, 2000 calculated with preference curves made from observations during the November 5, 1999 to January 27, 2000 at the Pyhäkoski impoundment. The number of fish individuals observed is too small for validation.

Methods for calculation of preference curves

Different methods of making preference curves were studied with the early winter pikeperch data from the Pyhäkoski basin. Water depth and flow velocity were picked from the hydraulic model data from the 57 places where pikeperch had been observed. The habitat availability was calculated for the whole basin for each fish-catching moment. The distributions are shown in Figures 3.47 and 3.49. Preference curves (Figures 3.48 and 3.50) were calculated from these.

The effects of different calculation methods were studied: the traditional use/availability method, Jacobs's selectivity index, division by uniform availability or interval, and the effect of the number of observations per class were tested. A comparison shows that the selection between using uniform availability or uniform interval made the biggest difference between the curves. When using uniform availability, the number of expected observations in each class is controlled and the curves should be more reliable. This suggests that when data are sparse, the traditional method of having uniform intervals should be replaced with the method of division by a uniform availability. However, the classes should be selected so that a single class wouldn't cover too large a range of different conditions. Special attention should be given to flow velocity values near zero.

Curves made with Jacobs's method did not have such large highest values as curves produced with the use/availability method.

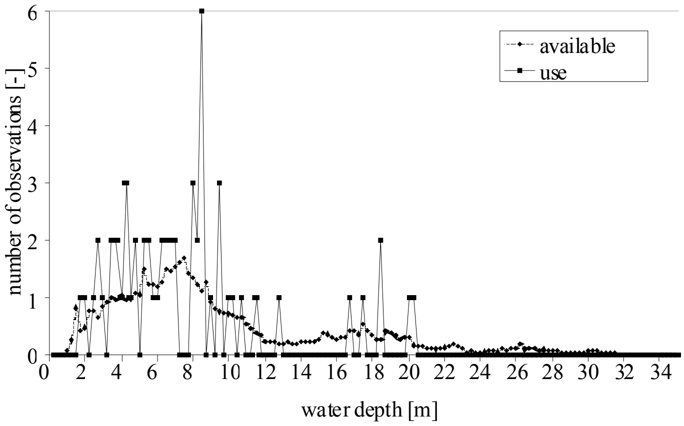


Figure 3.47 Available habitats and observed use of water depth at the Pyhäkoski impoundment.

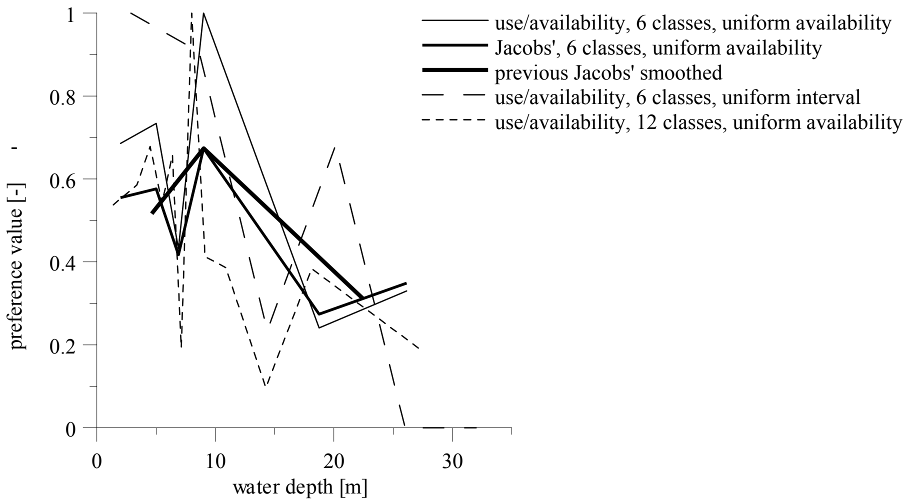


Figure 3.48 Preference curves for water depth made from observations November 5, 1999 to January 27, 2000 based on data from Vehanen & Lahti (2003) with different methods: traditional use/availability with six classes with uniform availability, the same with Jacobs's method, previous smoothed supposing existence of an optimum, use/availability with 6 classes with a uniform interval, and use/availability with 12 classes with uniform availability.

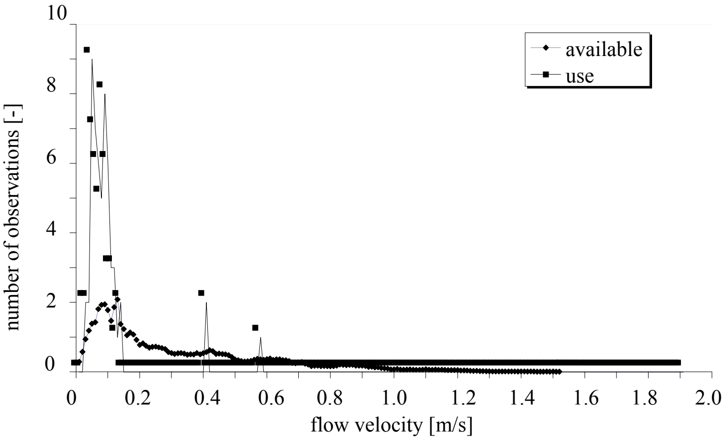


Figure 3.49 Available habitats and observed use of flow velocity at the Pyhäkoski impoundment.

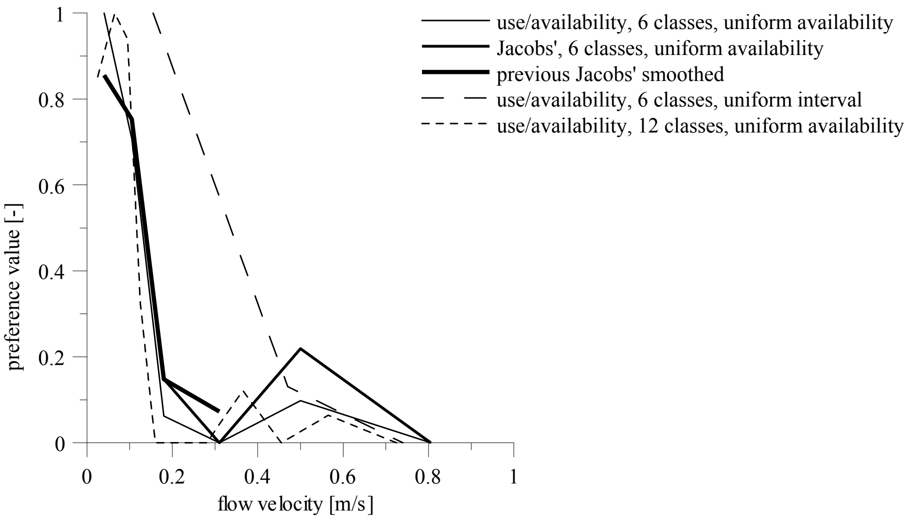


Figure 3.50 Preference curves for mean column velocity made from observations November 5, 1999 to January 27, 2000 based on data from Vehanen & Lahti (2003) with different methods: traditional use/availability with six classes with uniform availability, the same with Jacobs's method, previous smoothed supposing existence of an optimum, use/availability with 6 classes with a uniform interval, and use/availability with 12 classes with uniform availability.

A preference surface

Calculation with preference surfaces was also tested with the Pyhäkoski basin data. The fish observation data (November 5, 1999 to January 27, 2000) were sorted as pairs of values of water depth and flow velocity. The distributions of the values of the variable pairs were calculated for each fish-catching moment to get the distribution of available habitats. The observed values were obtained by taking the values of the nearest calculated point to each fish observation point. After that, the preference surface was calculated with Jacobs's method and normalised so that the average value was 0.5. The calculations were made by using the midpoints of the classes and triangulation. Habitat availability and habitat use were smoothed before using Jacobs's formula by taking the averages of the cell and the eight adjacent cells. The resulting preference surface is shown in Table 3.4 and in Figure 3.51. More data would have been needed, e.g. a separate suitable area with high flow velocities may not be biologically reasonable. A further smoothed surface is also shown in Figure 3.51. A smoother surface could also be created with other methods, e.g. by dividing the two-dimensional space formed by the variables into larger areas before comparison of use and availability or with mathematical spatial smoothing software.

Habitat value calculations were carried out (Figure 3.52) with the first multivariate preference function with the Pyhäkoski basin observation data. When making preference curves from a set of data, more data are usually available per a value interval of a variable than when making a surface. With preference curves, the resulting combined habitat suitability values are more similar to each other in the direction of the axes because of the multiplication in the habitat value calculation formula (Figure 3.53). This may be beneficial if the habitat preference depends much more on one variable than on the others. For example, if the fish choose their positions primarily according to flow velocity and a preference surface is then constructed from scant data randomness in the data may e.g. cause a preference surface with multiple minima and maxima. However, the result of the action of multiple variables can potentially be described more accurately with preference surfaces. If these are constructed carefully, more precise predictions should usually be achieved.

Table 3.4 A preference surface made from observations during the period (November 5, 1999 to January 27, 2000) at the Pyhäkoski impoundment with the classes smoothed once and then calculated with Jacobs's method. The variables are flow velocity (v, m/s) and water depth (d, m).

		v								
		0-0.05	**0.05-0.1**	**0.1-0.15**	**0.15-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**
d	**0-1**	0.80	0.78	0.80	0.36	0.00	0.00	0.00	0.00	0.00
	1-3	0.85	0.81	0.79	0.39	0.00	0.00	0.00	0.00	0.00
	3-5	0.85	0.81	0.76	0.38	0.00	0.00	0.00	0.00	0.00
	5-7.5	0.88	0.83	0.75	0.30	0.00	0.06	0.13	0.15	0.13
	7.5-10	0.85	0.79	0.69	0.22	0.00	0.13	0.21	0.23	0.15
	10-12.5	0.82	0.72	0.61	0.00	0.00	0.23	0.38	0.40	0.29
	12.5-15	0.58	0.42	0.28	0.00	0.00	0.24	0.44	0.47	0.00
	15-17.5	0.47	0.42	0.36	0.22	0.00	0.00	0.00	0.18	0.23
	17.5-20	0.30	0.35	0.31	0.30	0.00	0.00	0.00	0.00	0.14
	20-22.5	0.15	0.33	0.35	0.44	0.00	0.00	0.00	0.00	0.05

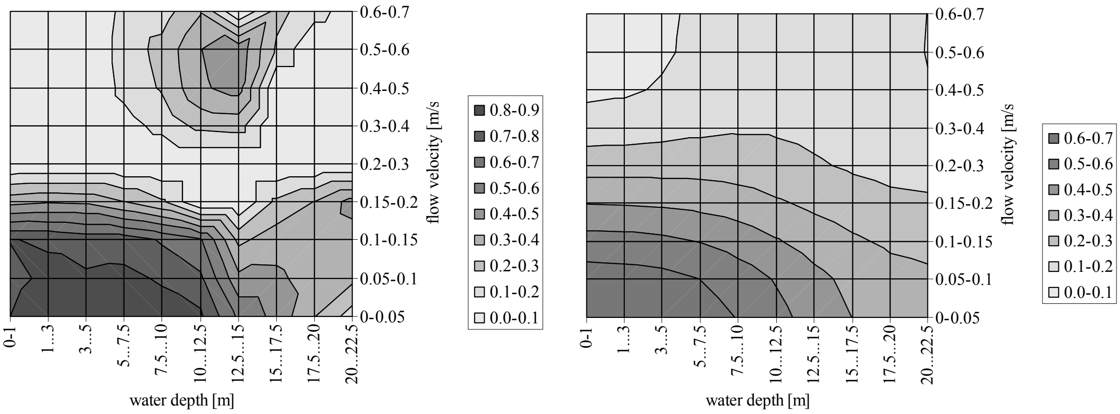


Figure 3.51 A preference surface made from observations during November 5, 1999 to January 27, 2000 at the Pyhäkoski impoundment with small classes calculated with Jacobs's method and a preference surface made by additionally smoothing the previous surface six times by taking an average of the cell and the surrounding eight cells.

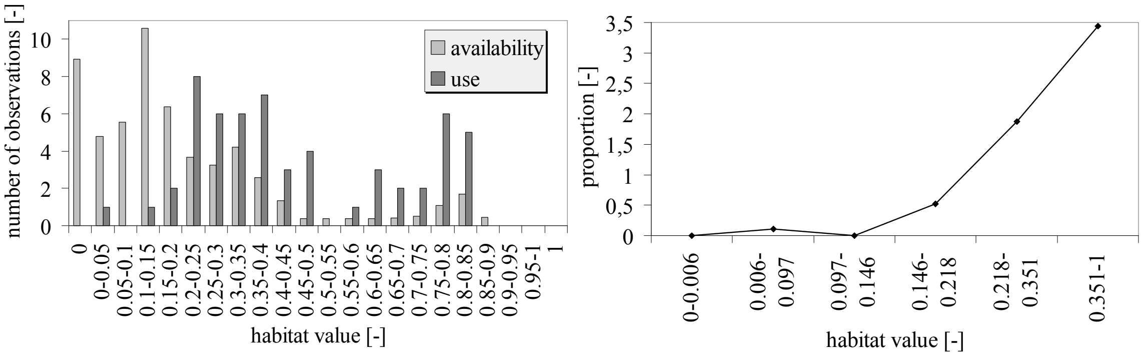


Figure 3.52 Available habitat and habitat use and proportion of use to availability for fish occurrences January 27, 2000 to April 10, 2000 calculated with a preference surface made from observations during the period (November 5, 1999 to January 27, 2000) with Jacobs's method at the Pyhäkoski impoundment.

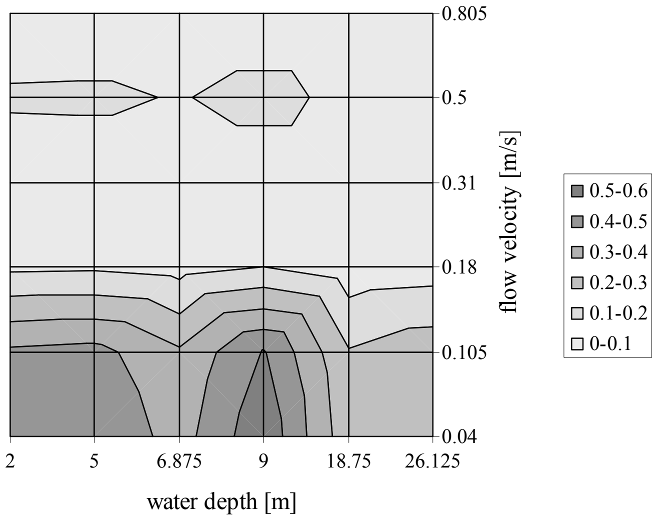


Figure 3.53 A preference surface resulting in habitat value calculation (multiplication) procedure from the preference curves represented in Figures 3.61 and 3.63.

3.1.3 The whole of the fish model

3.1.3.1 Residuals of modellings

River Simojoki

In order to check whether the model created describes the phenomenon, the residuals of the results of modellings at model validation (Figure 5.6a) at River Simojoki were calculated. A linear regression line was drawn, and the residuals compared to it were calculated (Figure 3.54). It can be seen, that the residuals are random, as they should, when the model describes all but the random variation. On the other hand, it may be possible, that there are multiple unknown factors causing the residuals, which are not known, but which could be explained by the model. A part of the variation is caused by inaccuracy in the observation data, not by model variation, because especially locating fish and measuring flow velocity are not precise. Also, the model measures habitat quality, whereas the habitat selection of e.g. salmonids is dynamic.

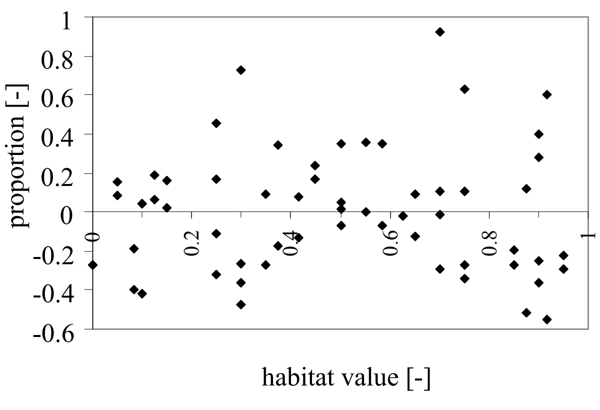


Figure 3.54 Residuals of modelling *Salmo salar* at River Simojoki represented in Chapter “Validation of the model”.

River Ala-Koitajoki

The residuals were calculated at Ala-Koitajoki (Figure 5.12) also. A logarithmic function was fit to the data (Figure 3.55). The river Ala-Koitajoki lies more southerly than River Simojoki, which might mean more nourishment and less harsh winter conditions leading to higher densities compared with northern conditions, from where the preference curves used in the modellings originate from. Denser population of the moderately good habitats could logically by explained by this (Rosenfeld et al. 2005). However, the densities of salmon at River Ala-Koitajoki were lower than at River Simojoki, but at River Ala-Koitajoki, the sum of the densities of salmon and trout was higher (Mäki-Petäys et al. 2002). Another reason might be that the linear relationship resulted because the curves were used in more similar type of conditions to those they originate from. The residuals seem to be randomly distributed. The residuals from modelling brown trout at River Ala-Koitajoki are shown in Figure 3.56. They seem to be random, however, the amount of data is low.

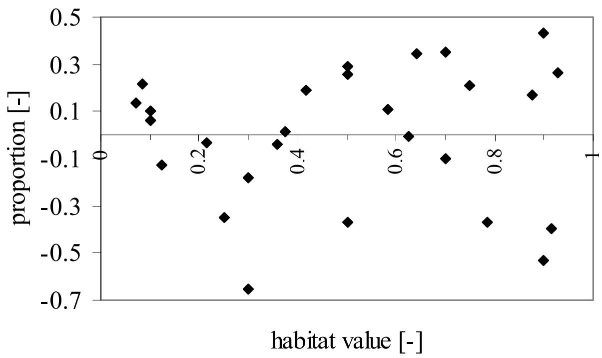


Figure 3.55 Residuals of modelling *Salmo salar* at River Ala-Koitajoki represented in Chapter "Validation of the model".

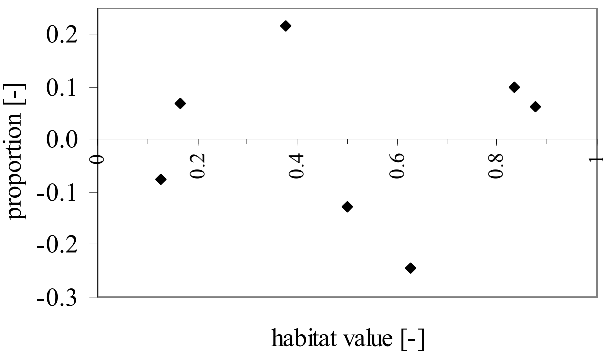


Figure 3.56 Residuals of modelling *Salmo salar* at River Ala-Koitajoki represented in Chapter "Validation of the model".

3.1.3.2 Prediction of fish abundance, biomass and position

To study the prediction of fish biomass, the observations were weighted with fish length and weight. With the two largest sets of data in the River Simojoki data, it was studied whether there would exist a relationship between fish length or biomass and habitat value. The fish biomass was calculated from an equation for *Salmo salar* (Binohlan 1995):

$$W = 0.0092*L^3, \tag{3.1}$$

where W is fish weight in grams and L fish length in centimetres.

Harrikoski Rapids

The prediction of habitat use was more accurate when observations were weighted with fish lengths; the significance was 0.001 (Table 3.5) and even better when weighted with weight (Table 3.6), 0.0002, compared with 0.003-0.002 without weighting. The proportions of biomass, fish length, and number of fish in the higher half of habitat values to the values in the lower half were 1.93, 1.78, and 1.7. No correlation between habitat value and the length or weight of individual fish was found at the Harrikoski Rapids (Figure 3.57). This could mean that larger fish didn't occupy solely the best habitats, but because the preferences change with fish size, no such conclusions can be drawn. The distribution of fish biomass was not observed to differ statistically significantly from the distribution of fish individuals. The average habitat value for fish of the size of 4-6 centimetres was 0.3990 and for fish of the size 7-9 centimetres 0.3996.

Table 3.5 Available habitat and habitat use and proportion of use to availability for salmon <10 cm weighted with fish length with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2995	68.86	49.52	0.72	5.43	5.16	-32.66	
0.2995-1	69.14	88.48	1.28	5.41	5.14	43.66	
sum	138	138	high/low	10.85	10.29	11.00	10.96
			1.78	0.001	0.001	0.001	0.001

Table 3.6 Available habitat and habitat use and proportion of use to availability for salmon <10 cm weighted with fish weight with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2995	68.86	46.95	0.68	6.97	6.66	-35.97	
0.2995-1	69.14	91.05	1.32	6.94	6.63	50.13	
sum	138	138	high/low	13.92	13.29	14.17	14.12
			1.93	0.0002	0.0002	0.0002	0.0002

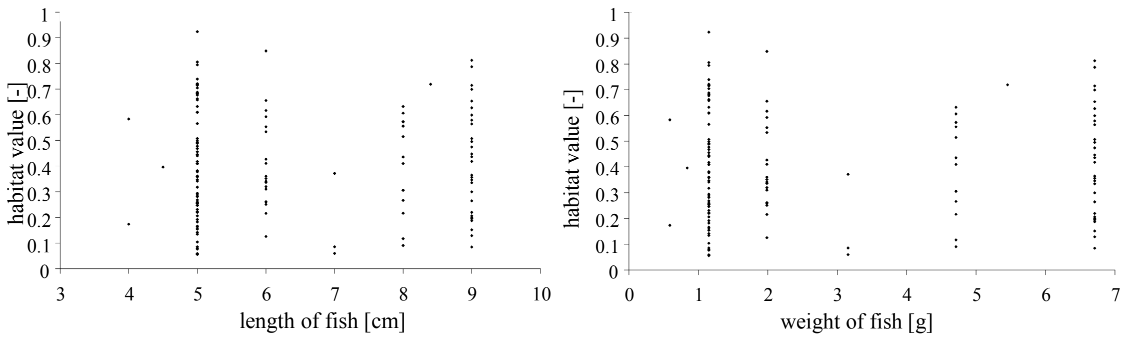


Figure 3.57 Habitat value as a function of fish length and weight of fish individuals at Harrikoski with the preference curves of Mäki-Petäys (2000).

Iso Tainikoski Rapids, lower study area

The prediction of habitat use was more accurate when observations were weighted with fish lengths (Table 3.7), the significance still being the same, 0.0001, and even better when weighted with weight (Table 3.8), >0.0001 compared with 0.0002 without weighting. The statistical significance of the difference of the p-values was not studied. The proportion of biomass in the calculated more suitable half of the habitat compared with the biomass in the less suitable half of the habitat was 3.91, which is clearly higher than the value calculated on the basis of the number of fish observed, 3.06. The proportion calculated with fish length was 3.21. A very weak and insignificant correlation between habitat value and fish weight was found at the Iso Tainikoski Rapids (Figure 3.58).

Conclusions

Biomass seemed to be predicted more accurately than density. Larger fish might get habitats of slightly higher quality or it may be that the preference curves do not work equally for differently sized fish between 4 and 9 centimetres. More studies are needed, because the differences noticed are relatively small, and the properties of preference curves may affect the comparison, because they may work differently in prediction of habitat use for different sized fish.

Table 3.7 Available habitat and habitat use and proportion of use to availability for salmon <10 cm weighted with fish length with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1993	28.44	13.51	0.47	7.84	7.32	-20.11	
0.1993-1	28.56	43.49	1.52	7.81	7.29	36.58	
sum	57	57	high/low	15.65	14.62	16.47	16.33
average			3.21	0.0001	<0.0001	<0.0001	<0.0001

Table 3.8 Available habitat and habitat use and proportion of use to availability for salmon <10 cm weighted with fish weight with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1993	28.44	11.57	0.41	10.01	9.43	-20.81	
0.1993-1	28.56	45.43	1.59	9.97	9.39	42.19	
sum	57	57	high/low	19.98	18.81	21.37	21.19
average			3.91	<0.0001	<0.0001	<0.0001	<0.0001

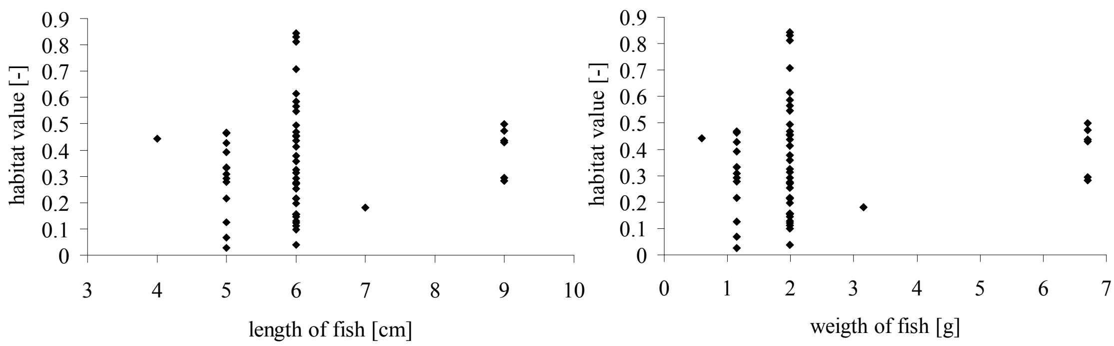


Figure 3.58 Habitat value as a function of fish length and weight at Iso Tainikoski, lower area, with the preference curves of Mäki-Petäys (2000).

Prediction of the positions of individual fish

More fish were found in habitats with higher modelled suitability index values. But can the model be used in predicting where the individual fish are? If we have a suitable habitat area, what is the probability that fish will be found there? Are the fish concentrated just in some good spots while other good areas are empty? The study with the preference curves of Mäki-Petäys and salmon <10 cm at the Harrikoski Rapids is used as an example. The probability of finding a fish in a spot with a high habitat value was 70% higher than that of finding a fish in a spot with a low habitat value (Table A1.1). The measurement resolution could have been higher for this kind of comparison, which was not the original purpose of the data. The precision of locating fish and measuring flow velocity may bring rather a large amount of variation to the comparison. The question also has to be studied by looking at the habitat value maps of the study areas drawn with fish observation spots (Figure A1.1). The study area is especially suitable: the number of fish observed in that area was 138, which corresponds to approximately 20 fish per acre. In this kind of study area, almost all area of which is rather suitable, finer details in river bed structure may be the decisive factor for habitat selection. Boulders and stones may offer a good micro scale habitat for small fish. Therefore, the coarse scale of measurements may not be sufficient to predict the precise habitat selection of individual fish. Still, fish abundance increases as habitat values get higher (Figure A1.2). This hints at an ability of the model to predict habitat use systematically. Additionally, the scale of modelling can be selected by adjusting the measurement resolution. It can also be seen that the habitats with the lowest habitat values were avoided. In different types of rivers, e.g. larger rivers or rivers with a lower habitat quality otherwise, e.g. only some areas near the banks could be suitable, and it would be much easier to make predictions of the abundance of fish than in these kinds of almost totally suitable areas.

3.2 Crayfish model

3.2.1 Testing the model at Lake Katumajärvi study areas 4-5

Lake Katumajärvi study areas 4-5 were modelled with the combination of variables with the highest correlation with crayfish abundance at the same lake: the product of erosion rate and water temperature, the preference curves for which were made with data from the same area (Figure 3.59). The tests of significance were calculated (Table 3.9). Available habitats and habitat use and proportion of use to availability are represented in Figure 3.60. A good prediction of abundance was achieved.

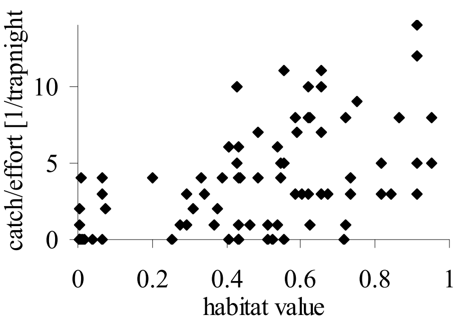


Figure 3.59 Catch/effort ratio at Lake Katumajärvi study areas 4-5 as a function of habitat value calculated based on erosion rate and water temperature.

Table 3.9 Lake Katumajärvi study areas 4-5, available habitat and habitat use (catch/effort ratio) and proportion of use to availability and goodness of fit tests.

Habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.4964	157.00	105	0.67	17.22	16.89	-84.48	
0.4964-1	157.00	209	1.33	17.22	16.89	119.58	
sum	314	314	high/low	34.45	33.79	35.11	35.05
			1.99	<0.0001	<0.0001	<0.0001	<0.0001

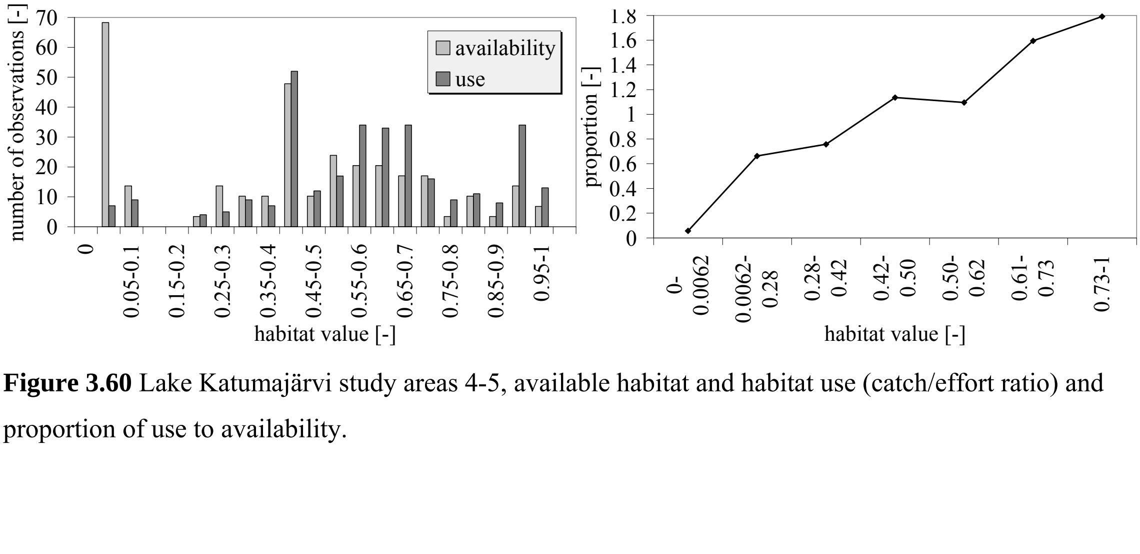


Figure 3.60 Lake Katumajärvi study areas 4-5, available habitat and habitat use (catch/effort ratio) and proportion of use to availability.

3.2.2 Testing the model at Lake Pääjärvi

A model was similarly calibrated and tested at Lamminsaari study area at Lake Pääjärvi. The relationship between catch/effort ratio and habitat value is shown in Figure 3.61. Tests of significance were calculated (Table 3.10). Available habitats and habitat use and proportion of use to availability are represented in Figure 3.62. The prediction was found to be moderate.

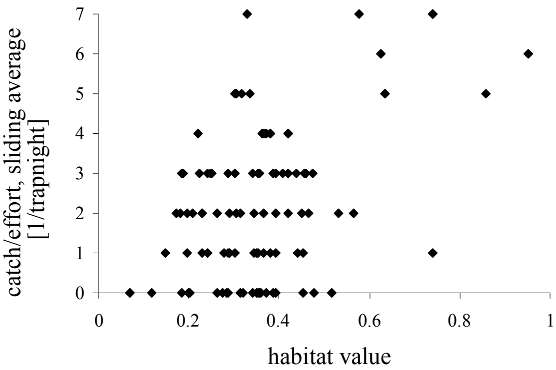


Figure 3.61 Lamminsaari Island, Lake Pääjärvi, habitat value and catch/effort ratios.

Table 3.10 Lamminsaari Island, Lake Pääjärvi, available habitat and habitat use (catch/effort ratio) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3543	127.00	96	0.76	7.57	7.32	-53.73	
0.3543-1	127.00	158	1.24	7.57	7.32	69.02	
sum	254	254	high/low	15.13	14.65	15.29	15.26
			1.65	0.0001	0.0001	<0.0001	<0.0001

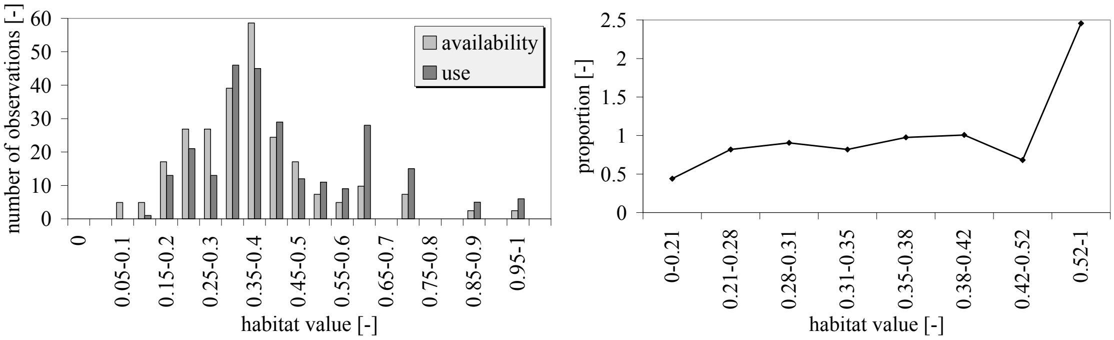


Figure 3.62 Lamminsaari Island, Lake Pääjärvi, habitat availability and habitat use (catch/effort ratio) and proportion of use to availability.

3.3 Vegetation modelling

3.3.1 The delta of the River Oulujoki

In this section, the calibration of the herb model with habitat preference information is represented. Description of the area and the organism studied is represented in Chapter "The models".

Measurements and modelling

In the delta of the River Oulujoki, the region around the shoreline was selected as the study area. The delta area was already habitat modelled (Lahti & Riihimäki 2000). The sea bed characteristics were mapped from the zone where *Persicaria foliosa* was known to grow, considering the distance from the shoreline. The characteristics of the sea bed were classified on the basis of the properties of two upper layers of the sea bed, with three variables recorded at each site:

The most common material type in the surface layer: 1 = humus/mud, 2 = other
The most common material type in the underlying layer: 1 = humus/mud, 2 = other
The second most common material type in the underlying layer: 1 = humus/mud, 2 = other

The mapping was performed with the help of accurate differential-GPS equipment (Kemijoki Oy). The bed characteristics were classified for the whole length of the seashore. The mapping points were placed at constant distances or when a change in the characteristics occurred. In large areas, where the bed characteristics were homogeneous, the density of the measurement points was reduced. Topographic information was also gathered from the measurement points. The topographic model was gained from measurements (Sirniö 2000) and the hydraulic modelling results from Talvensaari (2000). The habitat modelling was performed with a cell size of 5*5 metres. The coordinate systems were different in the modelling and observations, so the observation data were converted to the coordinate system used in the modelling. There is an angle difference of 3 gon. The centres of the observation cells were marked with circles on the map (Figure 5.32).

Preference data

One set of observations was made in cells of 100*100 metres. Another set of data (Lahti & Riihimäki 2000) was measured directly to coordinates with GPS. The preference curves were made from this set of data allowing the finding of more accurate values for the habitat variables, and the first set of data was used as validation data. The preference curve for water depth (Figure 3.63) was made on the basis of the elevations of the sites where *Persicaria foliosa* was found and water level information. The elevations of the 174 sites with *Persicaria foliosa* were measured. The curve was based only on the observed depths. The preference curve for sea bed characteristics (Figure 3.64) was made on the basis of an expert estimation (Lahti & Riihimäki 2000) on the suitability of bed characteristics observed at the sites where *Persicaria foliosa* was found.

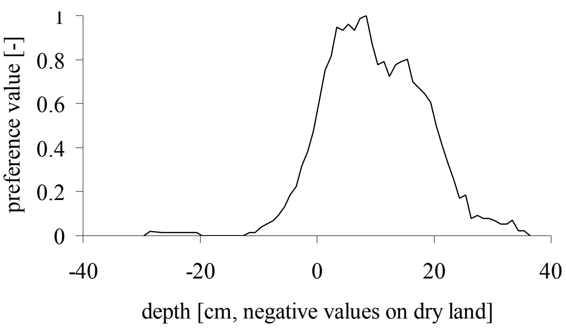


Figure 3.63 Preference curve for water depth for *Persicaria foliosa* in the delta of the River Oulujoki. The water depth value of 0 is the zero point of the water level system MW 2000 (Finnish Institute of Marine Research).

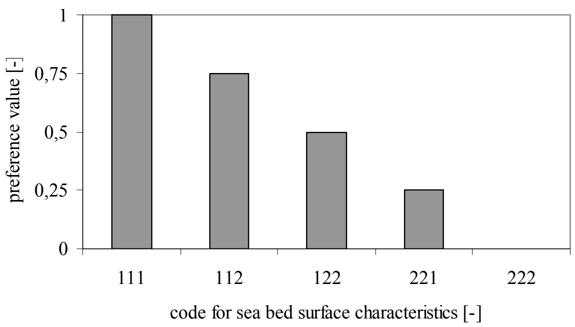


Figure 3.64 Preference curve for bed characteristics for *Persicaria foliosa* in the delta of the River Oulujoki. The bed characteristics were classified on the basis of the characteristics of the two upper layers of the bed structure; the numbers are in order from left to right in the code: the most common material type in the surface layer, 1 = humus/mud, 2 = other; the most common material type in the underlying layer, 1 = humus/mud, 2 = other, the second most common material type in the underlying layer, 1 = humus/mud, 2 = other.

4 VERIFICATION AND SENSITIVITY ANALYSIS OF THE MODEL

4.1 Fish model

In this chapter, the logicality of the behaviour of the model is studied with artificial data. It is tested, whether the model responds to changes in methods of calibration and modelling in a predictable way, and whether sub-models, e.g. topographical model, function the way required in the modelling. Additionally, the sensitivity of model results to different factors is studied. A part of the sensitivity analysis has already been performed in the previous chapter in the form of testing different preference curves. In this chapter, the work is completed e.g. by studying the relative importance of variability in preference data (4.1.3). Detailed sensitivity analyses of the physical model including e.g. field measurements (4.1.1) and hydraulic modelling (4.1.2) are carried out. At the Hotilankoski Rapids on the River Tainionvirta, the whole habitat modelling process is studied (4.1.4) for assessing the relative importance of different factors affecting the reliability of habitat-modelling results. The response of the crayfish model to different preference curves for potential erosion or lake size is studied (4.2.1).

4.1.1 Field measurements and empirical data models

Field data model measurement and interpolation methods

The most common data model interpolated directly from measurements is the topographic model. Usually, many other sets of data are calculated with a hydraulic model based on the topography. Therefore, topography is selected to represent all sets of data in the following study. The properties of the water depth set of data are very similar to those of the topographic model, and the changes in the values in flow velocity sets of data also usually roughly follow the direction of change of other data. Therefore, the recommended interpolation methods for these three are usually the same. Substrate is measured as scatter point measurements and interpolated with a nearest point method, because the size classes do not necessarily change gradually in nature.

The most accurate method to test the effect of the number of observations on data models would be to make measurements from the same area with different methods and sampling densities. Because this would be costly and the same can also be done with the help of a figurative test reach clearer in visual comparisons, such a test reach consisting of a regular V-shaped channel with a straight section and a section in the form of a quarter circle was created to test different interpolation methods (Figure 4.1). The measurement points were placed on five lines, which were divided into intervals, and within each of these a point was positioned randomly. The intervals were selected so that they would correspond to those of normal field measurements. The point density in the curved section was set in the middle between a uniform amount of points per metre and radius. Using plots and removing data points is an illustrative and easy method for testing. If different models are tested in a separate work concentrating solely on topographical models, estimates of error should also be calculated, i.e. a point at a time is removed and the value at it is estimated based on values at other points with the method being studied. The method producing the least error or variance, also considering the number of model parameters, would be chosen.

Triangulation gave the most accurate result, the reason being clear; the changes in the channel form are linear. Kriging also produced a good result, but inverse distange weighted interpolation was not useful with these kinds of data. But when measurement points were fewer, triangulation and Kriging worked roughly equally (Figure 4.2), triangulation predicting the shorelines more accurate and Kriging the mid-channel, even if the form of the channel was regular, because Kriging guesses trends better. Methods developed for making more accurate data models and for a more effective use of field measurement data, line measurements and curvilinear anisotropic interpolation, were also tested (Figure 4.3). These were found to improve the results remarkably.

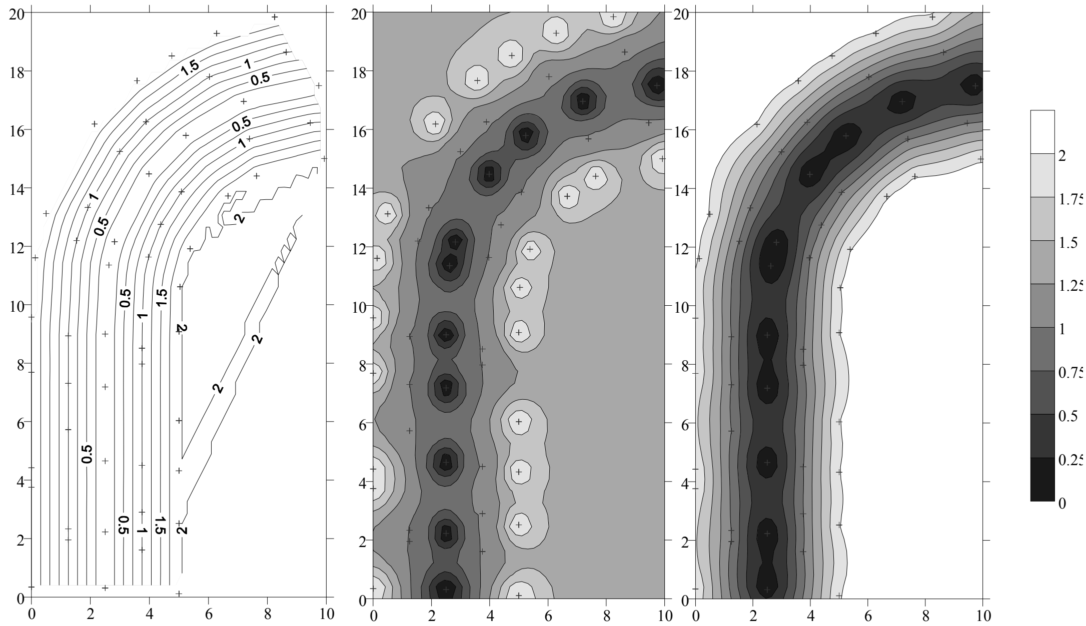


Figure 4.1 Interpolation with triangulation, inverse distance weighted interpolation, and Kriging.

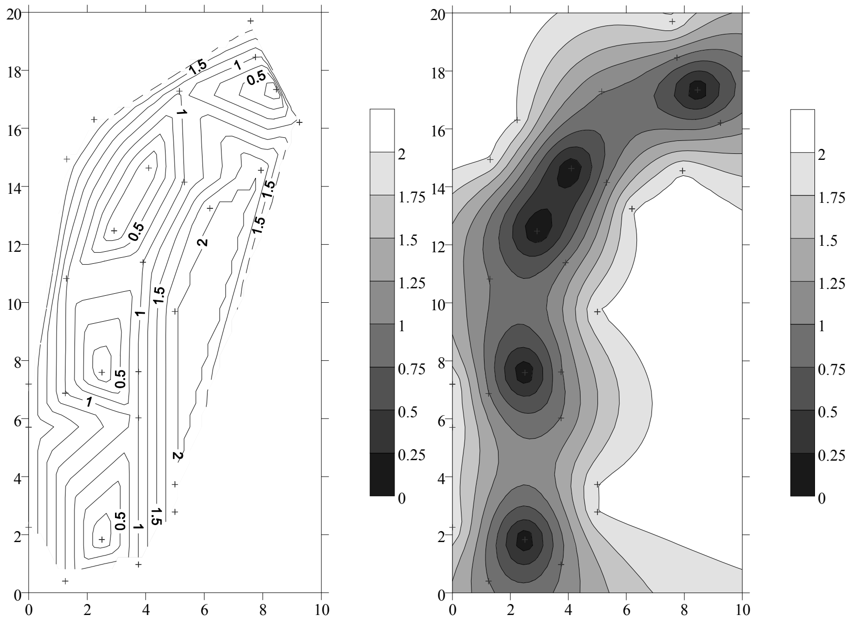


Figure 4.2 Interpolation with triangulation and Kriging when the number of measurement points is only half of the previous.

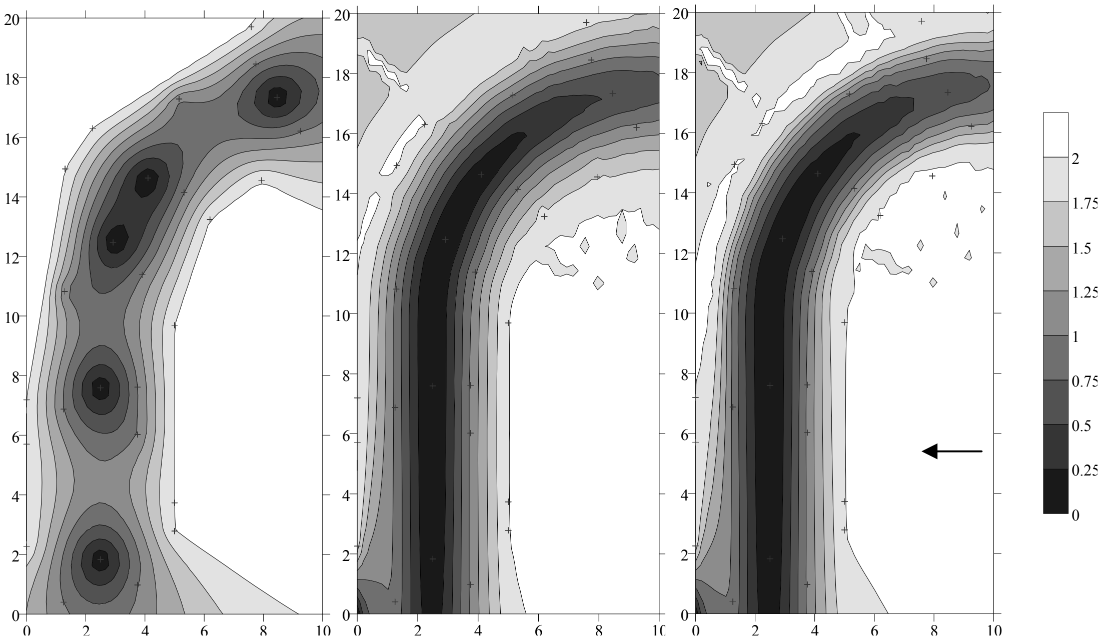


Figure 4.3 Interpolation with shoreline measurements with Kriging and with curvilinear anisotropic interpolation with Kriging, and both together, when half of the measurement points were removed.

In Figure 4.4, elevation profiles digitised from the topography models from the place shown with an arrow in Figure 4.3 are shown. The interpolated model follows the original topography relatively closely, with 54 measurement points and Kriging. With a halved number of measurement points, the topographic model differs significantly from the original. Shoreline interpolation helps in making the model accurate near the banks, but the mid-channel values are almost unaffected. The model interpolated with curvilinear anisotropic interpolation follows the original topography very closely, even with half the number of measurement points. In natural channels, the method may not be as efficient, because of irregularities in the topography along the river. Because the flow of water has usually formed the river in such a way that there is less relative variation in the topography along than across the river, the method is likely to be beneficial in many cases.

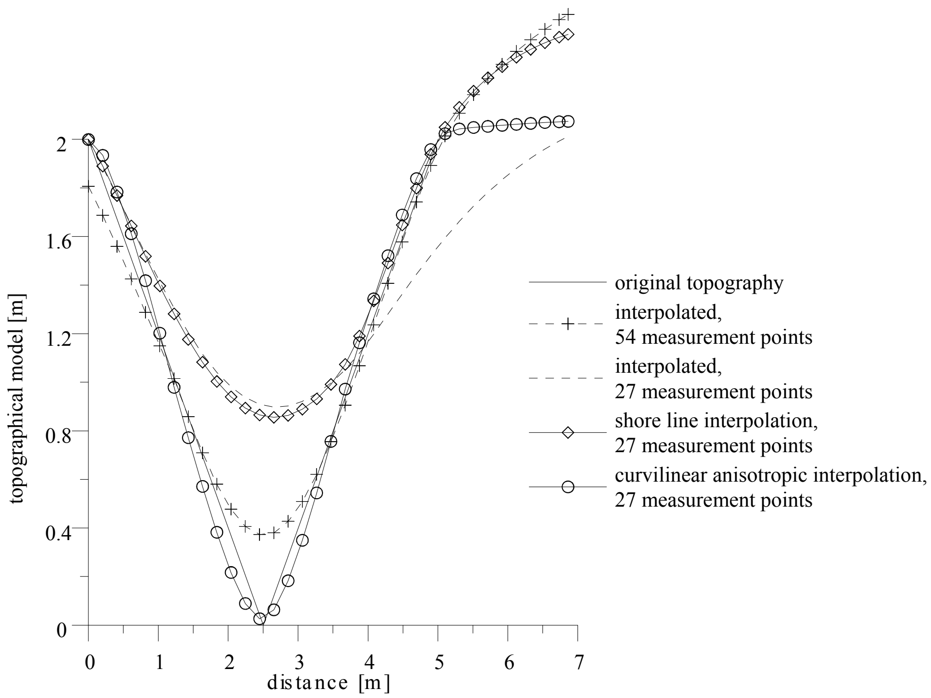


Figure 4.4 Original topography and interpolated topography with 54 and 27 measurement points in the figurative test reach.

Field measurement methods are studied further below. Whether cross-section or scatter point measurements should be used is studied (Figure 4.5). The cross-section measurements yielded some more accurate results than the scatter point measurements with the same amount of measurement points (Figures 4.2-4.3). In the field, in practice, cross-sections are usually measured with much denser lines, and thus the spaces left between lines become long compared with the distance between measurement points in the lines and the efficiency is lower. When making scatter point measurements, individual points can also be selected, taking the form of the topography into consideration. Therefore, in practice, with natural, varying channels, scatter point measurements should usually yield more accurate results with an equal amount of measurement points. If cross-section measurements are used in an irregular channel, the number of cross-sections should be high enough compared to the number of points in a cross-section, so as to get a grid-type measurement point pattern, as here, so that gaps between cross-sections would not be formed. There should not be large, non-linear changes in the channel between the cross-sections.

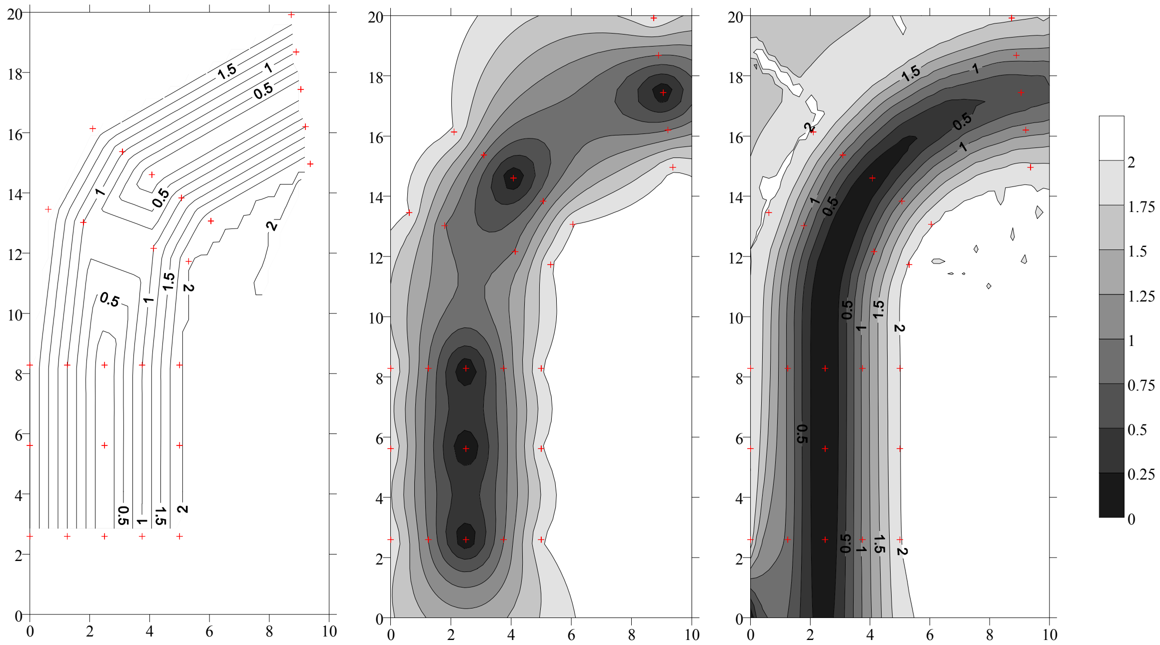


Figure 4.5 Interpolation of field data measured with cross-section measurements with triangulation, Kriging, and with curvilinear anisotropic interpolation with Kriging, when the number of measurement points was reduced to half of the original.

The effect of grid cell size

The effect of data grid cell size is studied with the same figurative study reach as above. The coarseness of the grid affects the results relatively little (Figure 4.6). Only small differences can be found between the first two and some differences between the grids interpolated with the finest and the coarsest density. The grid sizes were very small; the largest grid size, with a density of 0.5 metres, was only 21*41 cells. With a typical personal computer, grid sizes of 400*400 are easily calculated. The grid density can usually be set much higher than that of field measurements. Still, if the river reach is very long compared to the width, it may be reasonable to divide the river into smaller sections, to reduce the dry land areas in habitat value computation grids requiring computer time, and also for hydraulic modelling.

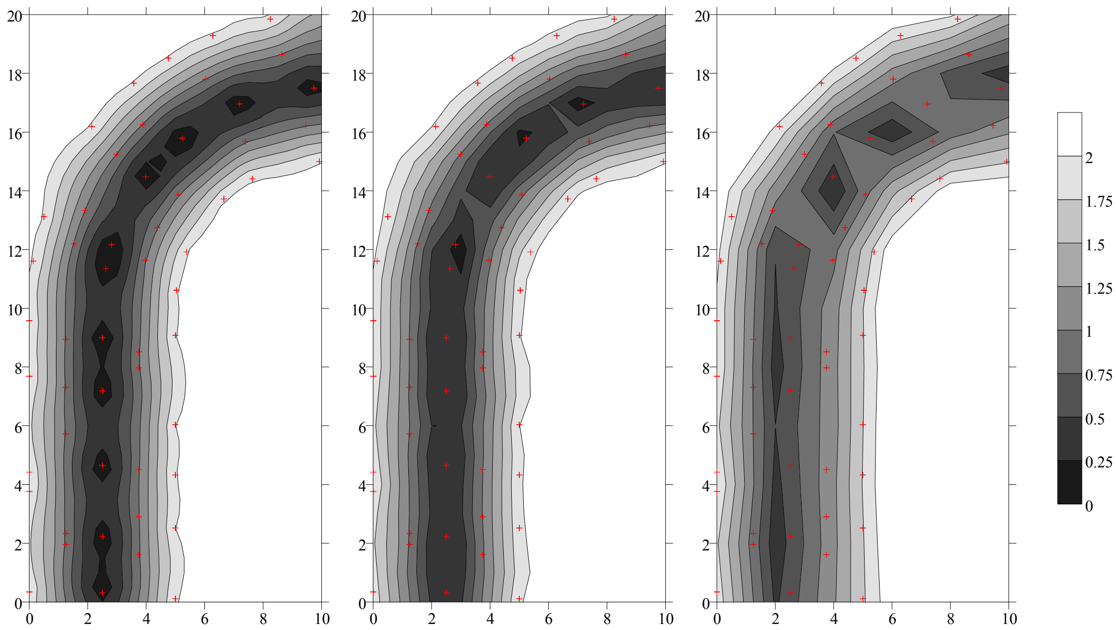


Figure 4.6 Topographic model of a figurative test reach with grid cell sizes of 0.5, 1, and 2 metres.

Measurement of boundary conditions

Water level

The accuracy of the measurement of water level affects water depth directly, and also flow velocities through the available cross-sectional flow area and calibration of the model. The direct effect on habitat modelling can be estimated roughly by considering the effect of a change in water depth on habitat preference curve values. The water level can usually be measured with an accuracy of a couple of millimetres or centimetres, an amount which causes only small changes in preference values for water depth. The effect on flow velocities after the calibration of the model can be estimated with sensitivity analysis, followed by the estimation of the effect on preference index values for flow velocity. In rapids, the difference in water level values between measurement points along the river is usually large, but in slow-flowing sections inaccuracy in measurements may cause problems in setting roughness values in calibration. The measurement points should be selected in such a way that there are no big temporal or small-scale spatial variations in the place. The difference between energy height and water level should also be remembered. Still, much more imprecision is usually caused by topography measurements, which have a major effect on the cross-sectional flow area.

Water level can usually be measured more accurately than a couple of centimetres, and averaging with e.g. five measurements from the same area or point will reduce the effect of temporal or small-scale spatial variation. Still, the measurement places must be chosen avoiding such variation.

Flow rate and flow velocity distribution

Discharge data is often available at hydro power plants or water level gauging stations with known hydrographs. When not available, in smaller rivers, flow rate is measured with a current meter, whereas in larger rivers, acoustic Doppler-based instruments are also practical. Flow velocity distributions can be measured with both methods. In a comparison, the deviation of discharge by ADCP measurements from results measured with a current meter or from validated power station discharge was usually not more than 2%, except one measurement with 6% deviation (Forsius 2001). The precision of discharge measured with a current meter is higher, 1-2% in good conditions. In natural channels, the values should be measured as an average of a longer period, because of the temporal variation of flow. The selection of the measurement place is important. Because of temporal variation, ADCP measurement should be recommended to be repeated several times, and an average of these should be used. Some areas at the sides and at the top of the cross-section are not accessible by the measurement method, and have to be estimated. Because, in modelling, calibration is normally made following a measured water level, the water depth and the location of the shoreline change very little if the flow rate is changed. Flow velocity distribution also changes gradually, which diminishes the effect of measurement inaccuracy on the results of habitat modelling even if the average flow velocity changes considerably. An error of 5-10% in flow velocity usually causes rather a small difference in habitat values. Thus, also the accuracy of flow rate measurements does not need to be 2%, but that could be a good goal. If the flow rate is measured carefully with the normal methods suggested for discharge measurements, the precision is sufficient. In many cases, the conditions at the measurement line do not meet the requirements for the 2% accuracy, however. Temporal variations in discharge and flow velocity caused e.g. by hydro power use of water or wind induced variations in water level of reservoirs can be large. If the discharge measurement is inaccurate, the effect on flow velocities is greater than the difference between the flow velocity values of two different flow rates in channel naturally, because the water level remains constant in the calibration of the hydraulic model.

A hydraulic model was set up at the Tolpankoski Rapids on the River Kiiminkijoki for a brief glance at the effects of erroneous flow rate and water level measurements on flow velocity distributions (Figures 4.7-4.8). The river reach is optimal for the study, because it is just a typical trout river for which habitat models are often used. However, perhaps because of the high density of boulders in the river reach making measurements more difficult, e.g. too many topography points might then be measured on the top of boulders locally the model converged best at water levels about 10 centimetres above the measured levels. However, a place was found at the top of the reach where the water level was two centimetres lower than modelled. It was a little too close to the upper boundary of the measurements and the model, but that was not thought to disturb the study of the effects too much, because the water there still has time to select its route. A cross-section of flow velocities here was plotted with different calibrations of the model. As expected, too high a measured flow rate resulted in slightly higher flow velocities, and too high a measured water level in lower flow velocities, but not directly proportionally. Another similar cross-section shows exactly the same thing: normal inaccuracies in the measurement of flow rate or water level do not usually cause major changes in flow velocities in a calibrated model (Figures 4.9-4.10).

Figure 4.7 Location of Cross-section One at the Tolpankoski Rapids on the River Kiiminkijoki.

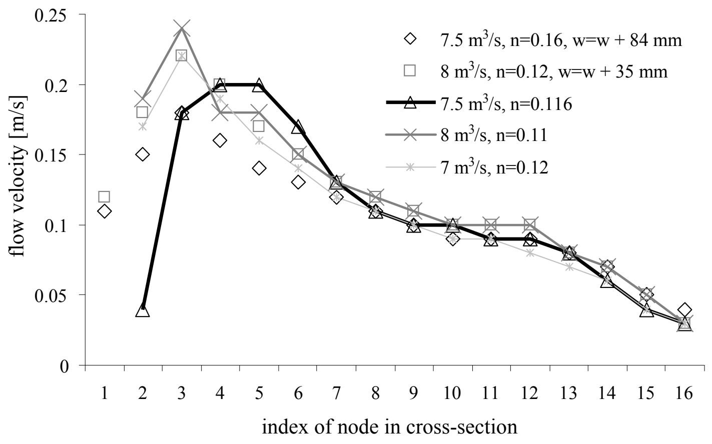


Figure 4.8 Flow velocity at Cross-section One of the Tolpankoski Rapids with measured values and with smaller discharges or higher water levels.

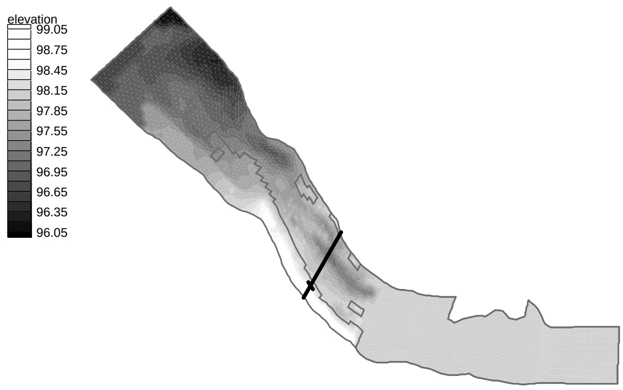


Figure 4.9 Location of Cross-section Two at the Tolpankoski Rapids on the River Kiiminkijoki.

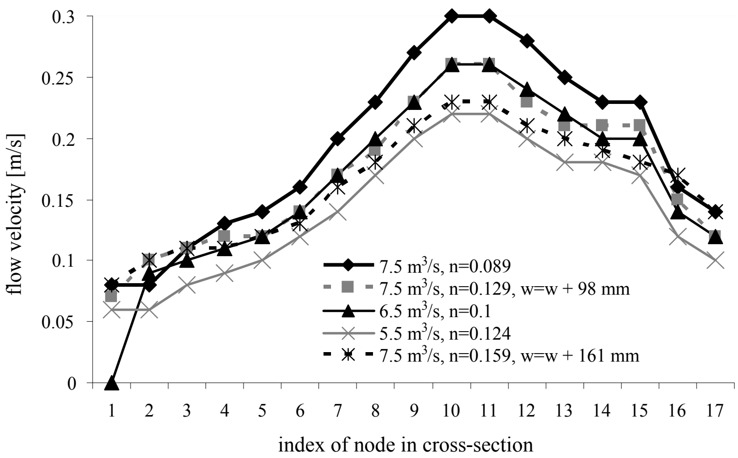


Figure 4.10 Flow velocity at Cross-section Two of the Tolpankoski Rapids with measured values and with smaller discharges or higher water levels.

4.1.2 Hydraulic model

Two-dimensional hydraulic models have been used e.g. for planning dredgings and structures. In these studies, changes in water level are often the effect that is studied. Often shallow water areas are cut away from the model, because they usually do not have a remarkable effect on water levels, but add a factor causing instability to the calculation model. The model is calibrated only along the river and no flow velocity profile calibrations across the river are made, to save labour costs. But in habitat modelling, the shallow areas are important for fish fry and juveniles, and the velocity profile affects the available habitats. The shallow areas may be inaccessible by boat or the GPS equipment invisible to satellites. When measuring large areas, the cost of tacheometer measurements may be high. Additionally, field measurements made for other purposes that do not require information about the near-bank areas may be available for habitat studies. Furthermore, hydraulic modelling is easier without shallow wetting and drying areas. When studying the habitats e.g. of bigger fish, the shallow areas are often not so important. But in all these cases mentioned, in order to get more exact values for the mid-channel, the adjustments to parameter values discussed above may still have to be made. Shallow areas that are lacking can sometimes be included in the water depth model by using a topography model interpolated from the original field measurements, including the shallow shores and water level taken from the hydraulic model instead of the modelled water depth. Modelled flow velocities cannot be calculated for missing cells of the hydraulic model near the shoreline in this way. Because of these, the inclusion of the shallow areas is recommended even if they are not studied, if they can be modelled easily enough.

In the two-dimensional hydraulic model RMA2, it is possible to have the shallow areas included in the model using a wetting and drying algorithm. In the method, calculation cells are excluded as dry or activated back into the calculation grid as wet during the calculation process. Still, some shallow areas are left outside the model, because the shore side of the nearest wet element is usually not exactly at the shoreline, but at some distance from it. Furthermore, the algorithm uses border values for wetting and drying, which mean some additional distance on average. However, these values can be adjusted. The total effect is smaller when the number of elements near the shore is larger. Still, a wet/dry boundary with vertical walls is formed in RMA2. This and also the fact that vertical friction cannot be applied to cells in RMA2 mean that some friction caused by the shallow area excluded from the model is left out, and the flow velocity may become too high near the shoreline. The use of a two-dimensional hydraulic model in habitat modelling, its calibration and these effects are studied in the following.

A figurative test reach

The effect of cutting the shallow areas away from the model was tested with a figurative reach (Figures 4.11 and 4.12) in order to exclude other factors. The effects of other model paramaters; roughness, and kinematic viscosity were also tested. Finally, the effect of the number of elements on results was tested. It can be concluded from Figures 4.13 and 4.14 that if the river topography model is cut below the waterline, the flow velocity values near the banks will be too high. This is because there is no wall friction in the model and friction caused by the shallow near-bank areas is excluded. Thus, even if the fish being studied were not near the banks, it is important that topography measurements are made up to the shoreline, even if it is more labour-demanding. Often these areas are not accessible by boat and trees block the visibility of GPS equipment to satellites near banks, which means a need for additional tacheometer measurements. It can also be seen from Figure 4.14 that a proper value of friction coefficient is important for flow velocity profiles even if only one value is used for the whole profile. The effect is greatest near banks. On that basis it can be concluded that the model should be calibrated accurately along the river with water level measurements, even if the inaccuracy in water level caused only small changes in preference values calculated with water depth, in order to get the right friction coefficients affecting the flow velocity profile. The effect of kinematic viscosity is also important.

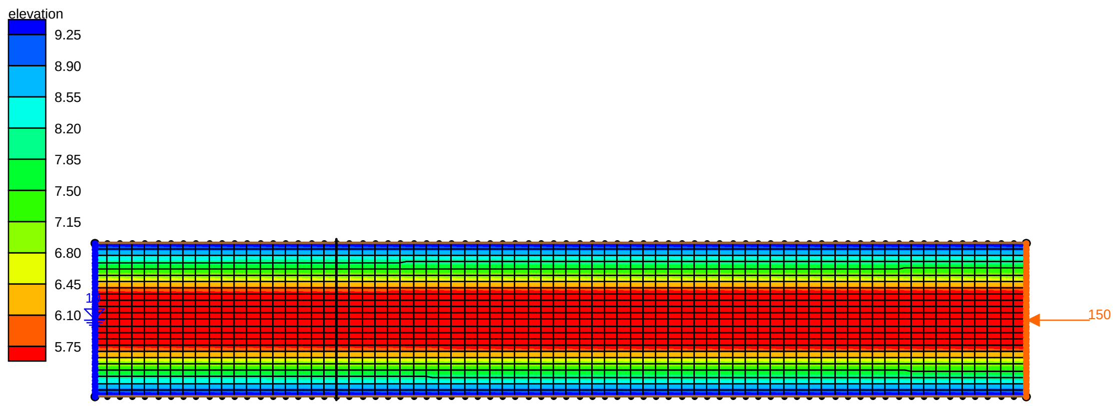


Figure 4.11 Topography of a figurative test river reach.

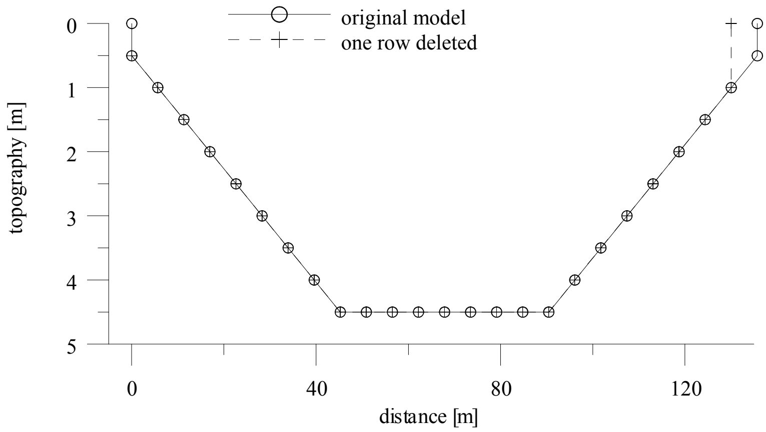


Figure 4.12 Topography profile of a figurative test river reach and a model with one row of cells deleted from the right bank.

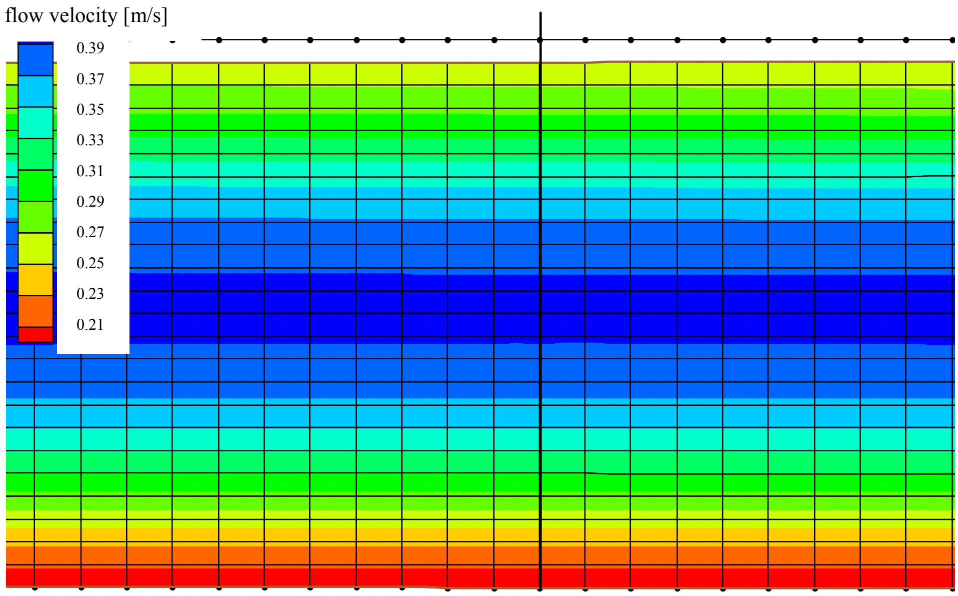


Figure 4.13 Flow velocity distribution in a figurative river reach when one row of calculation cells was deleted from another bank (the top of the figure).

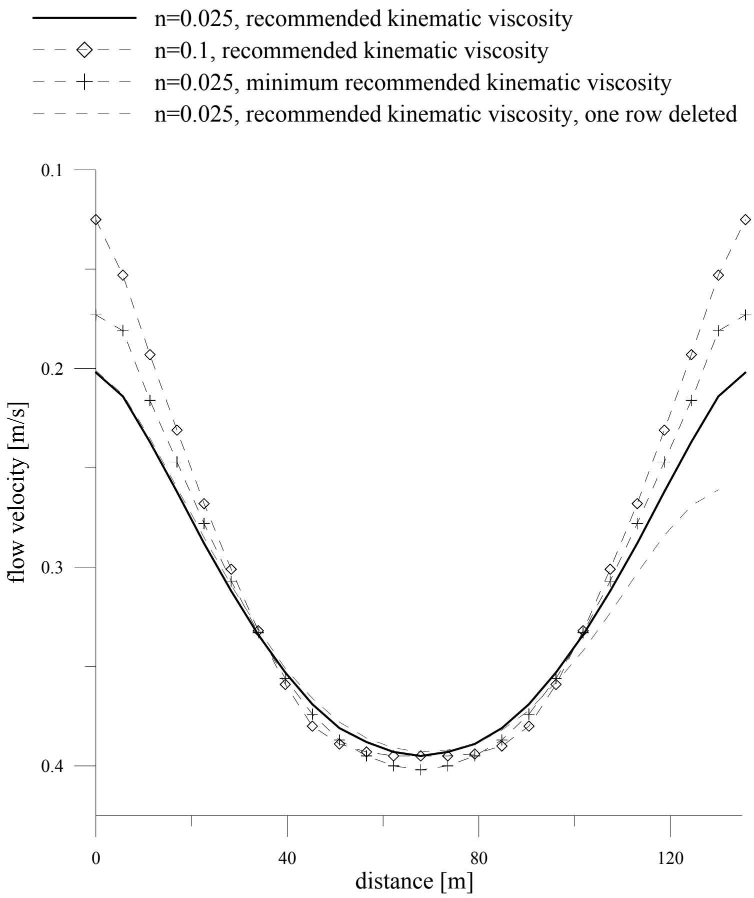


Figure 4.14 Flow velocity profiles of the figurative test river reach with different values of friction and kinematic viscosity and a model with one row of cells deleted from the right bank. The kinematic viscosity is set by automatic assignment on the basis of flow velocities and element sizes.

It can also be seen that the effect of cells that are lacking in shallow areas of the river can be roughly compensated by adding friction or reducing kinematic viscosity. In order to be most successful this requires both sides of the river to have a similar type of grid geometry and topography. Another method could be adding friction to the cells near the waterline.

It was surprising how little the amount of elements affected the results (Figure 4.15). The purpose was to test what the effect of elements is computationally, and thus the river geometry and the number of elements were set in such a way that the geometry remained the same in each modelling with different amounts of elements. In natural channels, of course, the topography would be less precise with fewer elements. The model was found to work consistently with different amounts of elements. The software also interpolated the right values for calculation/output nodes even if the elements were so large that the average values of elements were remarkably different.

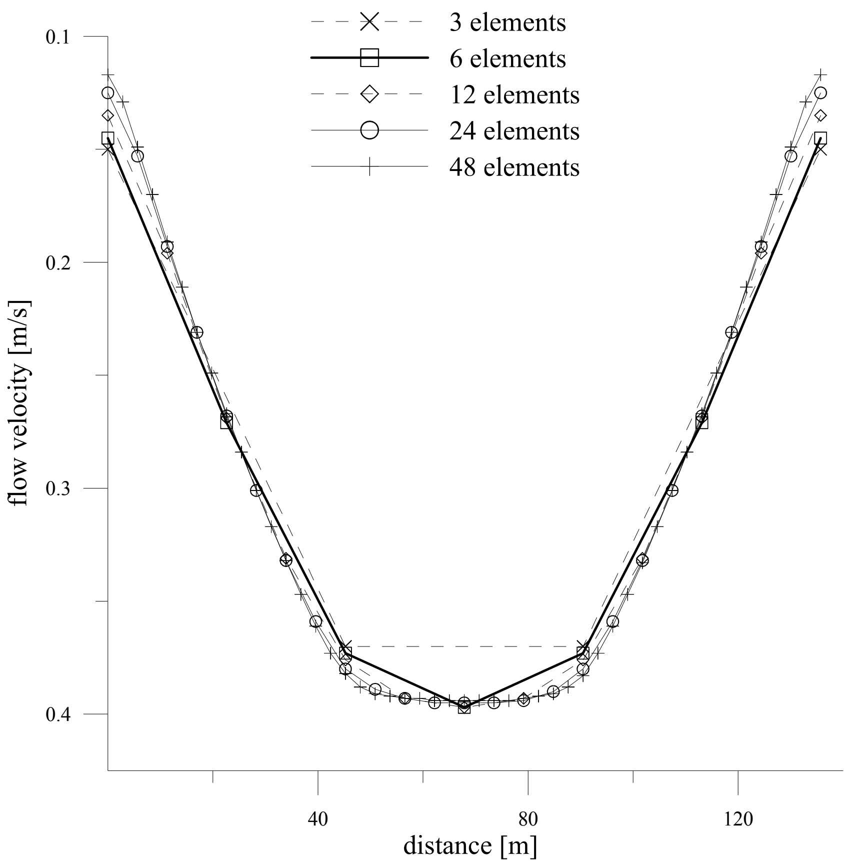


Figure 4.15 Flow velocity profiles in the test reach with different amounts of elements across the river.

Because the effect of the number of elements can be quite small, computation time can be saved by reducing the number of elements if the channel form or the density of the measurement points allows this without losing too much accuracy. It has been found out that the computation time is approximately proportional to the fourth power of the number of elements across the river (Lahti 2002). But the number of elements must still be sufficiently high that shallow areas near banks are also included, and also to get a better amount of friction to the model affecting the rest of the channel. Adjusting the grid geometry to fit the water line after an initial model run usually leads to the most accurate result and a numerically more stable grid. The effect of lost friction on the flow velocity distribution of the rest of the channel could also be compensated for by adding some friction to the nearest wet cells to the bank. This can be done on the basis of an initial model run or simply by adding roughness zones according to geometry or topography. Other methods could include using a slightly larger friction coefficient in the whole cross-section or by using smaller kinematic viscosity values, as previously mentioned. The effect of these different methods is studied with another grid that resembles natural rivers more closely.

A fluvial fish river-like figurative test reach

To assess the magnitude in natural river channels of the phenomena studied, a trout river was used as a cross-section geometry model when designing the reach. The shallow areas of the theoretical river reach were formed so as to resemble a typical trout and grayling river somewhat, using the geometry of the River Kuusinkijoki, but the mid-channel was made deep so that the modifications to be made in testing would not have a remarkable effect on the water level (Figures 4.16 and 4.17). The depths at the river edge of the shore elements in the River Kuusinkijoki hydraulic modelling grid were found to be from 0 to 0.5, but mostly between 0.1 and 0.3 metres, on average 0.15-0.2. The shallow areas were constructed in such a way that if one row of cells was deleted, the remaining grid would correspond to that of the River Kuusinkijoki. This was done to study the possible effect in a typical modelling case. The water level was kept approximately constant by adjusting the water level boundary condition of the model at the flow distribution check line in order to keep the situations calculated with different parameter values comparable. The effect on flow velocity distribution of removing elements from the shallow area is shown in Figure 4.18. The difference in flow velocity can be seen by comparing it with the uppermost line. Removing one row of elements from shallow areas resulted in an increase in flow velocity of 0.045 m/s near the shore. The water depth at the shore line increased from 7 to 17 centimetres. If we evaluate the effect of this on preference values based on the preference curve of trout fry in summer by Mäki-Petäys & Huusko (2001), this has only a very limited effect on the modelling results. In winter, the optimal flow velocity in the preference curves of Mäki-Petäys et al. (1997) is at 0.3 m/s and is still good at 0.1 and 0.4 m/s.

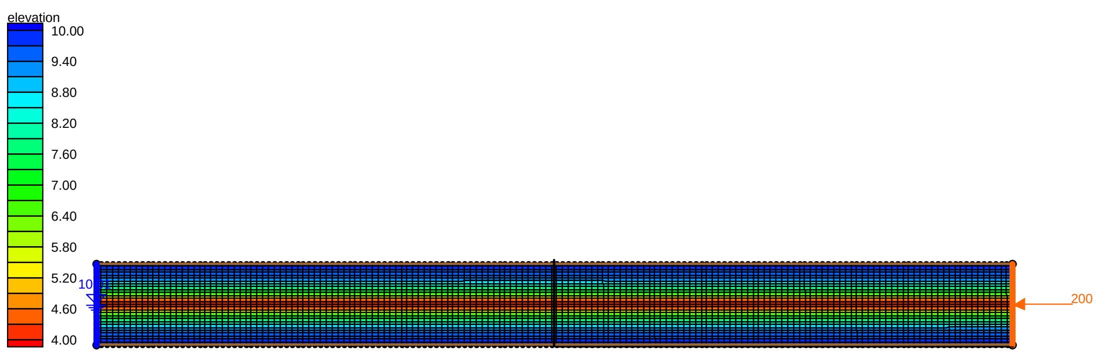


Figure 4.16 The elevation map of the figurative fluvial fish river-type reach. The flow velocity distribution check line is shown in the middle.

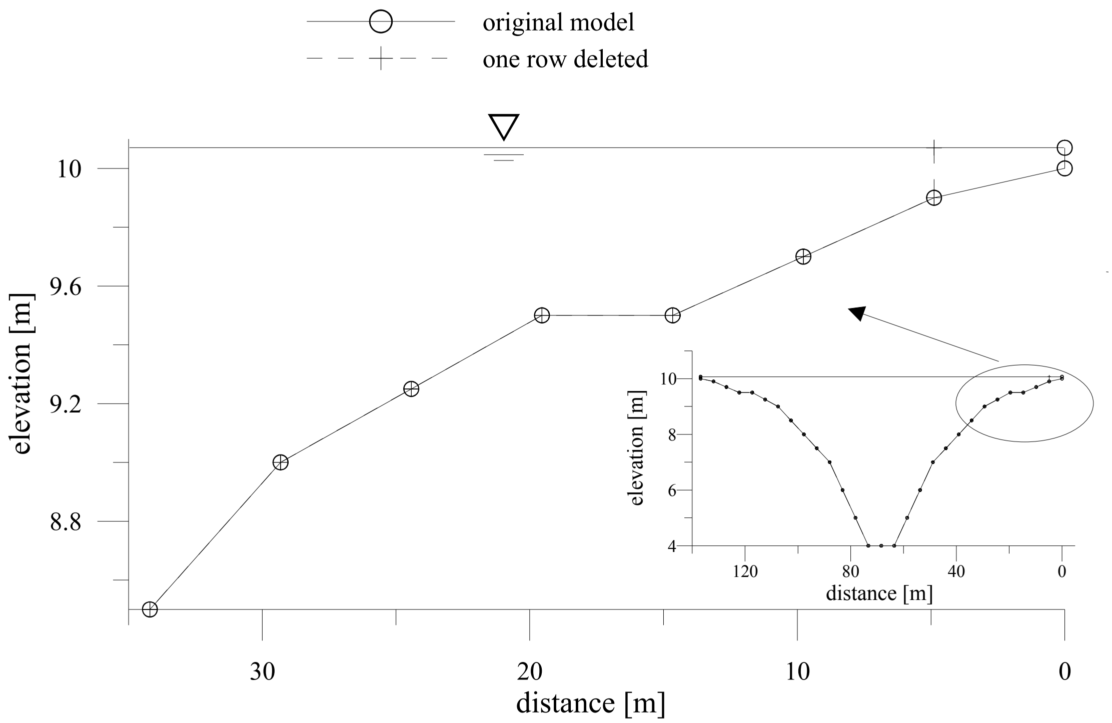


Figure 4.17 Topography profile of a figurative fluvial fish river-type reach and a model with one row of cells deleted from the right bank.

But if a longer section is modeled at several hydraulic situations with a coarse grid and small-scale shallow areas are still to be assessed when adjusting the shore line at each situation is thought to be too laborious, some compensatory methods should be used to correct the flow velocity distribution near the banks that results from large-sized elements there.

Different methods for compensating for the effect on flow velocity distribution of possibly absent shallow area elements were studied. A comparison between the velocity profile with the original geometry and with different compensatory methods is shown in Figure 4.19. It can be seen, as could have been supposed, that the addition of friction to the waterline elements would give the closest fit. Adding friction or lowering the kinematic viscosity in the whole channel also corrected flow velocity with a relatively small effect on values in mid-channel. But because the method would also be applied to the other side of the river in practice, they would cause too-low velocities on that side. If the other side is similar, this is not a problem.

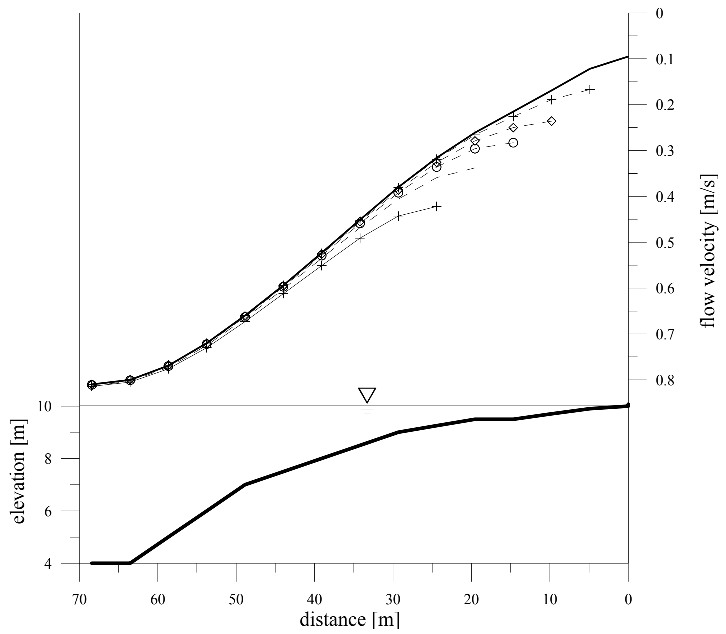


Figure 4.18 The effect on flow velocity distribution of removing elements from the shallow area. The uppermost line is a situation where the depth at the shoreline is only seven centimetres. The depths at the following element rows at the ends of the lines from the right are 17, 37, 57, 57, and 82 centimetres.

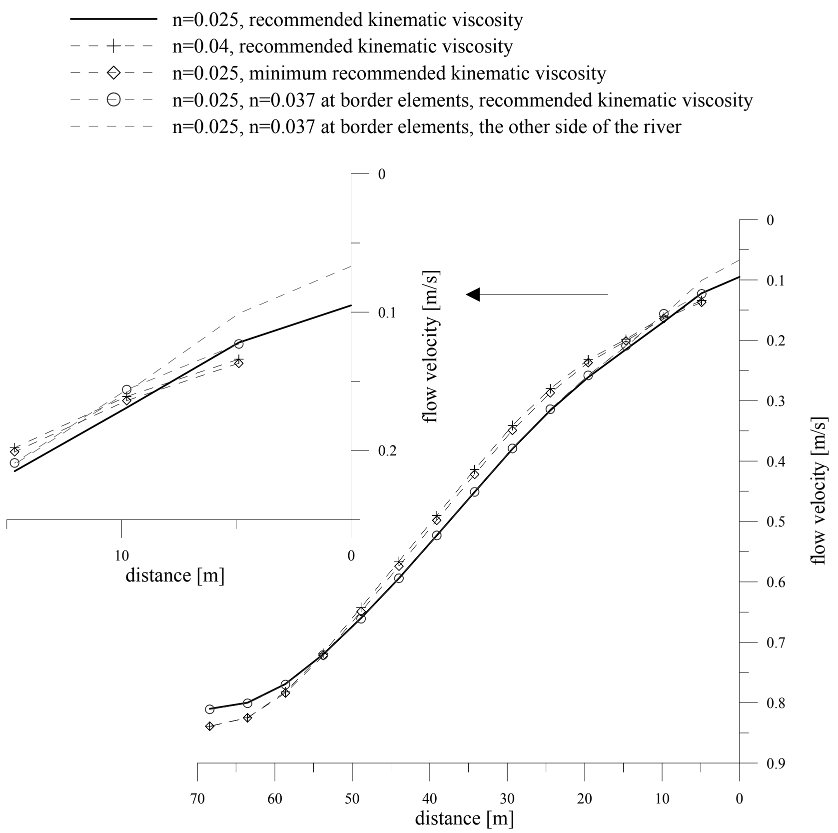


Figure 4.19 Flow velocity profiles of the figurative test river reach for the original geometry and the geometry from which a row of elements from the shallow area was deleted with different values of friction and kinematic viscosity. The effect on the other side of the river of the addition of friction to border elements is also shown (the uppermost longer dashed line in the figure).

The effect of the other methods on the other side of the river can be seen from Figure 4.20. The other methods also affect the distribution in the mid-channel, but the effect is not proportionally so big. Using additive friction at the shoreline may not always be feasible, because often the shoreline is not known before modelling. It can be digitised from preliminary modelling, but this is laborious. A less precise method could also be something between adding friction to one row or several rows of elements near the river shoreline. If the aim of habitat modelling is to study the habitats of fry or small juveniles, all three compensatory methods can be used depending on precision desired. In all cases but especially when the aim was to study the habitats of larger fish thriving in the mid-channel, adding friction to the shoreline would work best. It causes the least error to mid-channel values. On the other hand, the relative error in large channels caused by lacking elements may be so small that no corrections are needed. The effect of the lack of a friction zone near the bank was found to be smaller with greater roughness.

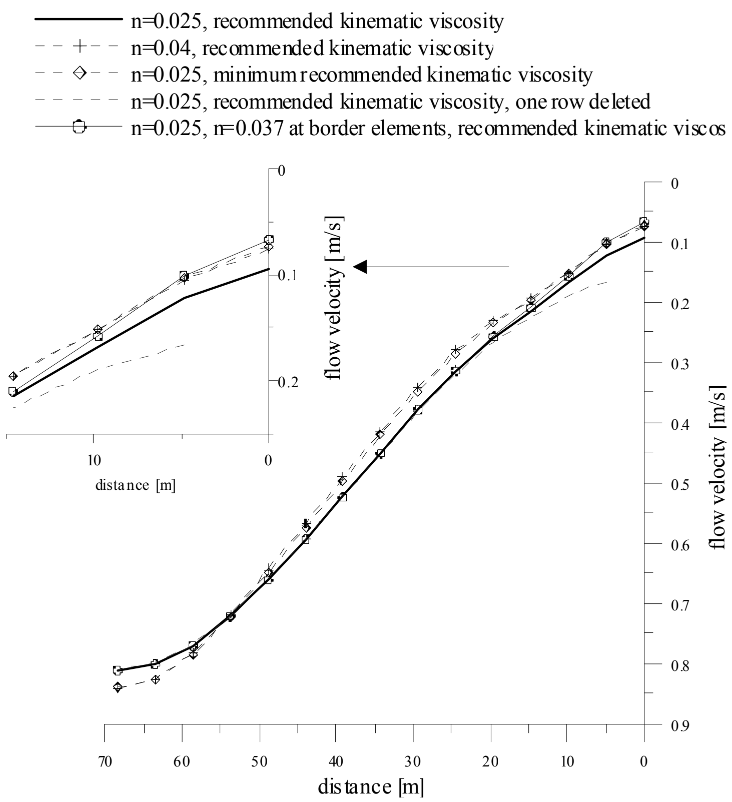


Figure 4.20 Flow velocity profiles of the figurative test river reach with different values of friction and kinematic viscosity and a model with one row of cells deleted from the right bank. The kinematic viscosity is set by automatic assignment on the basis of flow velocities and element sizes.

In conclusion, it was found that it is important to include the shallow areas in the hydraulic model. Small-sized elements near banks are useful. Increasing the value of the friction coefficient at the first wetted elements from the shoreline is a useful method to compensate for friction lost near banks, but in the first hand, the grid should follow the shore line closely, and if needed, it can also be adjusted after an initial model run. From two-dimensional hydraulic modelling, relatively accurate areal flow velocity and water depth values can be achieved on the larger spatial scale often used in habitat modelling. This requires proper field measurements and calibration of the model with the water level along and across the river. On the contrary, boulder- and stone-sized microhabitats may usually be smaller than the scales used and may be very heterogeneous.

4.1.3 A comparison of preference curves

4.1.3.1 The effect of data type and geographic location

Choosing between different preference curves can have a major effect on the results of habitat modelling, as has been seen in previous cases. Four different preference curves for brown trout fry were compared with each other.

1) Preference curve from River Kuusinkijoki by Mäki-Petäys et al. (1997)
2) Curves from several rivers in Northern Finland (Mäki-Petäys & Huusko 2001)
3) American-French curves (Souchon et al. 1989)
4) Raleigh et al. (1986)

1) The first curves were from only one river, the River Kuusinkijoki (Mäki-Petäys et al. 1997). The preference curves are for 0+-trout (*Salmo trutta*) in the River Kuusinkijoki in mid-July and in mid-August. The River Kuusinkijoki is in quite a natural state, and there is plenty of good habitats. These preference curves have quite narrow ranges for the highest habitat values. The mean flow in the River Kuusinkijoki is 4 m^3/s.

2) The second curves were made by using data from several rivers in Northern Finland (Mäki-Petäys & Huusko 2001): the Rivers Astervajoki, Koitajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki. They are also for small trout of a size <10 cm. These preference curves have larger intervals of high preference values for different variables than the curves from the single study on the River Kuusinkijoki.

3) The third curves are from America and Eurasia, and are modified and validated by Souchon et al. (1989) on the basis of data from 10 river sections in the Jura in France. The curves are according to Souchon et al. originally from Bovee (1982), not printed there, though. The curves have also been validated with 12 river sections in France. The validation was performed with the average habitat values of the sections and fish biomass, and they correlated well (Souchon et al. 1989). The curves used here are for young trout (alevin) aged under one year, but of a length over 5 centimetres. These curves were used to test whether foreign curves can be used.

4) The fourth curves are based on a literature survey made by Raleigh et al. (1986). In that survey, data collected from northern Utah were used. Because they had no data on the habitat requirements of fry; fish smaller than 5.08 centimetres in length, they decided to use the preference curves of the young-of-the-year for fry also. Thus, the fish size was for less than 14.5 centimetres in length. By calculating the habitat values, how much a difference in fish size affects the results can be assessed.

The curves are shown in Figures 4.21-4.23. The fourth curves are for a different size class. The one-river curves have a sharper and spikier form than the other curves; the multi-river curves of Mäki-Petäys & Huusko (2001) and the American and the American-French curves have a smoother and a more biologically reasonable and consistent shape. The latter two curves also seem to suit some bigger fish. Trout are known to switch to habitats of greater depth as they grow.

Small trout seem to avoid places shallower than 10 centimetres and deeper than 0.8 metres in summer. Their preferred depth range seems to be 0.15-0.5 metres. The flow velocity preference curves show the avoidance of zero mean column velocities and velocities higher than 0.75 m/s. The preferred range seems to be about from 0.1 to 0.5 m/s. The multi-river curves are again smoother and have a larger top value interval. The preference curves for substrate show a preference for coarser particle sizes. In the

American-French curves, finer, but not the finest, particles are also favoured. The curves are adapted to fit the same classification as used in the figure, so not all of them are exactly the same as the original ones.

It could be guessed that the multi-river curves would make a larger frame, inside which the spiky one-river curves could be placed, but, however, the curves here contain partly the same data. When many one-river curves are taken and an average of their values is calculated, a larger-topped curve is assumed to be achieved. This is due to the fact that variations in conditions, e.g. river geomorphology, hydrology, temperature, and nourishment may cause some changes in preferences. Additionally, the size of the sample may affect the results. The preferences for trout young-of-the-year (Raleigh et al. 1986) differ from the curves for fry; greater depths and less cover in the form of substrate is used. This is natural, because the fish are bigger.

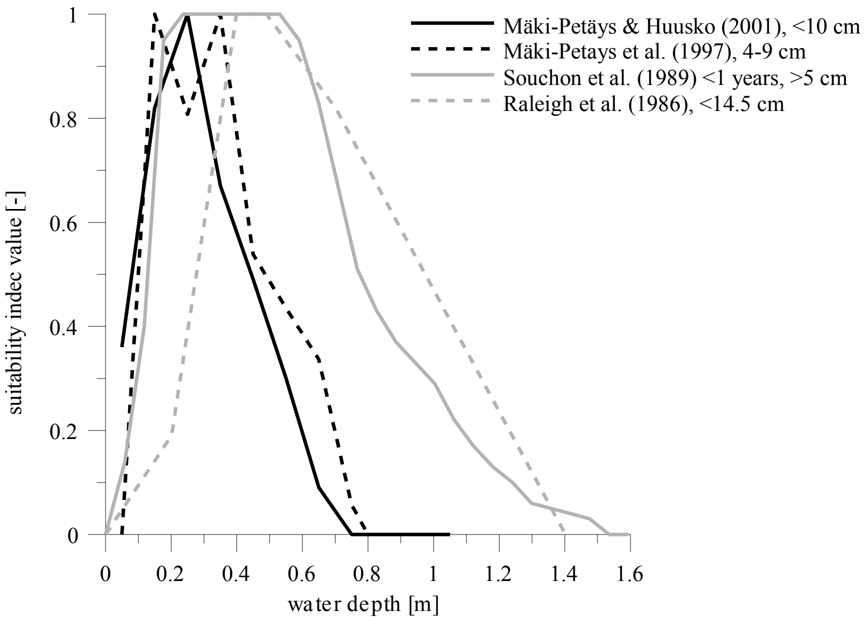


Figure 4.21 Different preference curves for trout fry for water depth (m): a multi-study curve of Mäki-Petäys & Huusko (2001), a single-study curve of Mäki-Petäys et al. (1997), a multi-study curve from America and Eurasia validated in France by Souchon et al. (1989), and the curve of Raleigh et al. (1986) for fish young-of-the-year.

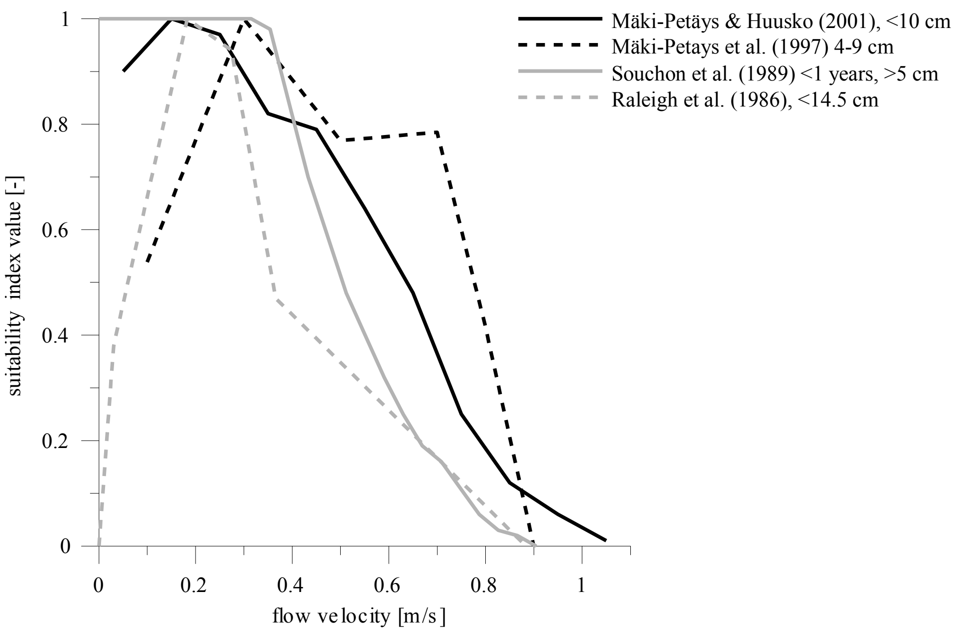


Figure 4.22 Different preference curves for flow velocity (m/s): a multi-study curve of Mäki-Petäys & Huusko (2001), a single-study curve of Mäki-Petäys et al. (1997), a multi-study curve from America and Eurasia validated in France by Souchon et al. (1989), and the curve of Raleigh et al. (1986) for fish young-of-the-year.

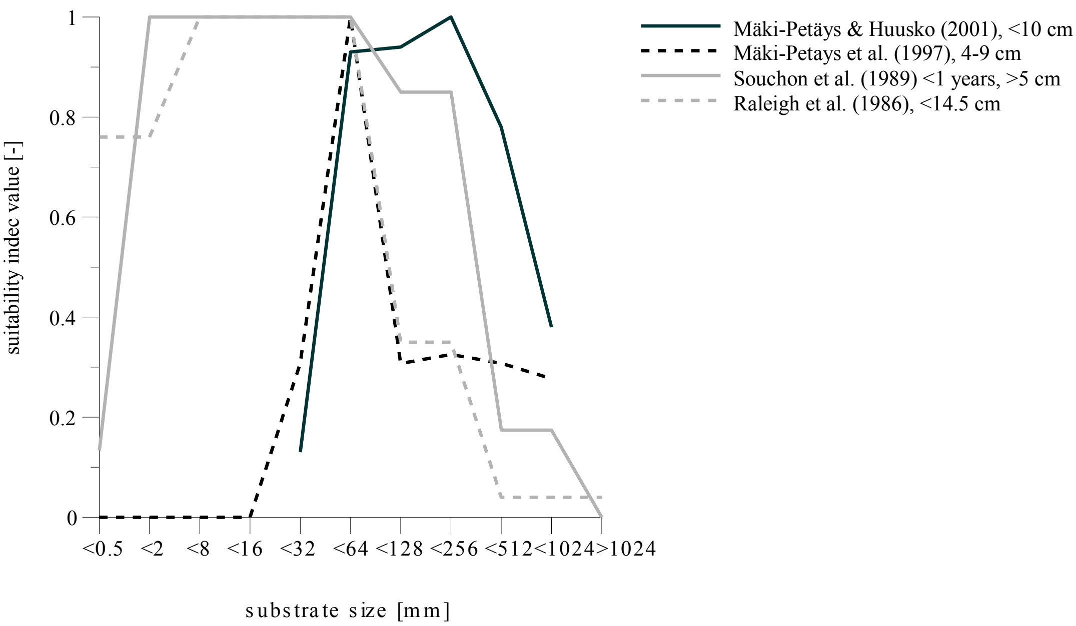


Figure 4.23 Different preference curves for substrate (mm): a multi-study curve of Mäki-Petäys & Huusko (2001), a single-study curve of Mäki-Petäys et al. (1997), a multi-study curve from America and Eurasia validated in France by Souchon et al. (1989) and the curve of Raleigh et al. (1986) for fish young-of-the-year. The size classes are marked on the x-axis in such a way that the ranges begin where the preceding class ends. Some of the preference curves have been adjusted to fit this classification.

Prediction of habitat use with these curves was tested with data from River Ala-Koitajoki. A total of 25 brown trout of lengths of 5-7 centimetres were observed at the Hiiskoski Rapids. Ten of these were 5 centimetres long, which is less than in the preference curves of Souchon et al. (1989), but the effect of fish size difference can be assessed this way. The lengths of the fish are inside the ranges of other preference curves. The preference curves of Mäki-Petäys & Huusko (2001) were modified in such a way that the River Simojoki data that were used in testing were removed. The modified curve is shown in Figure 3.24. The results from using curves 1) are shown in Table 4.1. The calculations with curves 2) produced identical results, which are shown in Table A4.3. Curves 3) also produced identical results (Table 4.2). The preference curves were so identical, that the same number of the 25 fish selected areas with the higher 50% of habitat values in three of four cases, one differing only by one fish (Table 4.3). Though, the first and second curves share River Kuusinkijoki fish observation data, causing some similarity it seems that the modelling of brown trout fry would be easy, because strong and almost identical predictions were the outcome with all the curves tested. This also indicates the possible existence of universal preference curves for brown trout fry.

Table 4.1 Available habitat and habitat use and proportion of use to availability and goodness of fit tests, Preference curve from River Kuusinkijoki by Mäki-Petäys et al. (1997).

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1332	12.46	6	0.48	3.35	2.85	-8.77	
0.1332-1	12.54	19	1.51	3.32	2.83	15.78	
sum	25	25	high/low	6.67	5.68	7.01	6.88
average	0.13	0.18	3.14	0.01	0.02	0.008	0.009

Table 4.2 Available habitat and habitat use and proportion of use to availability and goodness of fit tests, American-French curves (Souchon et al. 1989).

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1606	12.46	6	0.48	3.35	2.85	-8.77	
0.1606-1	12.54	19	1.51	3.32	2.83	15.78	
sum	25	25	high/low	6.67	5.68	7.01	6.88
average	0.22	0.34	3.14	0.01	0.02	0.008	0.009

Table 4.3 Available habitat and habitat use and proportion of use to availability and goodness of fit tests, Raleigh et al. (1986).

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0118	12.46	7	0.56	2.39	1.97	-8.07	
0.0118-1	12.54	18	1.44	2.37	1.96	13.00	
Sum	25	25	high/low	4.76	3.93	4.93	4.84
Average	0.04	0.05	2.55	0.03	0.05	0.03	0.03

4.1.3.2 The effect of season

The importance of using separate preference curves for winter was studied at Harrikoski Rapids and Iso Tainikoski Rapids with models calibrated with preference curves for salmon 4-6 cm long from River Utsjoki for different seasons: August, October, February, and April (Figure 4.24). Water temperatures during these measurements in different seasons were 13, 2.4, 0.5, and 1 Celsius, respectively.

1) Harrikoski Rapids

The water temperature was 0.5 °C (Mäki-Petäys et al. 2004) during the fish observations. Habitat suitability for salmon in October at the Harrikoski Rapids on the River Simojoki with preference curves for 4-6-cm fish from the Mantokoski Rapids on the River Utsjoki by Mäki-Petäys (2005) and fish observations are shown in Figure 4.25 with preference curves for: August (a), October (b), February (c), and April (d). Neither summer nor autumn preference curves did work under winter conditions (Tables 4.4 and 4.5). The winter and spring preference curves gave weak predictions under winter conditions (Tables 4.6 and 4.7).

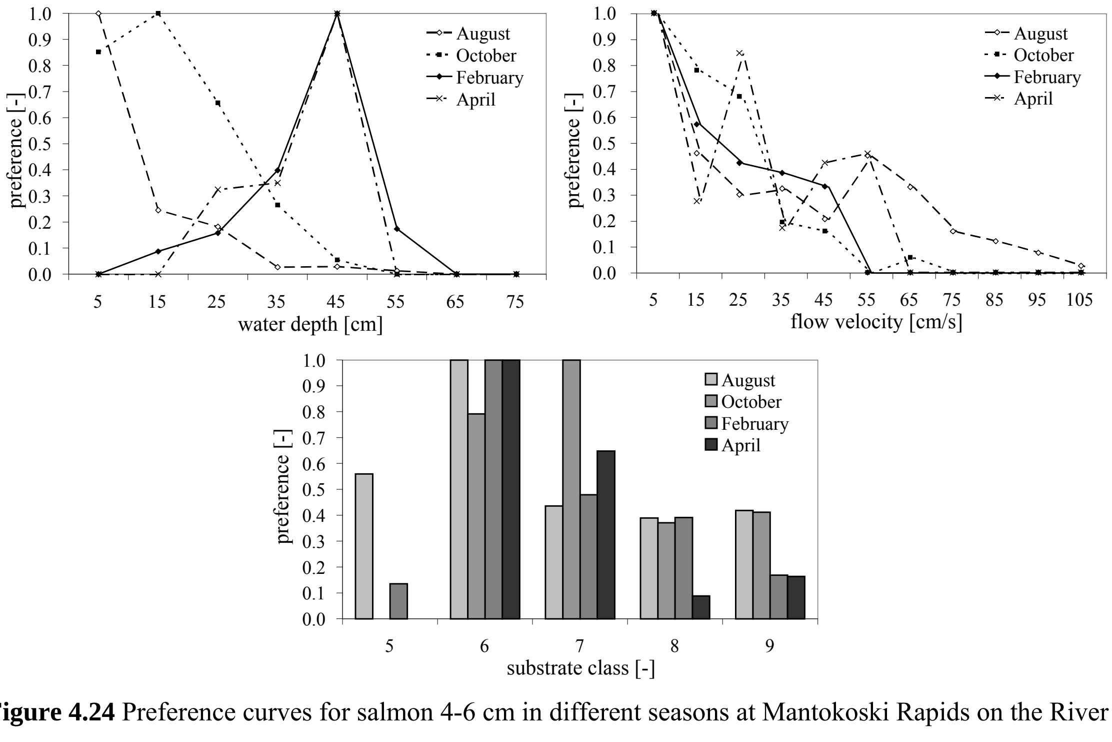


Figure 4.24 Preference curves for salmon 4-6 cm in different seasons at Mantokoski Rapids on the River Utsjoki by Mäki-Petäys (2005), substrate classes: 5, 32.2-64 mm; 6, 64.1-128 mm; 7, 128.1-256 mm; 8, 256.1-512 mm; 9 >512.1 mm. Water temperatures during these measurements in different seasons were 13, 2.4, 0.5, and 1 Celsius, respectively.

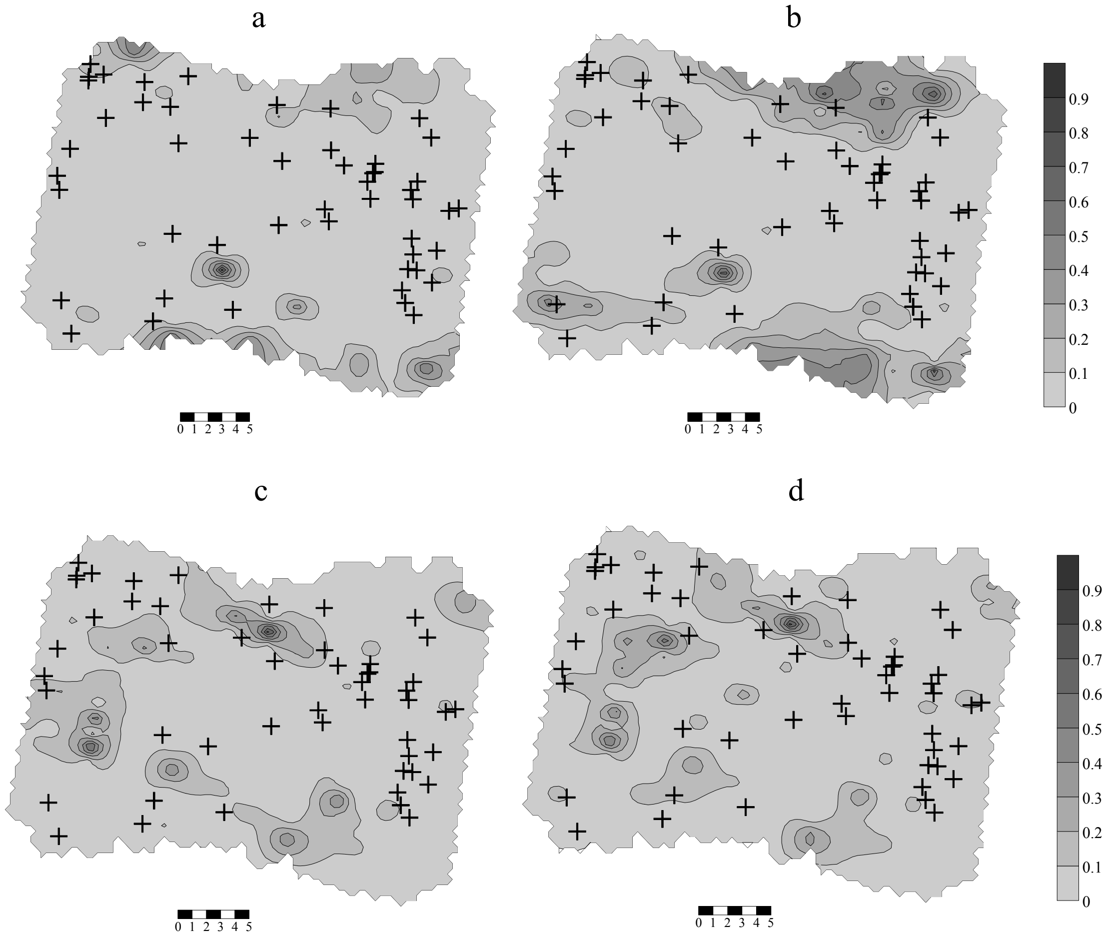


Figure 4.25a-d Habitat suitability for salmon in October at the Harrikoski Rapids on the River Simojoki with preference curves for fish of 4-6 cm in August (a), October (b), February (c), and April (d) from the Mantokoski Rapids on the River Utsjoki by Mäki-Petäys (2005) and fish observations.

Table 4.4 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at Harrikoski Rapids with preference curves for August according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0105	25.50	34	1.33	2.83	2.51	19.56	
0.0105-1	25.50	17	0.67	2.83	2.51	-13.79	
sum	51	51	high/low	5.67	5.02	5.78	5.72
average	0.05	0.02	0.50	-0.02	-0.03	-0.02	-0.02

Table 4.5 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at Harrikoski Rapids with preference curves for October according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0172	25.50	30	1.18	0.79	0.63	9.75	
0.0172-1	25.50	21	0.82	0.79	0.63	-8.15	
Sum	51	51	high/low	1.59	1.25	1.60	1.58
Average	0.09	0.06	0.70	-0.21	-0.26	-0.21	-0.21

Table 4.6 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at Harrikoski Rapids with preference curves for February according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0234	25.50	23	0.90	0.25	0.16	-4.75	
0.0234-1	25.50	28	1.10	0.25	0.16	5.24	
sum	51	51	high/low	0.49	0.31	0.49	0.49
average	0.06	0.06	1.22	0.48	0.58	0.48	0.49

Table 4.7 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at Harrikoski Rapids with preference curves for April according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0177	25.50	24	0.94	0.09	0.04	-2.91	
0.0177-1	25.50	27	1.06	0.09	0.04	3.09	
sum	51	51	high/low	0.18	0.08	0.18	0.17
average	0.06	0.07	1.13	0.67	0.78	0.67	0.78

2) Iso Tainikoski Rapids, lower side area

These curves for the four seasons were tested at the Iso Tainikoski Rapids. Habitat suitability maps for salmon in October at the Iso Tainikoski Rapids, lower side area, on the River Simojoki and preference curves for fish of 4-6 cm in from the Mantokoski Rapids on the River Utsjoki by Mäki-Petäys (2005) and fish observations are shown in Figure 4.26 August (a), October (b), February (c), and April (d). Neither the summer nor the autumn preference curves did work under winter conditions (Tables 4.8 and 4.9). The winter preference curves gave quite good test results under winter conditions (Table 4.10). However, the habitat values were so low that there was no good habitat at all in the study area calculated based on these curves. The spring preference curves gave moderate predictions under winter conditions (Table 4.11).

Conclusions

At both the study areas, the accuracy of prediction of abundance of organisms was the higher, the closer the temperatures at the study site and at the preference study site at the moment of data collection were. The prediction was negative even when the difference between temperatures was rather small with the curves for October. This indicates that it is important to have separate curves for different seasons and water temperatures.

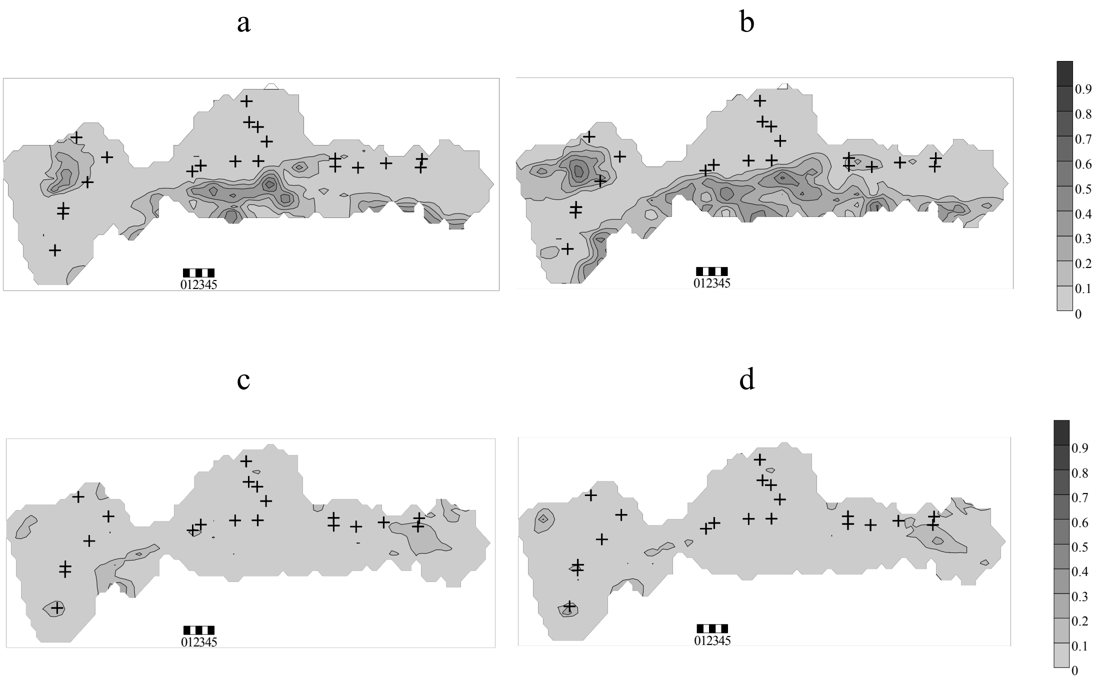


Figure 4.26 Habitat suitability for salmon in October at the Iso Tainikoski Rapids, lower side area, on the River Simojoki and preference curves for 4-6-cm fish in August (a), October (b), February (c), and April (d) at the Mantokoski Rapids on the River Utsjoki by Mäki-Petäys (2005) and fish observations.

Table 4.8 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at the Iso Tainikoski Rapids, lower side area, with preference curves for August according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0109	10.00	17	1.70	4.90	4.23	18.04	
0.0109-1	10.00	3	0.30	4.90	4.23	-7.22	
sum	20	20	high/low	9.80	8.45	10.82	10.55
average	0.07	0.01	0.18	-0.002	-0.004	-0.001	-0.001

Table 4.9 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at the Iso Tainikoski Rapids, lower side area, with preference curves for October according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0182	10.00	15	1.50	2.50	2.03	12.16	
0.0182-1	10.00	5	0.50	2.50	2.03	-6.93	
Sum	20	20	high/low	5.00	4.05	5.23	5.10
Average	0.11	0.02	0.33	-0.03	-0.04	-0.02	-0.02

Table 4.10 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at the Iso Tainikoski Rapids, lower side area, with preference curves for February according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0034	10.00	6	0.60	1.60	1.23	-6.13	
0.0034-1	10.00	14	1.40	1.60	1.23	9.42	
sum	20	20	high/low	3.20	2.45	3.29	3.21
average	0.04	0.08	2.33	0.07	0.12	0.07	0.07

Table 4.11 Available habitat and habitat use and proportion of use to availability for salmon 4-6 cm in winter (October) at the Iso Tainikoski Rapids, lower side area, with preference curves for April according to Mäki-Petäys (2005) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0	11.35	8	0.70	0.99	0.72	-5.60	
0-1	8.65	12	1.39	1.30	0.94	7.86	
sum	20	20	high/low	2.29	1.66	2.26	2.21
average	0.03	0.06	1.97	0.13	0.2	0.13	0.14

4.1.4 Assessment of the relative importance of different factors

To assess the relative importance of the effects of different factors in a trout river, habitat modelling was carried out in the River Tainionvirta. The results of hydraulic modelling were also compared with current meter measurements. The Hotilankoski Rapids are located on the River Tainionvirta, running from Lake Jääsjärvi to Lake Joutsjärvi in Central Finland, east of Lake Päijänne. The mouth of the River Tainionvirta is located in Southern Finland at 61°34N, 26°03E (Figure 4.27). The catchment area at the Kirveskoski Rapids about four kilometres downstream is 1510 km^2 and the lake percentage 24.5. The mean discharge from Lake Jääsjärvi is 11.8 m^3/s, HQ 31, and NQ 4.5 m^3/s. On the River Tainionvirta, the place with the most observations of juvenile trout was selected: a small tributary brook of the Hotilankoski Rapids (Figure 4.28). The length of the Hotilankoski Rapids is about 140 metres, of which the faster-flowing section is 80 metres, with a head loss of about 2.2 metres on average, which is concentrated to a leaking dam forming the mouth of the rapid. Water quality is good. 0+ and 1+ trout have been found in electric fishings. Trout <10 cm in summer were selected as the target species for modelling. The positions of the trout were not mapped, only the number of them was known, but in this study, a sensitivity analysis, the positions of observations are not needed; just the information that the place is a typical habitat of the target species modelled is sufficient. A topographic model of the Hotilankoski Rapids is shown in Figure 4.29. The dam is in the top right corner, where the channels start. The narrow brook-like channel on the left with observations of fry and juveniles of trout was chosen for modelling. The data were processed with line interpolation of measured lines and with curvilinear anisotropic interpolation. After that, a two-dimensional hydraulic model (RMA2) with 20 elements across the river was run (Figure 4.30).

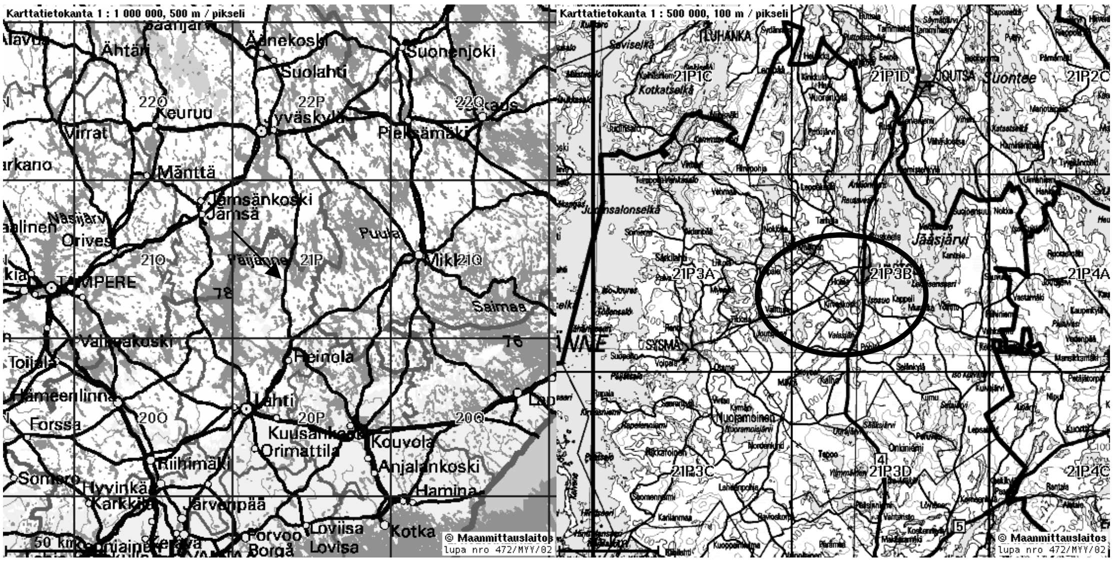


Figure 4.27 The location of the River Tainionvirta.

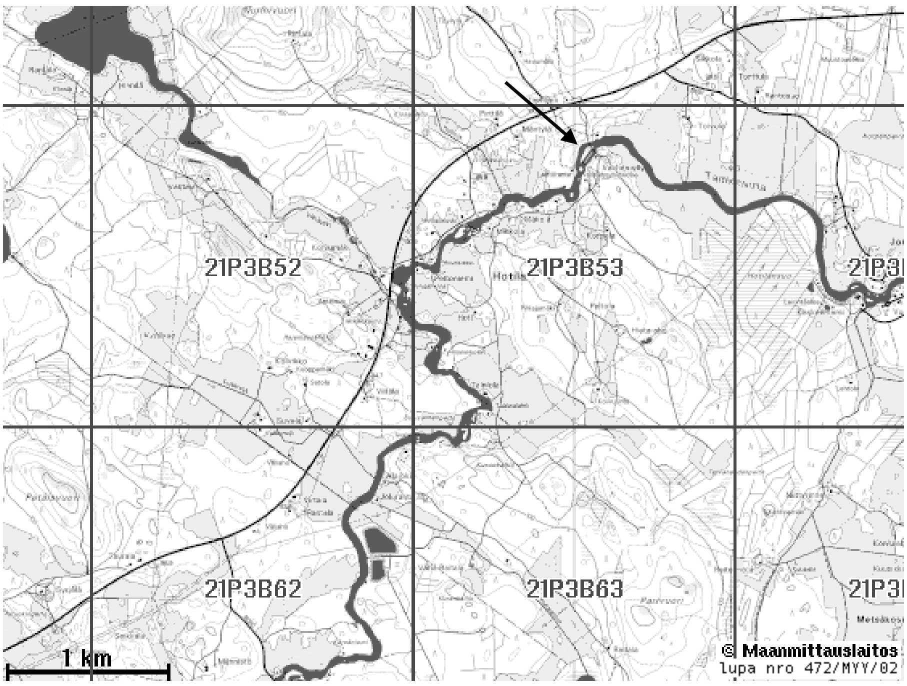


Figure 4.28 The location of the Hotinlankoski Rapids on the River Tainionvirta.

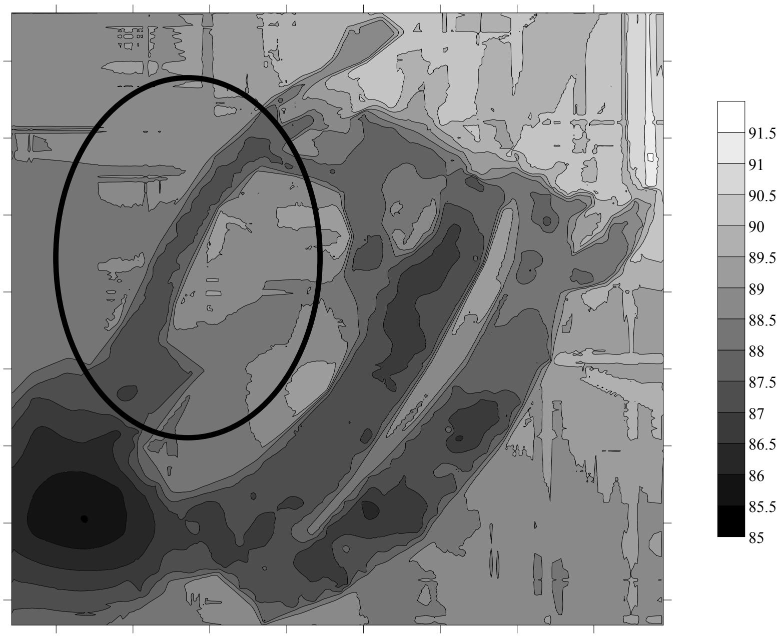


Figure 4.29 The topographic model of the Hotilankoski Rapids and the modelled area.

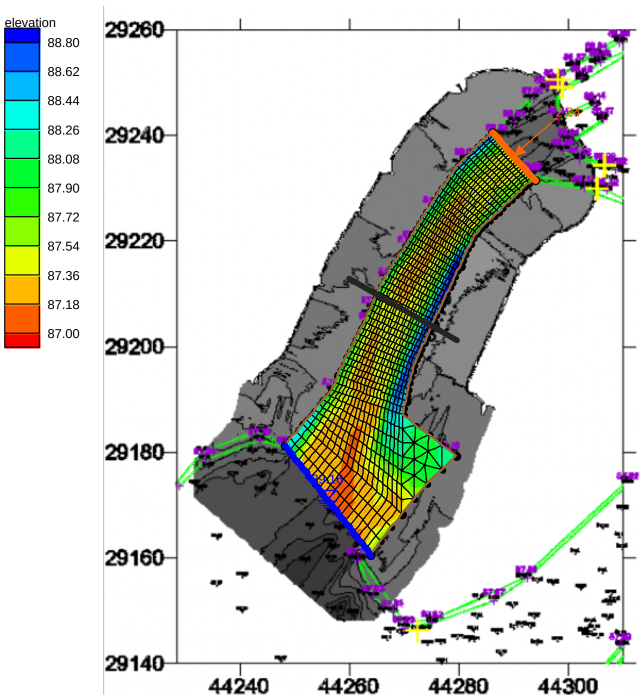


Figure 4.30 The hydraulic modelling grid, contours showing elevation. The line shows the validation line.

First, the accuracy of the model was studied (Figure 4.31). Then the effects of different factors on water depth and flow velocity distribution were tested. All other factors were kept the same. A sensitivity analysis was made for the following factors:

-1/3 of all topography measurement points including line measurements were removed
-1/3 of all topography but line measurement points were removed
-1/3 of all processed topography measurement points were removed after line interpolation
-only standard Kriging was used in interpolation after line interpolation
-water level was set 10 centimetres higher
-flow rate was set 20% higher
-kinematic viscosity parameter value was 37.5% smaller
-10 elements in the hydraulic model across the river

With 2/3 of the field measurement points, the topography model was so unrealistic (Figure 4.32) that it was not possible to calibrate the model with the upstream water level, so the model was calibrated in such a way that the water level was the same as in the model accuracy test case at the validation line.

The changes were much smaller when the line measurement data was unaffected (Figure 4.33). When 1/3 of the points were removed after the line interpolation, the results did not change much either compared with Figure 4.32 (Figure 4.34). The results imply that line measurements are important for the topographic model.

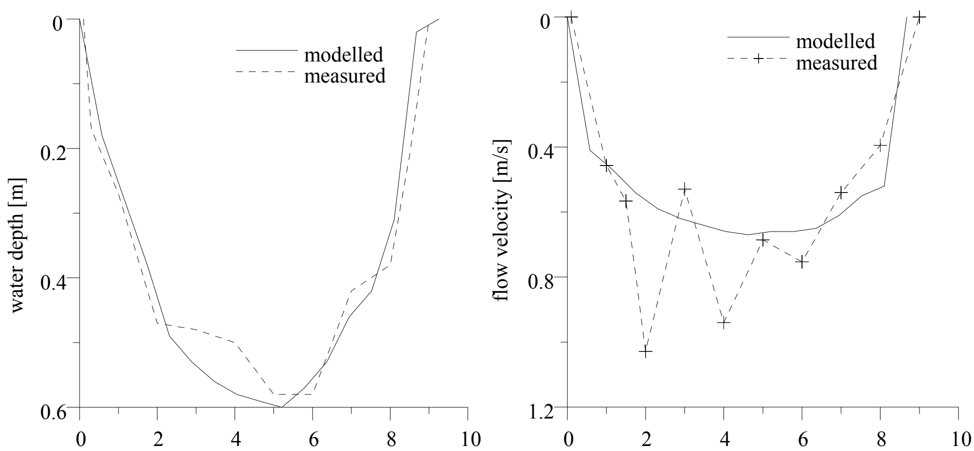


Figure 4.31 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with normal unchanged values and measured values.

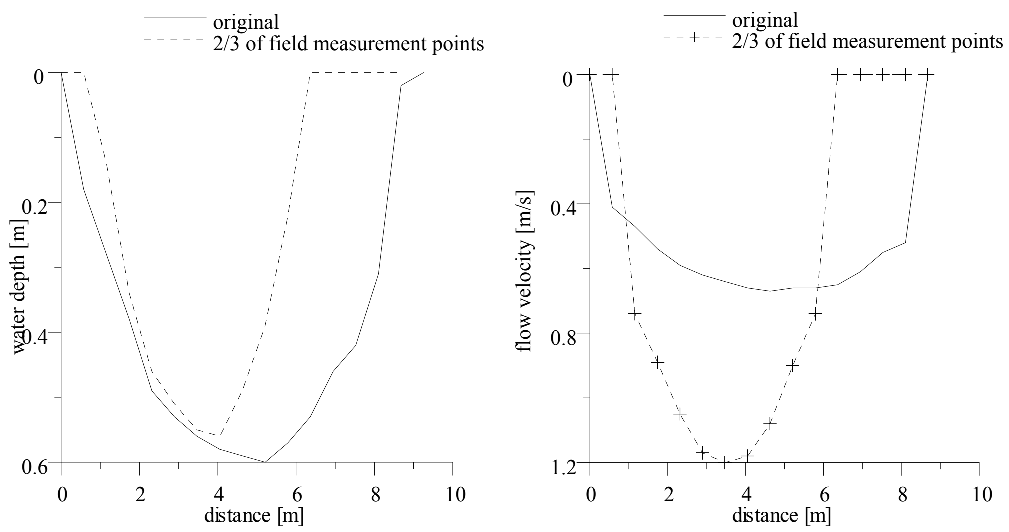


Figure 4.32 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with normal unchanged values and with 2/3 of all measurement points. Other values as in the original modelling.

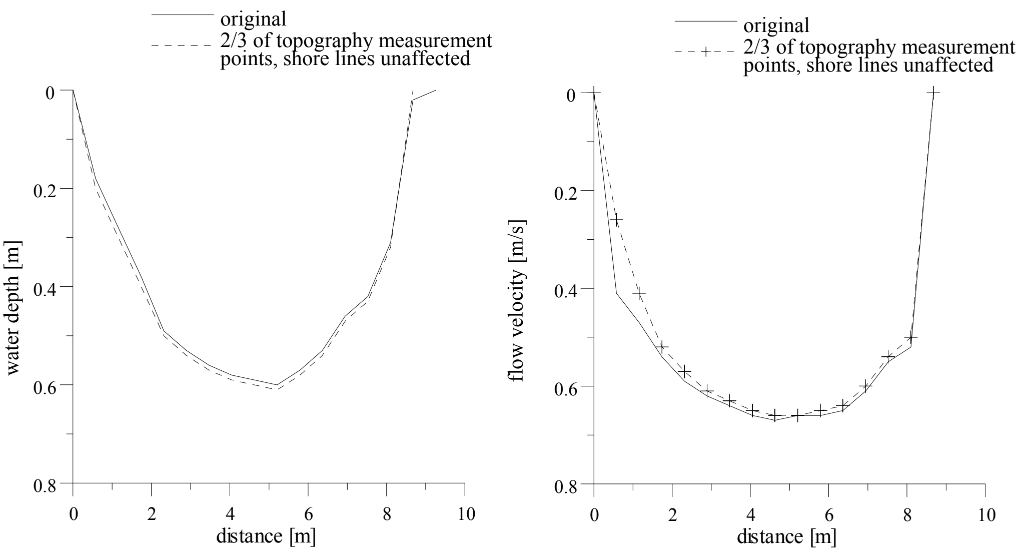


Figure 4.33 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and with 2/3 of topography measurement points, but line interpolation points unaffected. Other values as in the original modelling. The densely interpolated shore lines were not affected by the removal of points in practice.

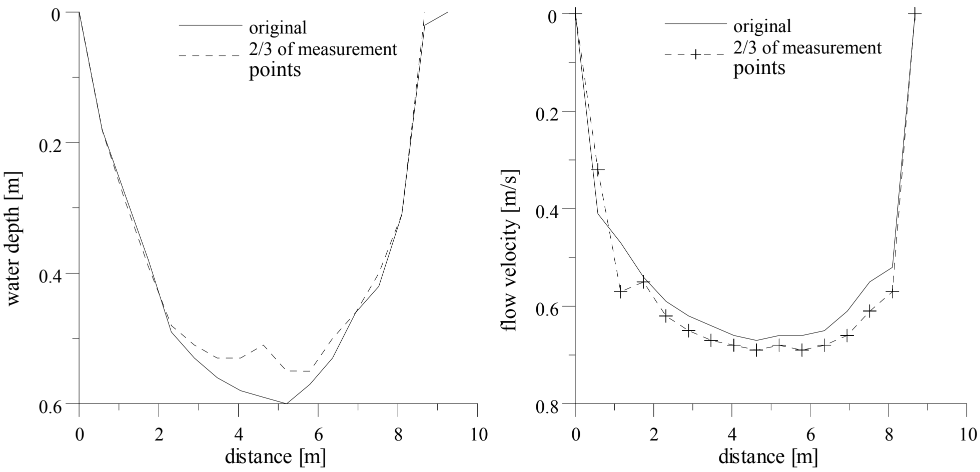


Figure 4.34 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and with 2/3 of measurement points after shore line interpolation. Other values as in the original modelling. The densely interpolated shore lines were not affected by the removal of points in practice. The sample of topography points is different from the previous figure, which explains the greater deviation from the values of the original model.

Using only standard interpolation with Kriging instead of curvilinear anisotropic interpolation changed the results a little (Figure 4.35). Changes in water level and discharge had greater effects (Figures 4.36 and 4.37).

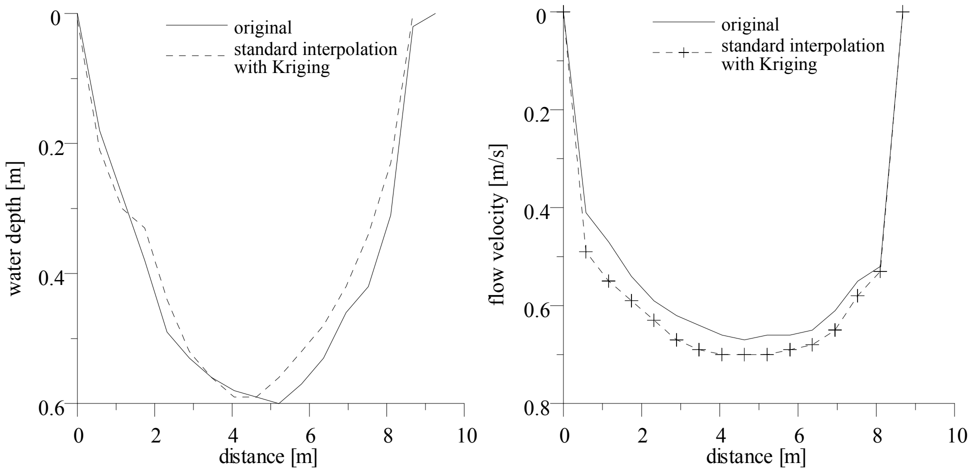


Figure 4.35 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and with only standard interpolation with Kriging. Other values as in the original modelling.

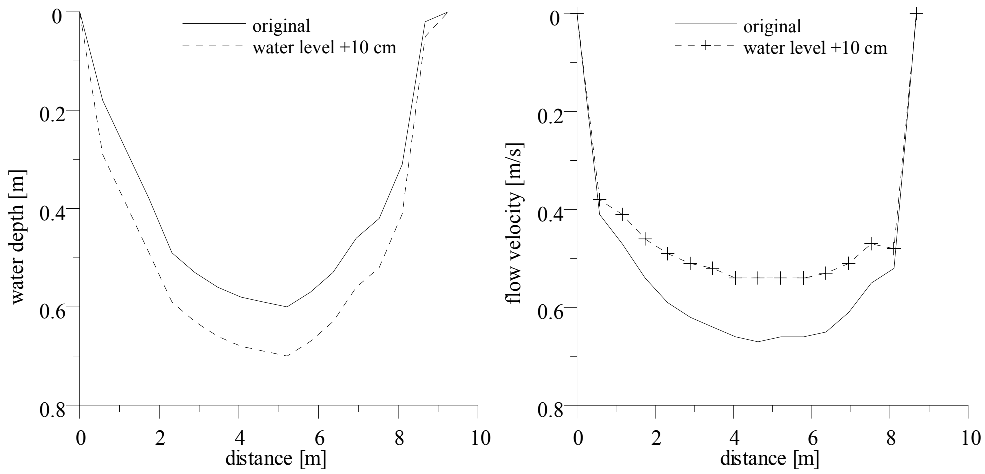


Figure 4.36 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and with a water level 10 cm higher. Other values as in the original modelling.

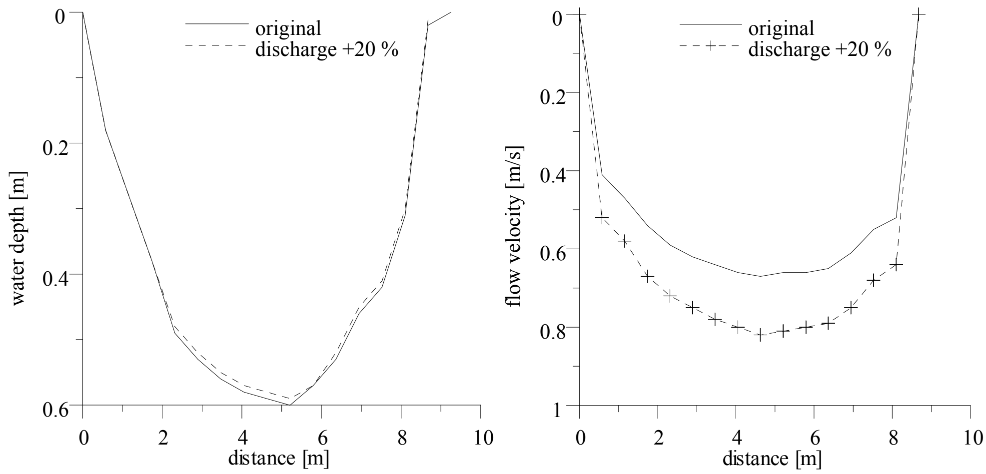


Figure 4.37 Modelled water depth and flow velocity at the Hotilankoski Rapids on the Tainionvirta River with normal unchanged values and with a flow rate 20% higher. Other values as in the original modelling.

Changing the value of kinematic viscosity did not have a remarkable effect (Figure 4.38). Reducing the number of elements in the hydraulic model had the greatest effect on the velocity values near the banks (Figure 4.39).

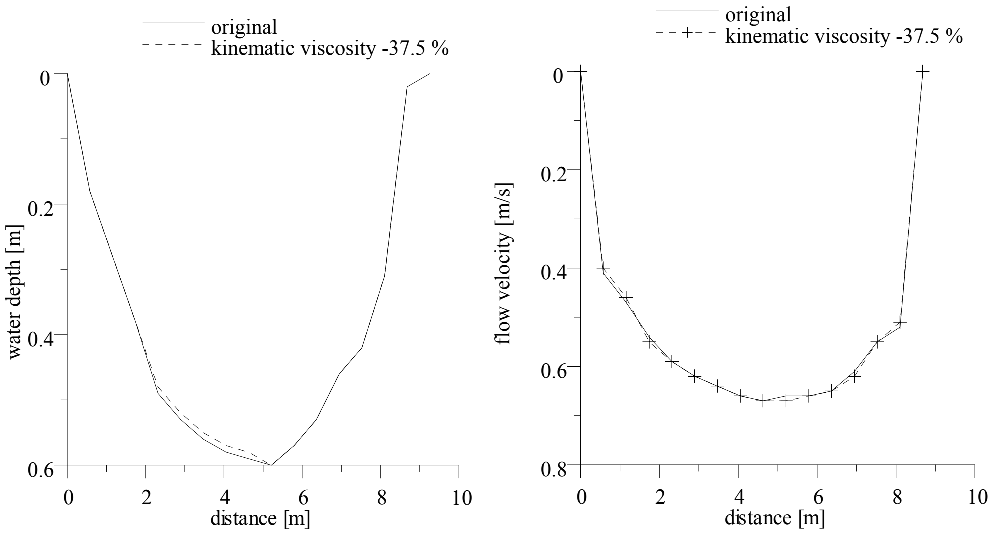


Figure 4.38 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and with 37.5% smaller kinematic viscosity. Other values as in the original modelling.

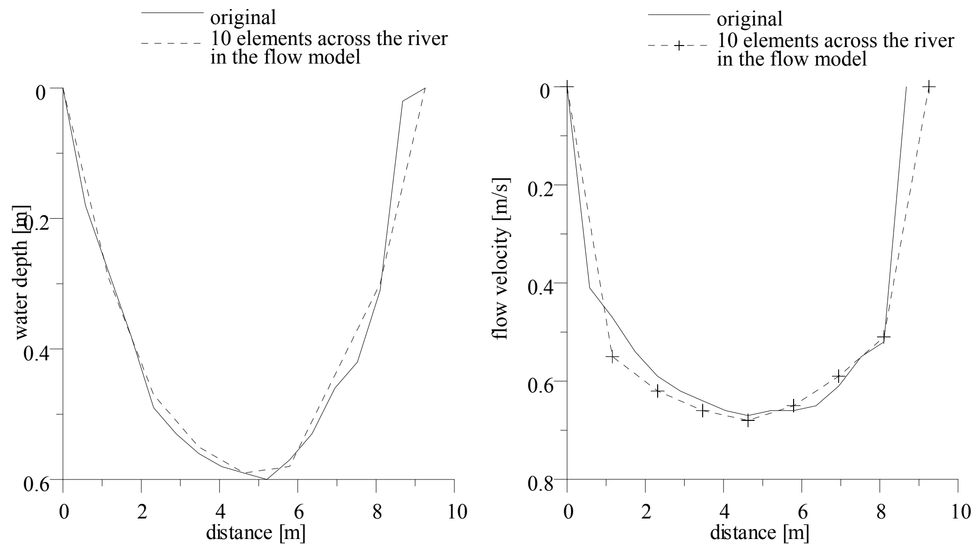


Figure 4.39 Modelled water depth and flow velocity at the Hotilankoski Rapids on the River Tainionvirta with unchanged values and 10 elements in the hydraulic model across the river. Other values as in the original modelling.

Next, the effects of the factors were tested by calculating habitat values using the calculated water depth and flow velocity values. Substrate was not used, because its effect would have been too random. Habitat values calculated with preference curves of Mäki-Petäys & Huusko (2001) for brown trout based on water depth and flow velocity values from the previous sensitivity analysis are shown in Figure 4.40. Of variables related to measurements, topographical and hydraulic modelling, the largest difference was caused by the removal of original measurement points. These results imply that topography measurements, especially shore line measurements, are important. Smaller differences were caused by changes in water level and flow rate, and reducing the number of elements caused differences near the banks.

Additionally, a sensitivity analysis of the effect using different preference curves was carried out (Figure 4.41). The preference curves used were the same curves that were used for preference curve comparison:

-Mäki-Petäys & Huusko (2001), <10 cm
-Souchon et al. (1989), <1 year, >5 cm
-Raleigh et al. (1986), <14.5 cm
-Mäki-Petäys et al. (1997), 4-9 cm

The first curves are based on a large sample and were selected as reference curves for all comparisons. Using different preference curves changed the magnitudes of habitat values quite considerably, but the locations of those habitats with the highest and the lowest suitability index values, were less affected. However, even originally, the preference values in different curves were not comparable with each other without scaling. The curves used were calculated by dividing habitat use by availability, not with Jacobs's method, with which calculations could result in better comparable values.

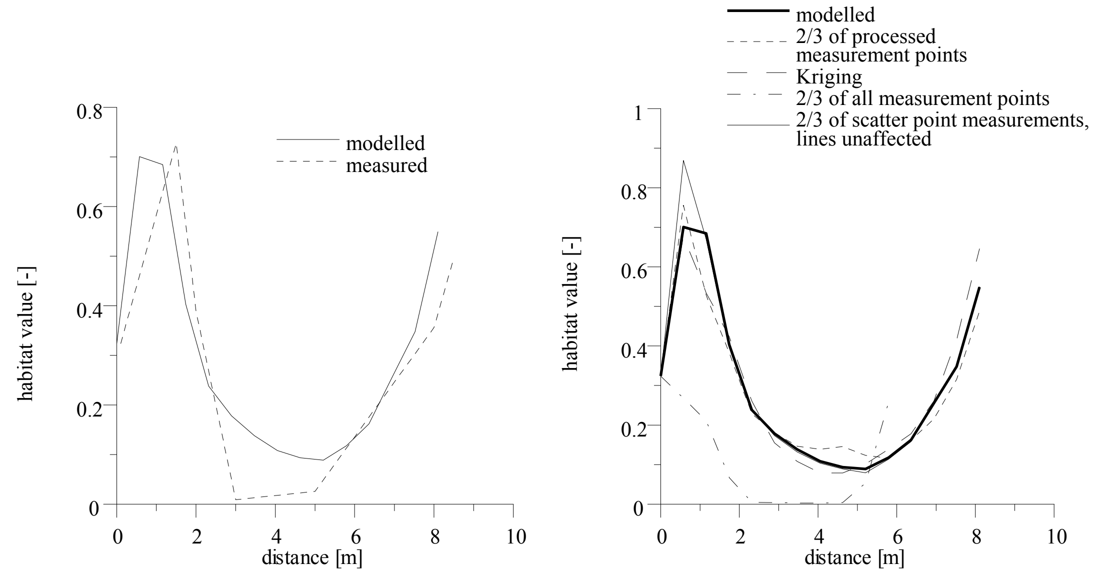


Figure 4.40 Habitat values calculated with the preference curves of Mäki-Petäys & Huusko (2001) based on modelled and measured water depth and flow velocity on the left, and habitat values based on original modelled values and with different different topographies at the Hotilankoski Rapids on the River Tainionvirta on the right. The placement of the origin for the distance values (x-axis) of measured and modelled values is approximate.

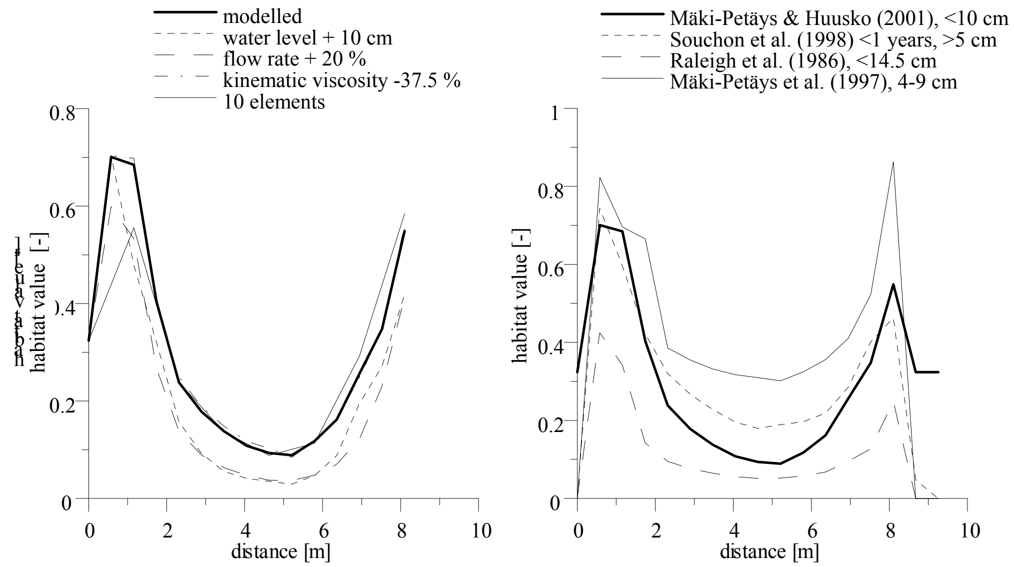


Figure 4.41 Habitat values based on original modelled values and with different parameter values on the left, and with different preference curves on the right at the Hotilankoski Rapids on the River Tainionvirta.

4.2 Crayfish model

4.2.1 Sensitivity of the model to different habitat preference data

The magnitude and the effect of potential erosion may be very different at lakes of different size and with different free wind reaches. Three modellings were carried out at Lake Slickolampi each of them with a different preference curve. The first curves are from a larger Lake Pääjärvi, where lake currents and waves concurrently affect the shores. In the second curves, the curve for potential erosion is replaced with a curve created based on data from all lakes. The third curves are modified curves from the study areas 4-5 at a larger Lake Katumajärvi.

The model created on the basis of data from Lake Pääjärvi was used in a habitat modelling to test whether the model would work at a smaller lake. Correlations between catch/effort ratio and habitat value with different habitat value calculation formulae were calculated (Table 4.12). Correlations were either insignificant or negative, possibly because Lake Slickolampi is much smaller than Lake Pääjärvi. The potential erosion rates at Lake Slickolampi were lower than the lowest value in the preference curve made at Lake Pääjärvi; it should therefore not be used in modelling Lake Slickolampi. The water temperature was higher and in a narrower range at Lake Slickolampi (20-22.5 ˚C) compared with the values in the data of the curve at Lake Pääjärvi (11-24 ˚C). At Lake Slickolampi, it may be that erosion is too low in other parts of the lake than near the banks, and the bed material gets too muddy for crayfish.

Table 4.12 Habitat value calculations at Lake Slickolampi with preference curves from Lake Pääjärvi, correlations between catch/effort ratio and habitat value with different habitat value calculation formulae.

habitat value calculation formula	correlation
sand/fine sand	0.31
soft material	0.25
water depth	0.06
potential erosion	0.00
water temperature	-0.51
product of all	-0.16
product (potential erosion, water temperature)	-0.51
product (sand/fine sand, soft material, water depth, potential erosion)	0.20
product (sand/fine sand, soft material, potential erosion, water temperature)	-0.34
product (water depth, potential erosion, water temperature)	-0.25
product (sand/fine sand, soft material, water depth, water temperature)	-0.16
sum of all	-0.06
sum (sand/fine sand, soft material, potential erosion, water temperature)	0.01

At Lake Pääjärvi, the potential erosion rates are much higher, and the bed material is clean to quite considerable depths. Despite the different conditions the modelling was still performed, and the correlation between the suitability index value and catch/effort ratio was -0.34. The results are shown in Figures 4.42-4.44 and Table 4.13.

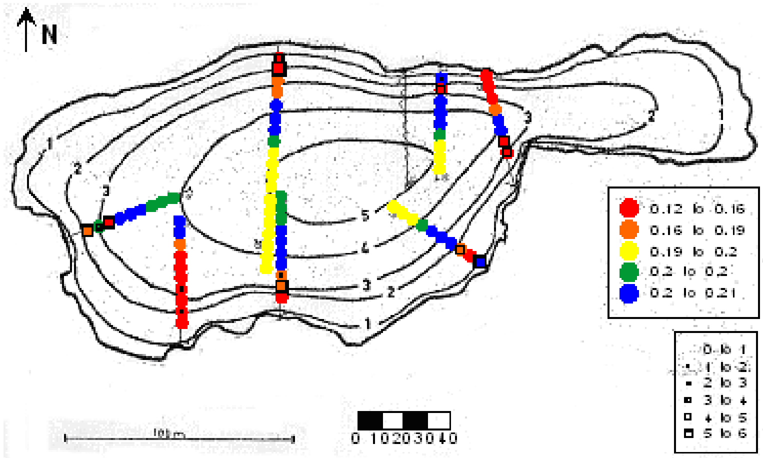


Figure 4.42 A calculated habitat map and catch/effort ratios (circles) at Lake Slickolampi with the original model created at Lake Pääjärvi. Habitat suitability index values are shown with colours. The sizes of the boxes indicate the number of crayfish caught.

Table 4.13 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with original preference curves from Lake Pääjärvi and goodness of fit tests.

habitat value	available	use	proportion	chi-square	Yates	log-likelihood	Williams
0-0.197	24.65	36	1.46	5.22	4.77	27.26	
0.197-1	18.35	7	0.38	7.02	6.41	-13.49	
Sum	43	43	high/low	12.24	11.18	13.77	13.61
Average			0.26	-0.0005	-0.0008	-0.0002	-0.00002

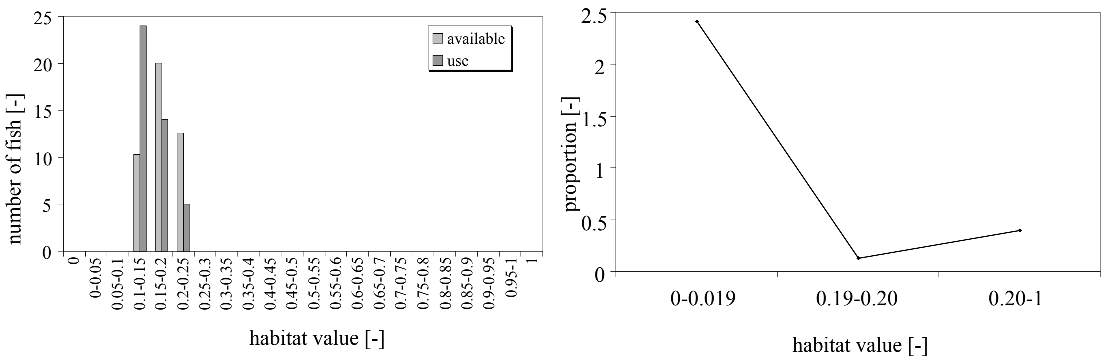


Figure 4.43 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with original preference curves from Lake Pääjärvi.

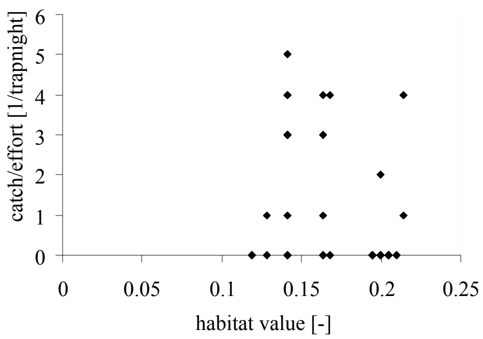


Figure 4.44 Catch/effort ratio as a function of habitat value at Lake Slickolampi calculated with the model created at Lake Pääjärvi.

To see whether the model would work with good-quality preference data, a modelling was also made with preference curves for potential erosion made from the data from all lakes, although this means that a part of the test data is a part of the calibration data. In Figures 4.45 and 4.46 catch/effort ratios for *Pacifastacus leniusculus* as a function of potential erosion from all lakes are represented. Information from Lake Valkjärvi is not included in the figures, because there were no appropriate data for *Pacifastacus leniusculus*, because during the sampling of the data there were water quality changes and a competing species (*Astacus astacus*) possibly affected the habitat selection.

In Figure 4.47, the catch/effort ratio is represented as a function of potential erosion. It can be converted to a preference curve by scaling it so that a preference value of 1 corresponds the catch/effort ratio of 5 catches/trapnight. The curve is based on digitising on the moving average lines. Correlations between different habitat value calculation formulae and the catch/effort ratio were also calculated (Table 4.14). A habitat suitability index map calculated with the Lake Pääjärvi model but with the erosion curve replaced with a curve made from the data from all the lakes studied is shown in Figure 4.48, and the test of significance in Table 4.15. Distributions of available habitat and habitat use and proportion of habitat use to availability are shown in Figure 4.49. Catch/effort ratio as a function of habitat suitability index value is shown in Figure 4.50.

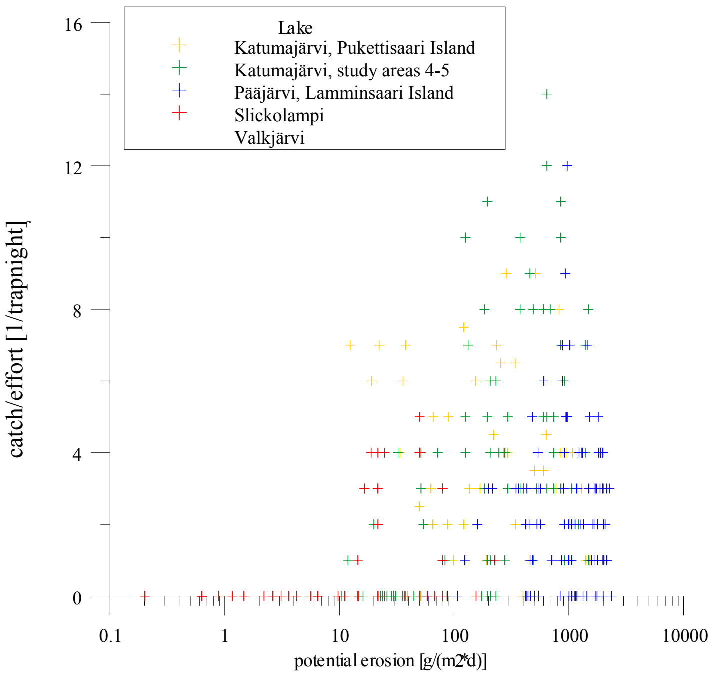


Figure 4.45 Catch/effort ratios as a function of potential erosion from all lakes for *Pacifastacus leniusculus*.

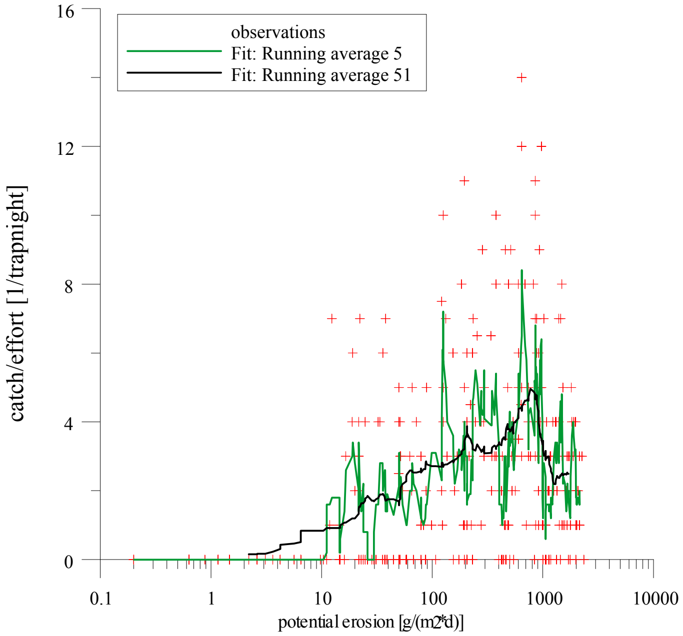


Figure 4.46 Catch/effort ratios as a function of potential erosion from all lakes for *Pacifastacus leniusculus*, and fits with moving average with window sizes of 5 and 51.

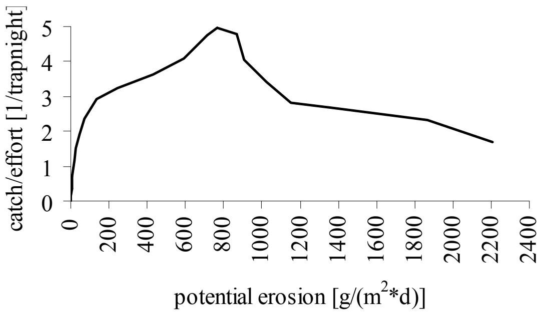


Figure 4.47 Catch/effort ratio as a function of erosion with data from all lakes.

Table 4.14 Correlations between catch/effort ratio and habitat value with different habitat value calculation formulae in habitat value calculations at Lake Slickolampi with preference curves from Lake Pääjärvi, except erosion curve made on the basis of data from all lakes.

habitat value calculation formula	correlation
sand/fine sand	0.31
soft material	0.25
depth	0.06
potential erosion	0.46
water temperature	-0.51
product of all	0.51
product (erosion, water temperature)	0.46
product (sand/fine sand, soft material, depth, erosion)	0.54
product (sand/fine sand, soft material, erosion, water temperature)	0.50
product (depth, erosion, water temperature)	0.46
product (sand/fine sand, soft material, depth, water temperature)	-0.16
sum of all	0.32
sum (sand/fine sand, soft material, erosion, water temperature)	0.43

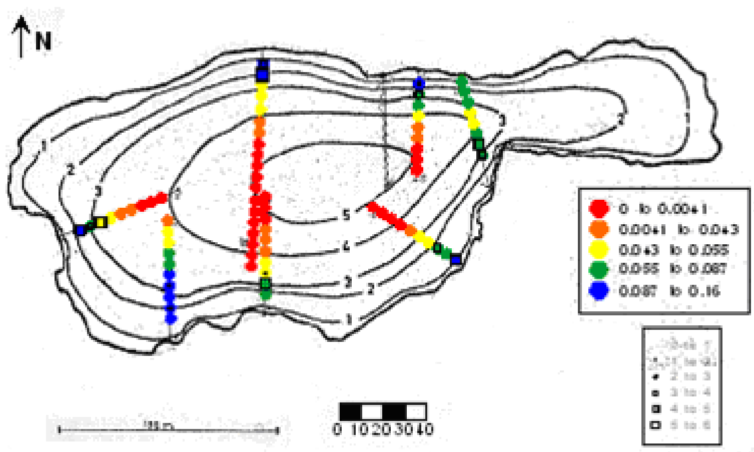


Figure 4.48 A calculated habitat map and catch/effort ratios (circles) at Lake Slickolampi with the original model created at Lake Pääjärvi but with the erosion curve from data from all lakes. Habitat suitability index values are shown with colours. The sizes of the boxes indicate the number of crayfish caught.

Table 4.15 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with the original model created at Lake Pääjärvi but with the erosion curve from data from all lakes and goodness of fit tests. This table should not be used for model validation, because validation data are included in calibration data.

habitat value	available	use	proportion	chi-square	Yates
0-0.04	20.64	0	0.00	20.64	19.65
0.04-1	22.36	43	1.92	19.05	18.14
sum	43	43	high/low	39.69	37.79
average			large	<0.0001	<0.0001

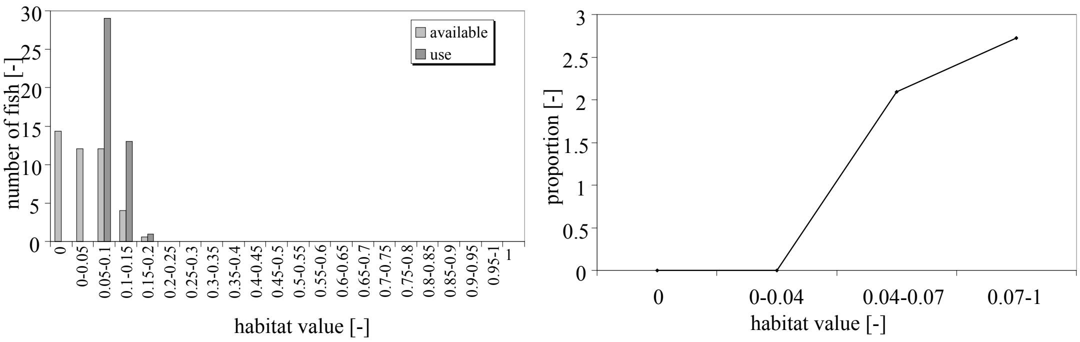


Figure 4.49 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with the original model created at Lake Pääjärvi but with the erosion curve from data from all lakes.

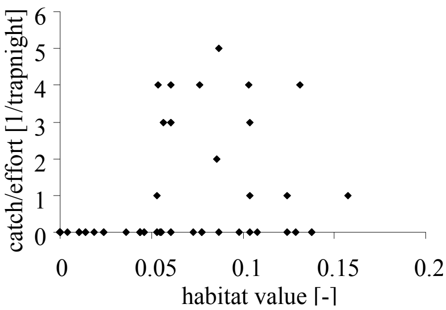


Figure 4.50 Catch/effort ratio as a function of habitat value at Lake Slickolampi with the original model created at Lake Pääjärvi but with the erosion curve from data from all lakes.

The prediction was very good, but some of the test data were included in the calibration data in the preference curve for potential erosion. The form of the preference curve for potential erosion hints at a universal existence of a maximum. Low values of erosion can’t keep the material clean from mud, but too high velocities make moving difficult. However, the data is clustered, which means that the evidence is weak and more studies are needed on the relationship.

Next, it is studied, whether habitat modelling would be possible with high-quality potential erosion preference data from one lake. The preference curve for potential erosion created at Lake Katumajärvi study areas 4-5 is used, because there are mostly very small erosion rates at the smaller Lake Slickolampi. The preference curve was even modified, especially near the origin, based on an assumed dependence between habitat preference and potential erosion. Because erosion is known to keep bed material clean of mud which is harmful to crayfish, but too much water movement may not be favourable, it was assumed that an optimum between these exists. The rather irregular original curve was made modified based on that. The curve for erosion was drawn with the assumption that the curve begins at the origin and has a peak, at 700 g/(m^2*d), from where it declines following the data. From Figures 4.46, 4.51 and 4.52, it can be seen that the catch/effort ratios are going towards the origin, with smaller potential erosion rates at Lake Valkjärvi and Lake Katumajärvi. Values below 30 g/(m^2*d) were not available in the data, and were originally given an equal value in the curves, which may not be correct. In Figure 4.52, catch/effort ratio and a well-fitting sliding average curve are shown, and a dotted line is drawn roughly on the basis of these. The catch/effort ratios were scaled to preference values. With this curve and the preference curve for water temperature created at Lake Katumajärvi study areas 4-5 (Figure 2.5), the habitat value map, the chi-square test, the distributions, and the catch/effort ratio as a function of habitat value were calculated and drawn: (Figures 4.53-4.55 and Table 4.16). In Figure 4.56, catch/effort rate is shown as a function of potential erosion rate and water temperature with data from Lake Pääjärvi, the Lake Katumajärvi study areas 4-5, and Lake Slickolampi. There were no temperature measurements at the Pukettisaari Island study area. The potential erosion curve made at the Lake Katumajärvi study areas 4-5 (Figure 4.52) continues near zero, and gave much better results at Lake Slickolampi than the curve made from data from Lake Pääjärvi. Therefore, erosion preference curves should be made on the basis of data with a wide range. Additionally, strong currents caused by wind-induced large scale water level fluctuations in the lake hit the shores at Pukettisaari Island at Lake Pääjärvi (Erkamo 2002), which may have a remarkable effect on the shores in addition to the water movement caused by waves described with potential erosion. With potential erosion data from other lakes in the two other validation tests, the prediction was very accurate.

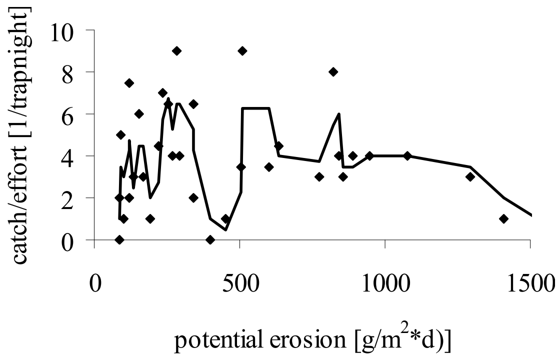


Figure 4.51 A moving average of erosion rate at the Pukettisaari Island study area at Lake Katumajärvi.

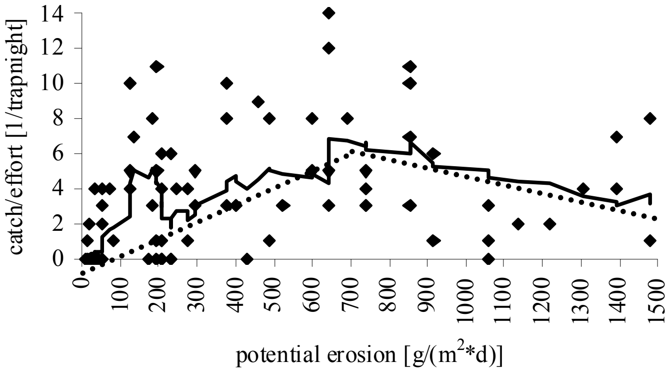


Figure 4.52 Preference curve for erosion made at Lake Katumajärvi study areas 4-5, making a more precise preference curve at small values of potential erosion.

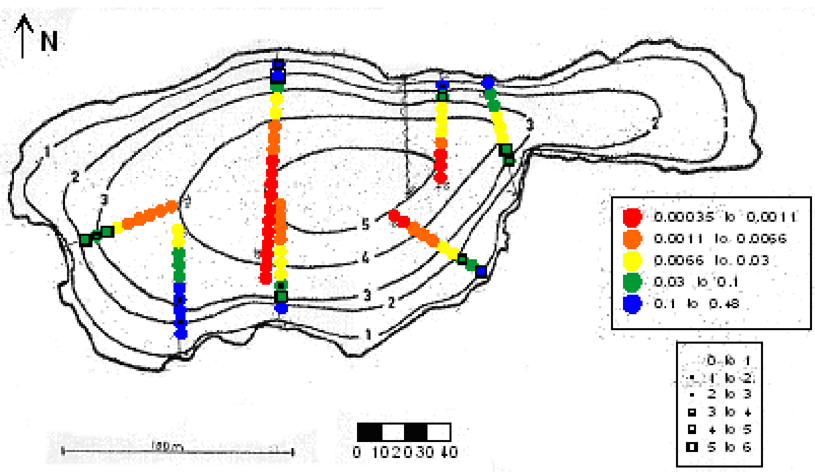


Figure 4.53 A calculated habitat map and catch/effort ratios (circles) at Lake Slickolampi with preference curves made at Lake Katumajärvi study areas 4-5, the preference curve for erosion as in the sketch. Habitat suitability index values are shown with colours. The sizes of the boxes indicate the number of crayfish caught.

Table 4.16 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with preference curves made at Lake Katumajärvi study areas 4-5, the preference curve for erosion as in the sketch and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates
0-0.0119	20.64	0	0.00	20.64	19.65
0.0119-1	22.36	43	1.92	19.05	18.14
sum	43	43	high/low	39.69	37.79
			large	<0.0001	<0.0001

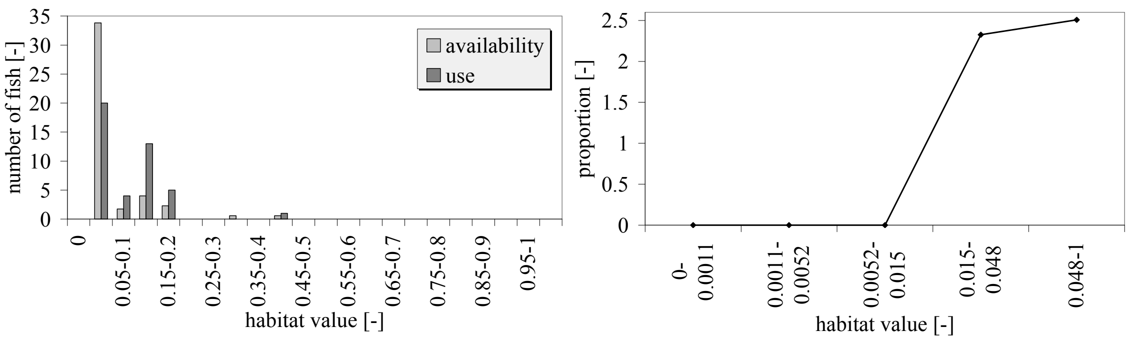


Figure 4.54 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with preference curves made at Lake Katumajärvi study areas 4-5, the preference curve for erosion as in the sketch.

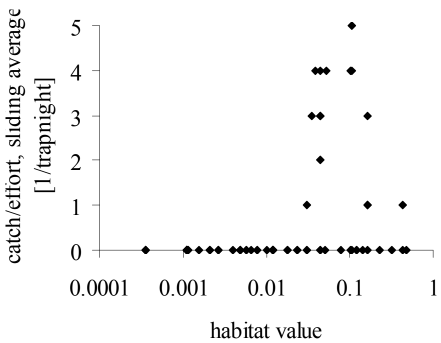


Figure 4.55 Catch/effort ratio as a function of habitat value at Lake Slickolampi with preference curves made at Lake Katumajärvi study areas 4-5, the preference curve for potential erosion as originally, but the curve smoothed to start at the origin.

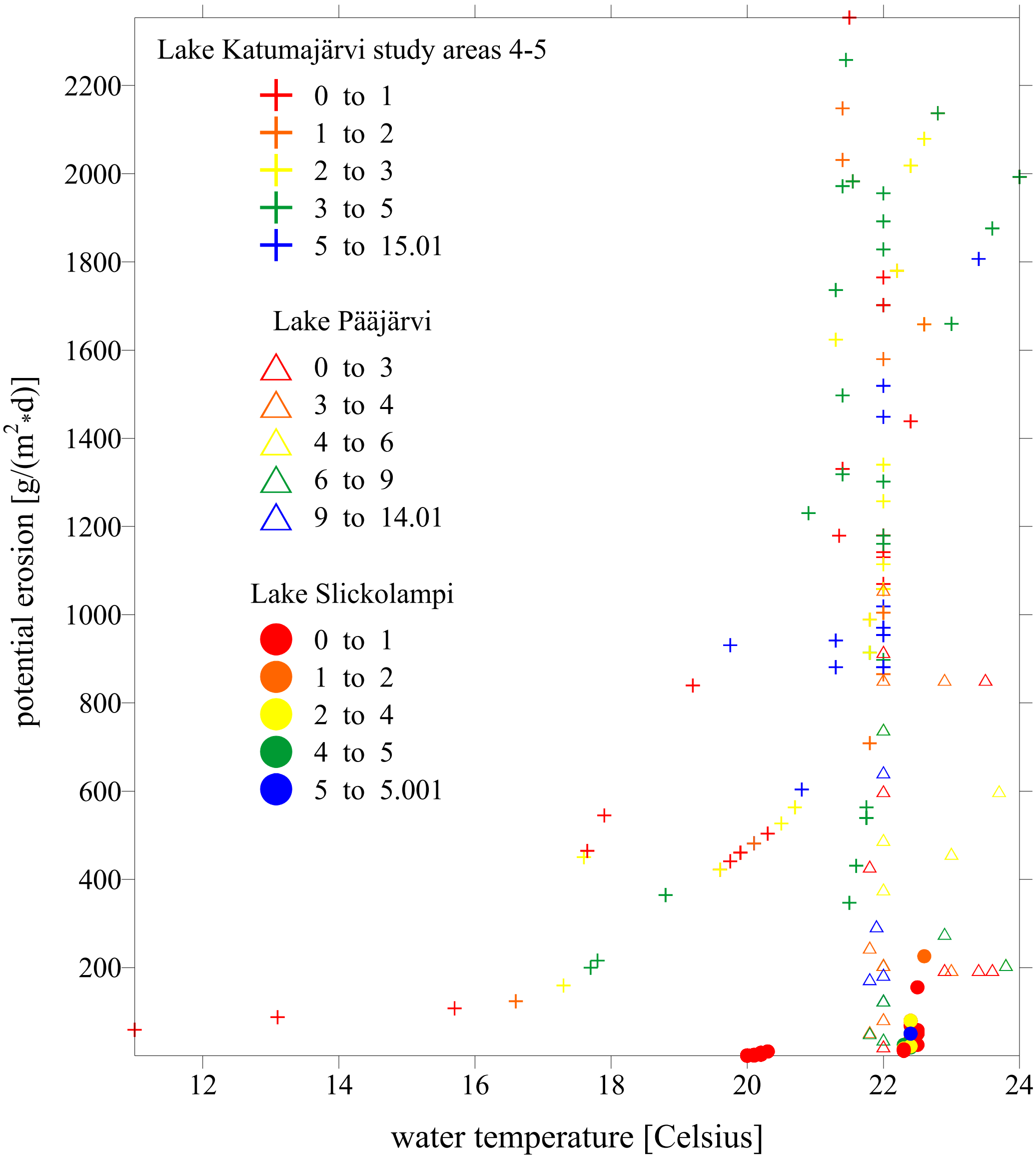


Figure 4.56 Catch/effort ratio [1/trapnight] as a function of erosion rate and water temperature at Lake Pääjärvi at the town of Lammi, Lake Katumajärvi study areas 4-5, and Lake Slickolampi.

5 VALIDATION OF THE MODEL

5.1 Fish Model

5.1.1 River Simojoki

Description of the areas and the organisms studied

The model was validated (Appendices A1-A3) with fish observation data at River Simojoki, where electric fishings had been carried out at Harrikoski Rapids and Iso Tainikoski Rapids lower side and upper side. The study areas are located in the Simojoki River in Northern Finland at latitude 65°45' north and longitude 25°30' east (Figure 5.1). The mean discharge is approximately 38 m^3/s. The catchment area of the river is 3160 km^2 and the slope is 1.0%. The fishing length of the Harrikoski Rapids is 250 metres and they are stony. The current is locally strong. The head of the Harrikoski Rapids is 1.5 metres. The Iso Tainikoski Rapids are one kilometre long and with a varying flow. The numbers of observations in different set of datas are shown in Table 5.1. Field measurement data of water depth, flow velocity and substrate were measured from fish catching spots and covering whole the study areas. The season modelled in the River Simojoki is summer. Description of the areas and the organisms studied are represented in Chapter ”Calibration of the model”. Habitat modellings with preference curves represented in Table 5.1 were carried out and the results were compared with observations at study areas on the River Simojoki.

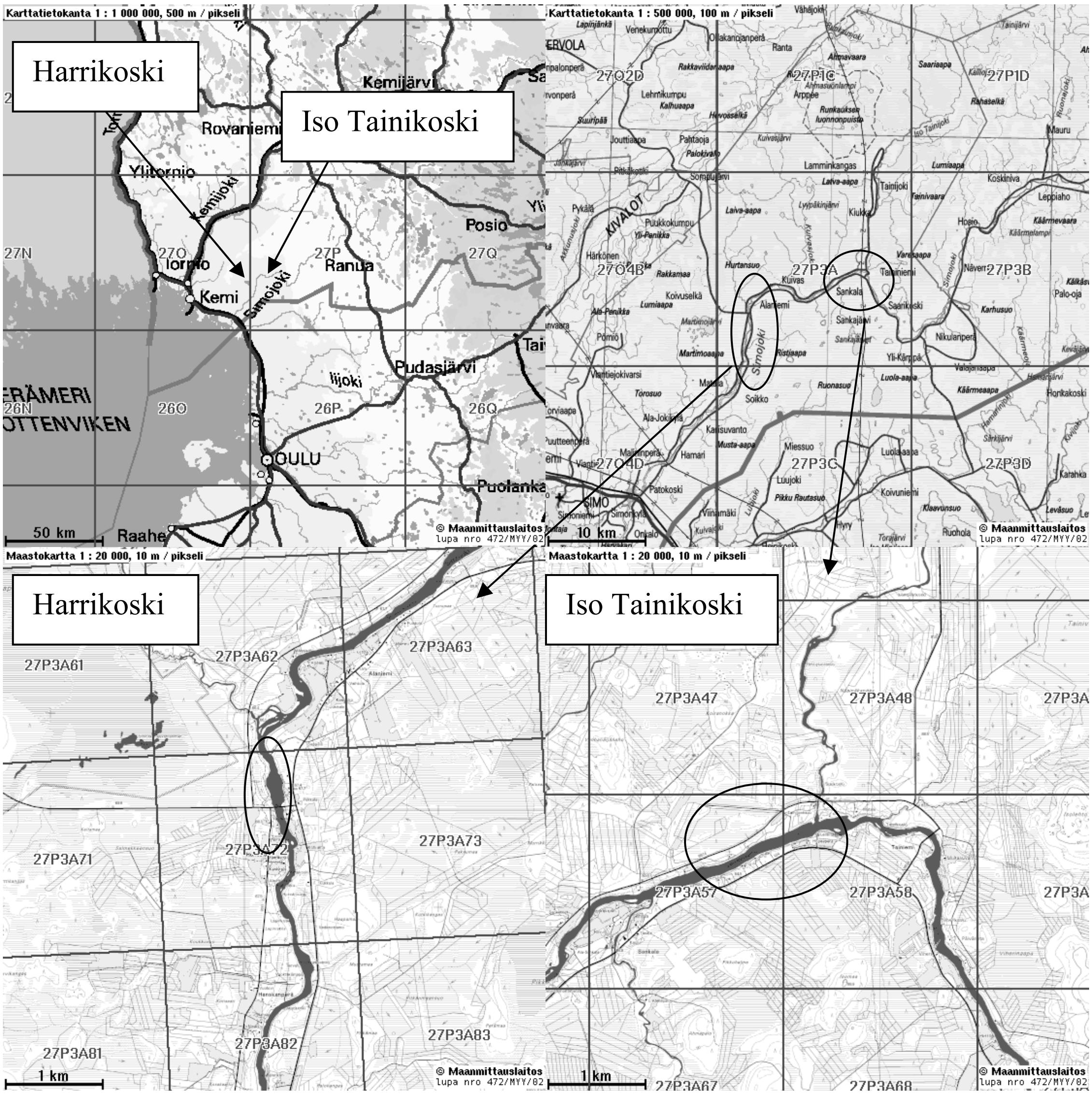


Figure 5.1 The locations of the River Simojoki and Harrikoski and Iso Tainikoski Rapids.

Table 5.1 Numbers of fish observations and preference curves used in modelling with different sets of data in the River Simojoki.

species	size	pref.	Harrikoski	Iso Tainikoski, low	Iso Tainikoski, top
salmon	<10	Mäki-Petäys	138	57	-
		Heggenes	138	57	-
	>10	Mäki-Petäys	31	43	45
		Heggenes	31	43	45
grayling	4-9	Hubert	-	21	-
stone loach	5-13	Harrikoski	-	20	-
	5-12	Lamouroux	31	20	-
bullhead	2-7	Harrikoski	-	25	-
	4-7	Lamouroux	41	25	-

Measurements and modelling

The measurements were made by the Finnish Game and Fisheries Research Institute for earlier fish preference studies (Huusko et al. 2003). The amount and quality of data are high. The locating of fish was done by electric fishing with a point-like area measurement method. The values of habitat variables were measured from fish finding points. The flow velocity was measured with a current meter from a depth of 60% from the water surface. The type of current meter used was a Schiltknecht Miniwater Type 642 w-m/l; the diameter of the impeller was 20 mm. Water depth and the coarsest, dominant, and second most dominant particle sizes from the river bed were also measured. Habitat availability was measured systematically with an interval of 0.5 metres with the help of line rods, and the lines were one meter apart from each other (Mäki-Petäys et al. 2002), allowing the interpolation of contoured maps for visualisation. The locations of the measurement points were measured to coordinates with a tacheometer and water depth was measured with a measurement rod. Substrate was measured to a modified Wentworth scale (Mäki-Petäys et al. 1997). Single physical measurement and fish observation points outside the homogeneously measured area were removed from the data. Habitat values were calculated directly from the measured values. Interpolation was used only for making figures. The contoured maps were interpolated with a search radius of 2.5 metres, because the shorelines were not known exactly.

Results

The significances between observed and expected habitat use in all the River Simojoki data are shown in Table 5.2, and the proportions of use of areas with higher habitat quality index values to use of areas with lower values are shown in Table 5.3. The difference in use of higher- and lower-value habitats was significant in eight out of ten cases for salmon. In all of these ten cases more fish were found in areas with higher habitat values. The difference between the use of areas with higher and lower habitat suitability index values was strongly significant for all four cases of salmon <10 cm and strongly significant in three, significant in one, and insignificant in two cases of six of salmon >10 cm. The difference was strongly significant for grayling and insignificant for stone loach in all three cases and strongly significant for bullhead in one case and insignificant in one. The number of observations affects the percentages. In all modelling for salmon, grayling, and bullhead, more fish were observed in the higher habitat value class than in the lower. Stone loaches were observed more often in the lower habitat value classes in two cases. The set of preference data used for making the preference curves used for stone loach and bullhead at the Harrikoski Rapids was small.

The significances and proportions are plotted in the axes of Figure 5.2. The proportions of habitat use to availability are shown in Figures 5.3-5.4

Table 5.2 P-values for difference [-] between distributions of available habitats and observed habitat use with log-likelihood test with Williams' correction.

species	size	pref.	Harrikoski	Iso Tainikoski, low	Iso Tainikoski, top
salmon	<10	Mäki-Petäys	0.002	<0.0001	-
		Heggenes	0.007	<0.0001	-
	>10	Mäki-Petäys	0.02	0.001	0.31
		Heggenes	0.6	0.002	0.0001
grayling	4-9	Hubert	-	0.004	-
stone loach	5-13	Harrikoski	-	-0.37	-
	5-12	Lamouroux	-0.07	0.08	-
bullhead	2-7	Harrikoski	-	0.002	-
	4-7	Lamouroux	0.17	0.26	-

Table 5.3 Proportions of the proportions of habitat use to habitat availability in the habitat value class with higher suitability index value to the value in the class with lower suitability index value.

species	size	pref.	Harrikoski	Iso Tainikoski, low	Iso Tainikoski, top
salmon	<10	Mäki-Petäys	1.7	3.06	-
		Heggenes	1.6	3.73	-
	>10	Mäki-Petäys	2.43	2.9	1.36
		Heggenes	1.21	2.9	3.48
grayling	4-9	Hubert	-	4.23	-
stone loach	5-13	Harrikoski	-	0.66	-
	5-12	Lamouroux	0.51	2.27	-
bullhead	2-7	Harrikoski	-	2.12	-
	4-7	Lamouroux	1.54	1.58	-

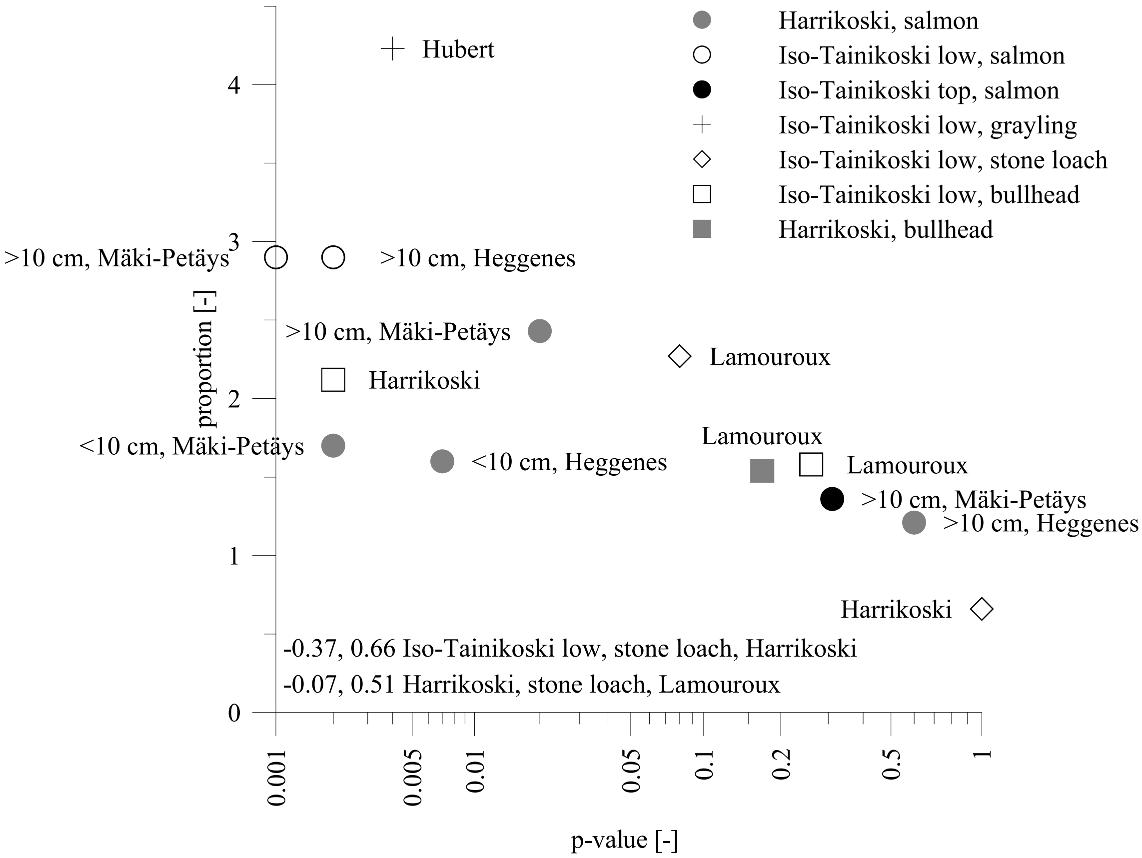


Figure 5.2 Significances of differences between distributions of habitat use and habitat availability and proportions of habitat use to availability in the River Simojoki for salmon and brown trout. A value of 0.05 is significant, 0.01 strongly significant.

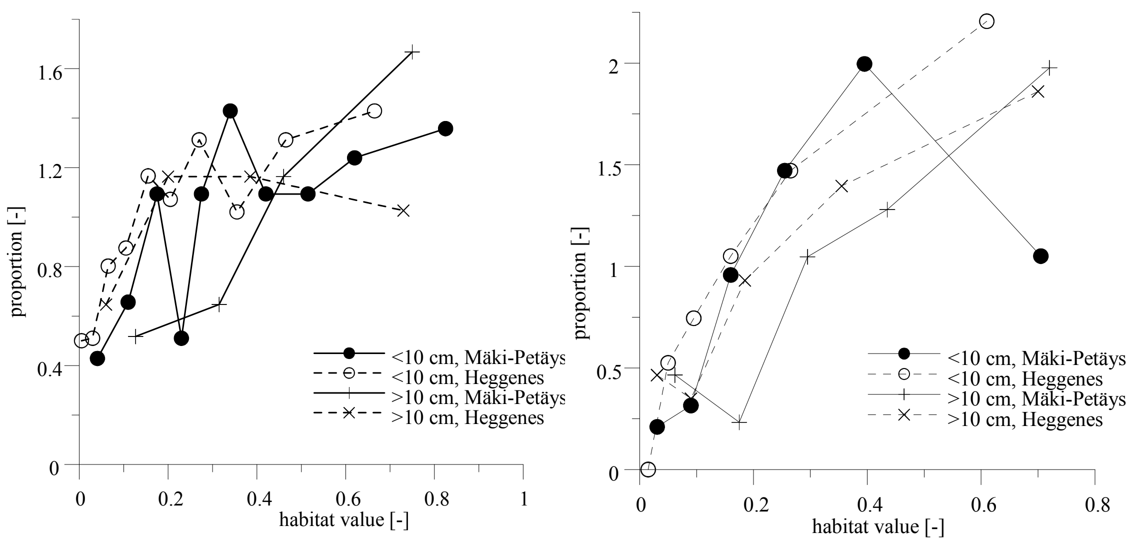


Figure 5.3 Proportions of habitat use to available habitat for salmon at the Harrikoski and Isotainikoski Rapids, lower side area, at midpoints of habitat value classes. The first classes begin from the first value and the last class ends respectively.

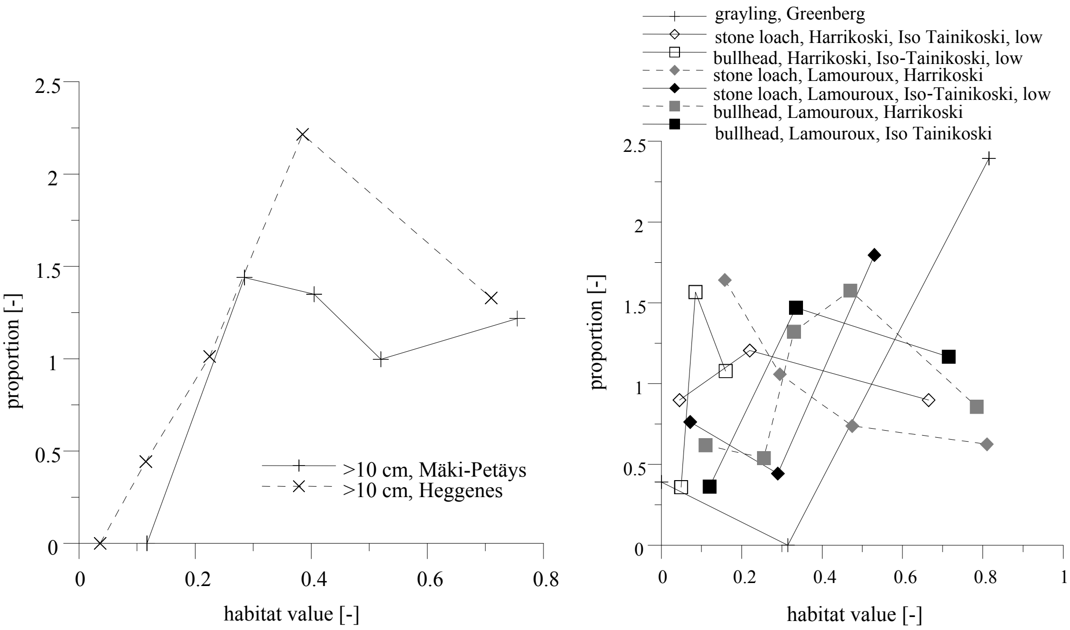


Figure 5.4 Proportions of habitat use to available habitat for salmon at the Iso Tainikoski Rapids, upper side area, and for grayling, stone loach, and bullhead at the Iso Tainikoski Rapids, lower side area, and at the Harrikoski Rapids.

In Figure 5.5, clear avoidance of the lowest habitat values can be seen for salmon. The averagely valued habitats are used in proportion to their amount and the areas with the higher habitat values are preferred.

Figure 5.6a shows a graph demonstrating the preference of salmon for using areas with different calculated habitat values, summarising previous figures. Figure 5.6b shows the same for grayling, stone loach, and bullhead together. The coefficient of determination for salmon is quite high, 0.63. For grayling, there was only one set of data available, in which the preference for higher values was strong. The results from sets of data for stone loach were contradictory. The preference curve sets of data for stone loach and bullhead from the Harrikoski Rapids was small.

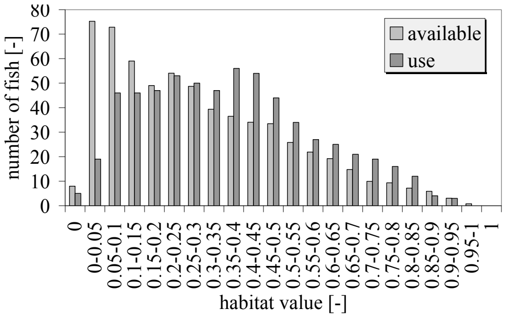


Figure 5.5 All availabilities and uses of habitat of salmon data used in the River Simojoki study.

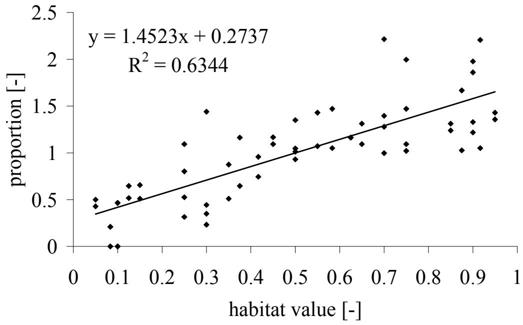


Figure 5.6a All proportions of use to availability values divided uniformly from habitat value of 0 to value of 1 of salmon data used in the River Simojoki study (previous figures) together.

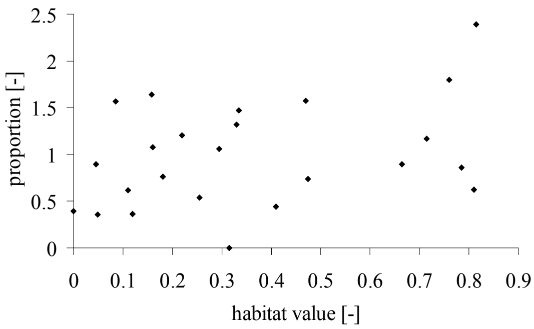


Figure 5.6b All proportions of use to availability values divided uniformly from habitat value of 0 to value of 1 of grayling, stone loach, and bullhead data used in the River Simojoki study (previous figures) together.

5.1.2 River Ala-Koitajoki

Description of the area and the organism studied

The fish model was validated with fish observation data at Hiiskoski and Tyltsykoski Rapids on River Ala-Koitajoki. The study areas are located on the River Ala-Koitajoki in Eastern Finland at latitude 62°51' north and longitude 30°28' east (Figure 5.7). The catchment area of the river is 6795 km^2 and the slope is 2.2%. The average discharge of approximately 2 m^3/s is discharged to the original channel, passing a hydro power plant, and it is maintained the whole year. Trout and salmon reproduce naturally in the river.

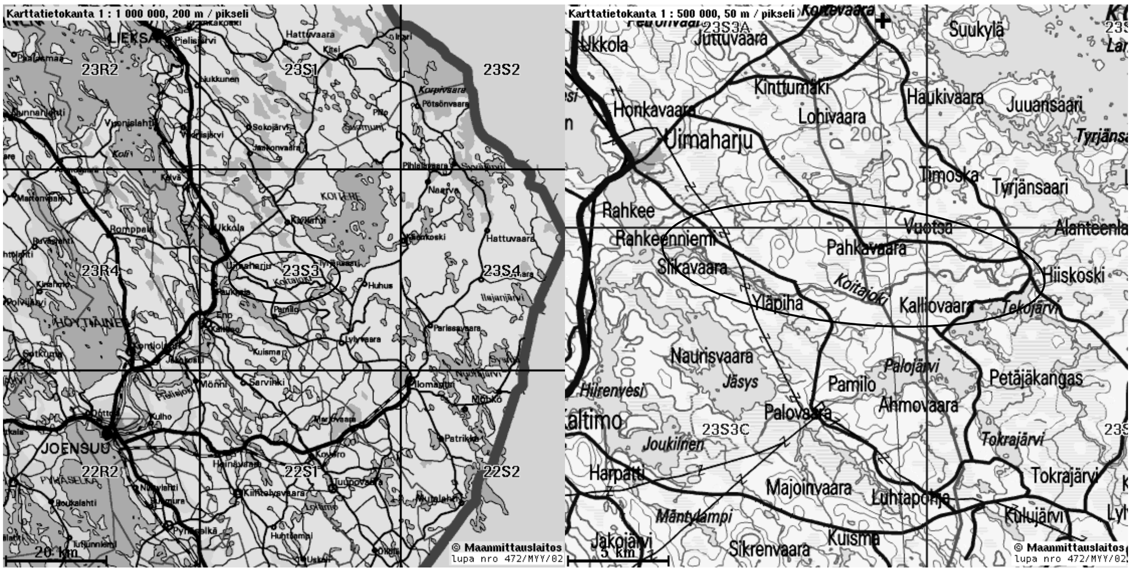


Figure 5.7 The location of the River Ala-Koitajoki.

Measurements and modellings

The field measurement methods were the same as with the River Simojoki, except that a measurement tape was placed across the river and the availabilities were measured with uniform dense intervals compared with the distances between lines and without geographical coordinates, which did not allow contoured maps to be interpolated for visualisation. In the figures drawn in this study, the distance between measurement lines is set to be equal, but the cross-sectional direction is in scale. The availability of habitats and the fish observations were measured from the same area (Mäki-Petäys et al. 2002). The lines were measured at roughly constant intervals along and across the study area (Mäki-Petäys et al. 2002), which meant that the measurements could be used as availability data. Water temperatures varied between 14-20 °C in the River Koitajoki during the period from summer to autumn (Mäki-Petäys et al. 2002), so the same summer preference curves were used for both seasons. The fish species modelled were salmon and trout (Appendices A4 and A5). The numbers of observations in sets of data gathered with electric fishing are shown in Table 5.4.

The significances in all the River Ala-Koitajoki data are shown in Table 5.5, and the proportions of use of areas with higher habitat suitability index values to use of areas with lower habitat values are shown in Table 5.6. The difference between the uses of higher- and lower-value habitats was classified as strongly significant in one and significant in one case out of 5 cases for salmon (Table 5.5 and Figure 5.8) and strongly significant in both cases for brown trout. In all cases more fish were found in areas with higher habitat values. The ascending trend of proportions of use to availability towards higher habitat values is clear in these data with good-quality preference curves (Figures 5.9 and 5.10).

In Figure 5.11, a clear avoidance by salmon and trout of the lowest-value habitats can be seen. The average-valued habitats are used in proportion to their amount and the habitats with the highest suitability index values are preferred. Figure 5.12 shows a graph demonstrating the preference of salmon and of grayling for using areas with different calculated habitat values summarising previous figures. The correlations for salmon and brown trout are quite high, however, the brown trout set of data was small.

Table 5.4 Number of fish observations, season of fish observations, and preference curves used in modelling with different sets of data in the River Ala-Koitajoki.

species	size	season	pref.	Hiiskoski	TyItsykoski
salmon	<10	summer	Mäki-Petäys	-	77
		autumn	Mäki-Petäys	-	40
	>10	summer	Mäki-Petäys	48	29
		autumn	Mäki-Petäys	65	-
brown trout	<10	summer	Mäki-Petäys	25	-
	16-25	summer	Mäki-Petäys	35	-

Table 5.5 P-value for difference [-] between distributions of available habitats and observed habitat use with log-likelihood test with Williams' correction.

species	size	season	pref.	Hiiskoski	TyItsykoski
salmon	<10	summer	Mäki-Petäys	-	0.002
		autumn	Mäki-Petäys	-	0.11
	>10	summer	Mäki-Petäys	0.16	0.2
		autumn	Mäki-Petäys	0.04	-
brown trout	<10	summer	Mäki-Petäys	0.009	-
	16-25	summer	Mäki-Petäys	0.02	-

Table 5.6 Proportions of the proportions of habitat use to habitat availability in the habitat value class with higher suitability index value to the value in the class with lower suitability index value.

species	size	season	pref.	Hiiskoski	TyItsykoski
salmon	<10	summer	Mäki-Petäys	-	2.08
		autumn	Mäki-Petäys	-	1.67
	>10	summer	Mäki-Petäys	1.52	1.64
		autumn	Mäki-Petäys	1.7	-
brown trout	<10	summer	Mäki-Petäys	3.14	-
	16-25	summer	Mäki-Petäys	2.38	-

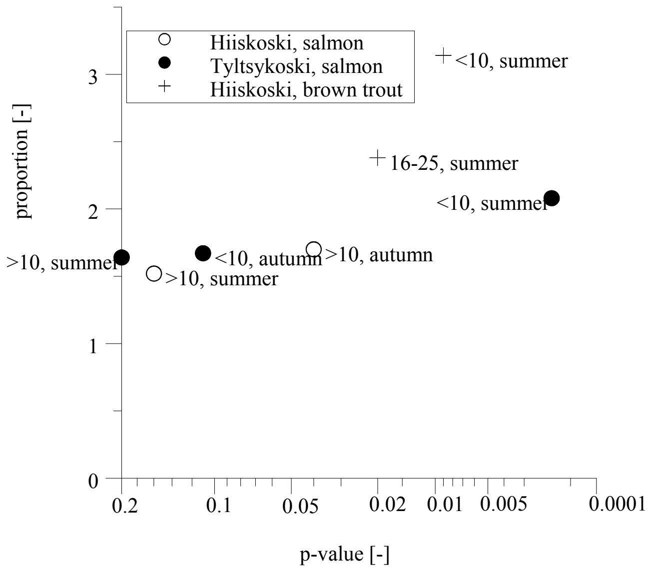


Figure 5.8 Significances of differences between distributions of habitat use and habitat availability and proportions of habitat use to availability in the River Simojoki for salmon and brown trout. 0.05 is significant, 0.01 strongly significant.

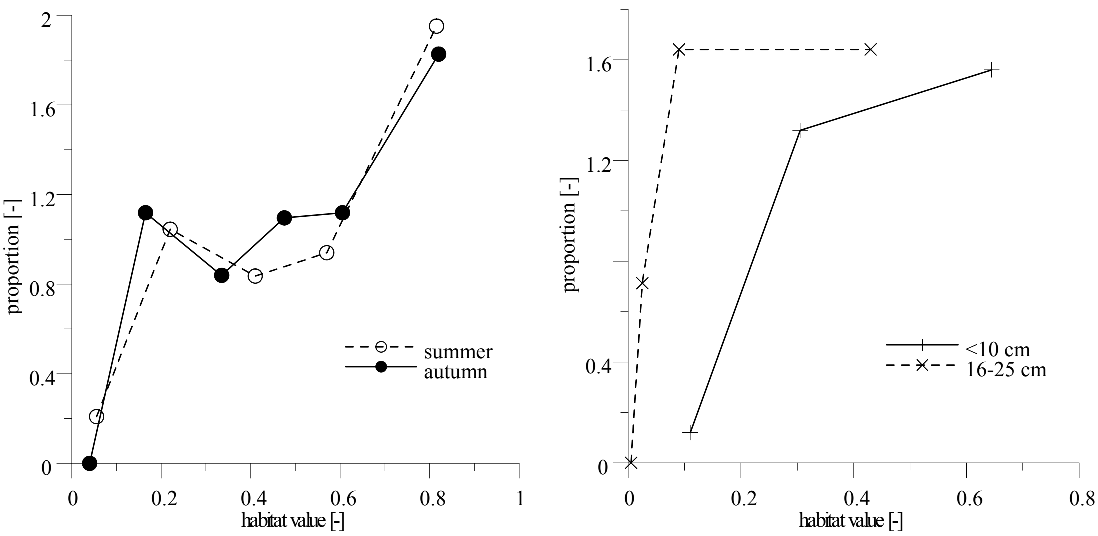


Figure 5.9 Proportions of habitat use to available habitat for salmon >10 and brown trout in summer at the Hiiskoski Rapids with the preference curves of Mäki-Petäys (2000).

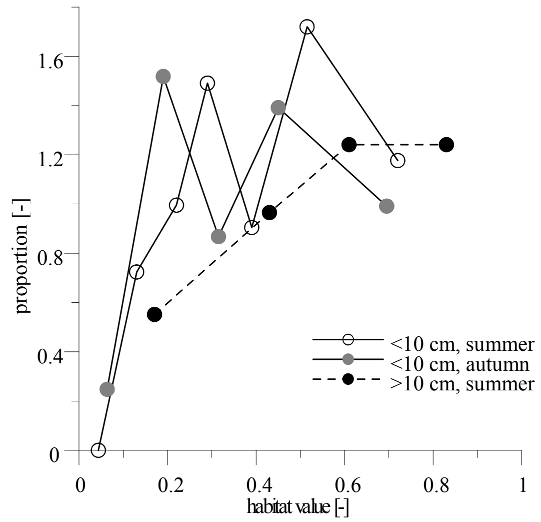


Figure 5.10 Proportions of habitat use to available habitat for salmon at the Tyltsykoski Rapids with the preference curves of Mäki-Petäys (2000).

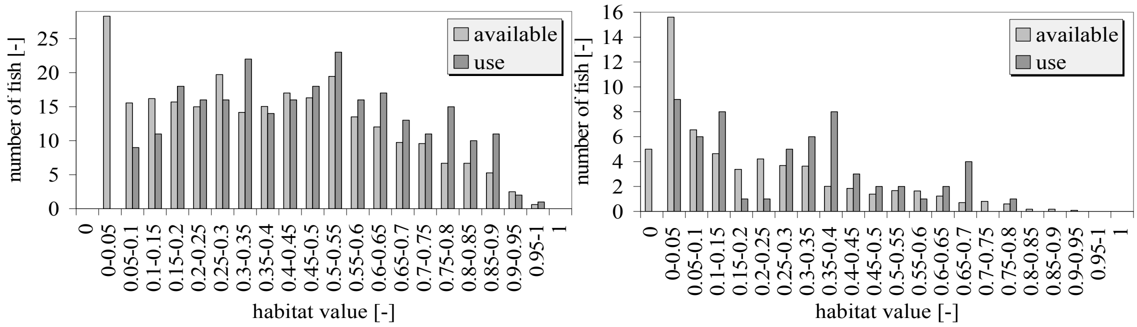


Figure 5.11 All availabilities and uses of habitat of salmon and brown trout data used in River Ala-Koitajoki study.

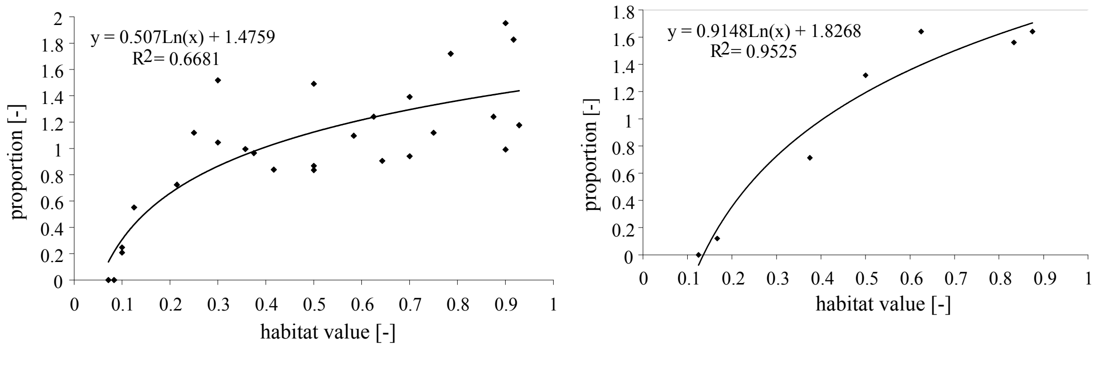


Figure 5.12 All proportions of use to availability values divided uniformly from habitat value of 0 to value of 1 of salmon data used in River Ala-Koitajoki study (previous figures) and for brown trout.

5.1.3 Laukka area

Description of the area, the organism studied, and of the field measurements is shown in Chapter “Calibration of the model”. The model was validated at Laukka area with preference curves from Vehanen et al. (1998, 2003). The fish observations before rehabilitation were used in chi-square validation tests. Some presentations only of the fish after rehabilitation are shown, because the number of observations is too low. Figure 5.13 shows a comparison between modelled habitats for adult grayling with the preference curves from Vehanen et al. (1998, 2003) and fish-catching places in the Laukka area of the River Oulujoki before rehabilitation. The flow rate varied during the observation period. As a graphical example describing the area, fish caught during flows of 56-242 m^3/s and a habitat map for a flow of 110 m^3/s are shown. The areas with the highest habitat values are shown with a darker colour and the fish are marked with squares. They coincide well. The slight displacement of fish-catching places from the area with the highest habitat values in the middle of the channel may be due to the difference in the flow situation or to the modelling methodologies or preference data, or may also be due to inaccuracies in marking the fish on the map in situ, digitising and the topography or that some of the fish would be having a feeding trip just a little way outside the best living habitat. In marking on the map, these fish-catching places in the largest dark-coloured area may have moved a little towards the north, outside the dark area, because so many fish were marked there that there were no room left for fishermen's markings on the region on the paper (Yrjänä 2000). The bridge is shown with arrows (Figure 5.13). Most of the fishing was done from the bridge.

The results are shown in Table 5.7 and Figures 5.14 and 5.15. No fish from the total of 31 individuals were observed in the less suitable habitat value class. In both the sets of data, before and after rehabilitation, the proportions of habitat use to habitat availability are clearly ascending. The calculated chi-square value showing the difference between available habitats and the observed use before rehabilitation is also high. The distributions differ remarkably ($p<0.001$) from each other.

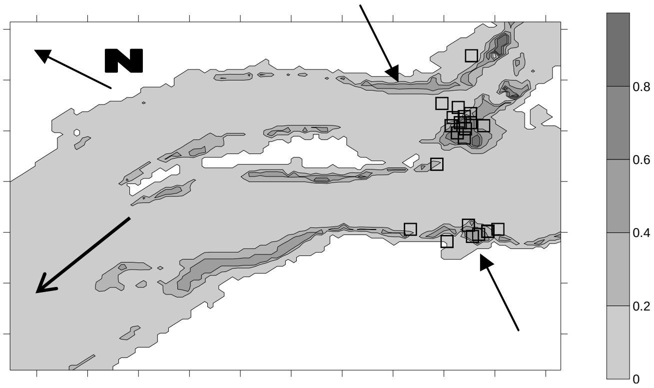


Figure 5.13 Adult grayling, River Oulujoki, Laukka area. A comparison between modelled habitats with the preference curves from Vehanen et al. (1998, 2003) and fish-catching places before rehabilitation. The habitats wtih the highest suitability index values are shown in a darker colour and the fish with squares. The fish-catching places during flows of 56-242 m^3/s and a habitat map for a flow of 110 m^3/s are shown.

Additionally, in order to compare how the model works in rehabilitated rivers, a comparison without tests of significance was made between the situations before and after rehabilitation with the locally determined preference curves (Figures 5.14-5.15). To test if the inaccuracy in placing the observations on the map while keeping a log book while fishing would affect the results or if the feeding habitats of grayling differed from their average living habitats, validation with habitat values calculated as averages of circular areas was also performed with the preference curves of Vehanen et al. (1998, 2003) with the data gathered before rehabilitation. The radius of the circles was the same ten metres as the declared observation accuracy. Because the fish observations were made by fishing, the habitat selection may differ from that found when observing e.g. with the telemetry of electric fishing, when the fish are in their average living habitats, because observations of the fish that best notice the lure and catch it may be more abundant in the data. This might lead to an overrepresentation of hungry fish in the sample, and the fish may be proportionally caught more often in feeding habitats.

Table 5.7 Available habitat and habitat use calculated with the preference curves of Vehanen et al. (1998, 2003) before rehabilitation in the Laukka area and goodness of fit tests.

habitat value	**available**	**use**	**proportion**	**Pearson**	**Yates**
0-0.023	15.41	0	0.00	15.41	14.42
0.023-1	15.59	31	1.99	15.22	14.25
sum	31	31	high/low	30.63	28.67
			large	<0.0001	<0.0001

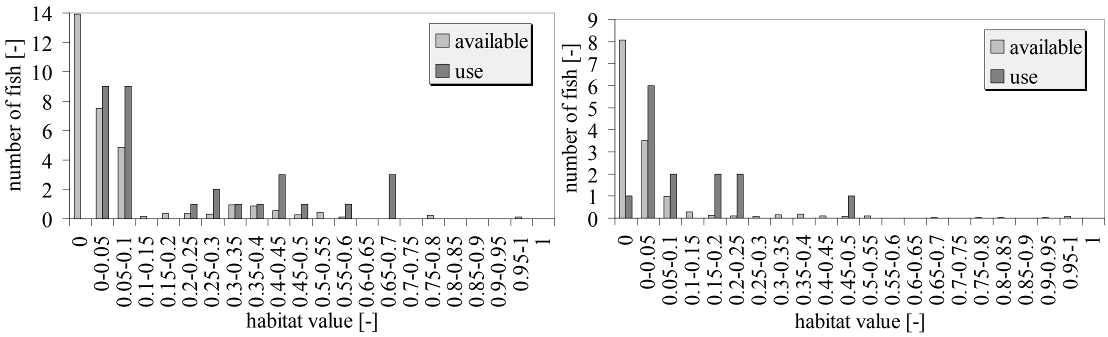


Figure 5.14 Distributions of available habitat and habitat use calculated with the preference curves of Vehanen et al. (1998, 2003) before and after rehabilitation in the Laukka area.

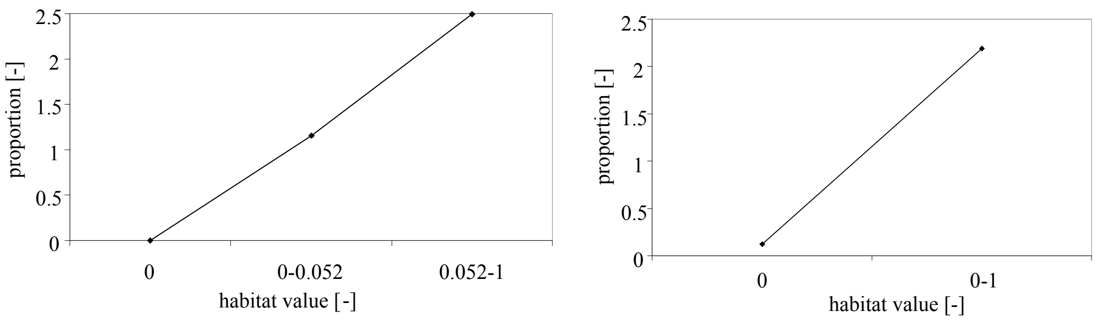


Figure 5.15 Proportions of habitat use to available habitat calculated with the preference curves of Vehanen et al. (1998, 2003) before and after rehabilitation in the Laukka area.

The results are shown in Table 5.8. From Figure 5.16 it can be seen that the prediction is even better than that calculated with point values. This may reflect the inaccuracy of fish mapping, or a difference caused by fish-catching places being a little more in feeding-places near resting habitats than in the average habitats, or slight displacement between the values of the preference curves and the habitat selection. The fish may also also still have been irritated to feed in their normal resting habitats. The fish mapping was known to have been inaccurate, so it is possible that the prediction of habitat use would have been even more accurate with a more precise fish-mapping technique.

The locally determined preference curves of Vehanen et al. (1998, 2003) seem to predict the fish abundance well. With the circle-averaged values, the result was even clearer. However, there are some problems with the test data. The fish are located while fishing; the area is not fished thoroughly as is the case when the locating is made with electric fishing. If some areas are favoured by the fishermen over other areas, the preference values of these areas may be overrepresented in the habitat use distribution. It is easier to fish from the bridge than from a boat. However, the bridge approximately takes a cross-section providing many types of habitats typical of the area. Additionally, if some fishing was carried out as catch and release –fishing, the effective sample size may be smaller, because observations may be of the same fish. Additionally, changes in the flow rate change the distributions of available habitats. If the changes were large, and the fish would prefer habitats that are sparse during some fishing, this could lead to overrepresentation of other, but more abundant, habitats in the study. This is always a problem in habitat preference studies; all types of habitats may not be available to choose from. Additionally, though taking territories; grayling may be grouped like shoaling, which may reduce the effective number of observations in the test. Taking these factors into consideration does not change the conclusion, because the prediction of habitat use is so strong, and the preferences for water depth and flow velocity clearly define the preferred areas.

Table 5.8 Available habitat and habitat use, both calculated as averages of a circle of 10 metres. Oulujoki, Laukka area, adult grayling, preference curves of Vehanen et al. (1998, 2003), and goodness of fit tests.

habitat value	**available**	**use**	**proportion**	**Pearson**	**Yates**
0-0.03	14.79	0	0.00	14.79	13.81
0.03-1	16.21	31	1.91	13.50	12.60
sum	31	31	high/low	28.29	26.41
			large	<0.0001	<0.0001

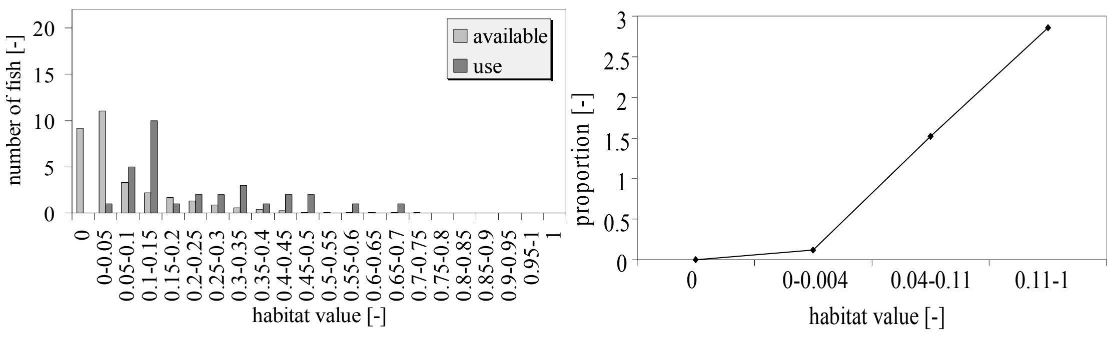


Figure 5.16 Distributions of available habitat and habitat use and proportions of habitat use to available habitat calculated as averages of a circle of 10 metres. Oulujoki, Laukka area, adult grayling, preference curves of Vehanen et al. (1998, 2003) before rehabilitation in the Laukka area. One class more than in the table is shown in this figure. On the right proportions of habitat use to available habitat.

5.1.4 Pyhäkoski impoundment

Description of the area, of the organism studied and the measurements is shown in Chapter "Calibration of the model". The model created is validated with telemetry observations during summer of 1999. Pikeperch observations of selected fish from June 8, 1999 to September 21, 1999 were used in making the habitat preference curves for validation of the model (Figure 5.17). The group of fish used in making the preference curves consisted of 190 observations of 12 fish, which resulted in 137.0 effective observations when autocorrelation was taken into account with assumptions in Matalas (1967). Pikeperch observations during June 8, 1999 to October 2, 1999, but from different fish individuals, were used as a validation group. No shoaling was observed (Vehanen 2003), because large pikeperches are predators hunting individually. The size of the validation fish group was 124 observations of seven fish, which produced 57.9 effective observations with assumptions in Matalas (1967). That the number of fish was only seven also reduces the variation of the observation data. With so large a number of observations and the information that the fish moved daily long distances, the effective number of observations probably exceeds the 20 required. A habitat map showing the weighted usable area with a flow rate of 200 m^3/s and fish observations with flow rates between 160 and 250 m^3/s is shown in Figure 5.18. The fish seem to favour the areas that the modelling shows suitable, also in Figure 5.19, but that is statistically insignificant (Table 5.9). One reason for this could be that in spring and in autumn the fish are searching for habitats for the next season (Vehanen & Lahti 2003) and the observations started in summer, so the fish may not yet have found their places at the beginning of the summer period (Vehanen & Lahti 2003). Another explanation would be that in the deep, partly lake-type impoundment, pikeperch would select habitats based on abundance of nourishment, which might not be explained by the variables used. The number of fish inside the study area reduced during the study. This is not a problem, because all the telemetry fish left in the impoundment were located each time the locating was made. Additionally, changes in the flow rate change the distributions of available habitats. If the changes were large, and the fish would prefer habitats that are sparse during some fishing, this could lead to overrepresentation of other, but more abundant, habitats in the study. This is always a problem in habitat preference studies; all types of habitats may not be available to choose from.

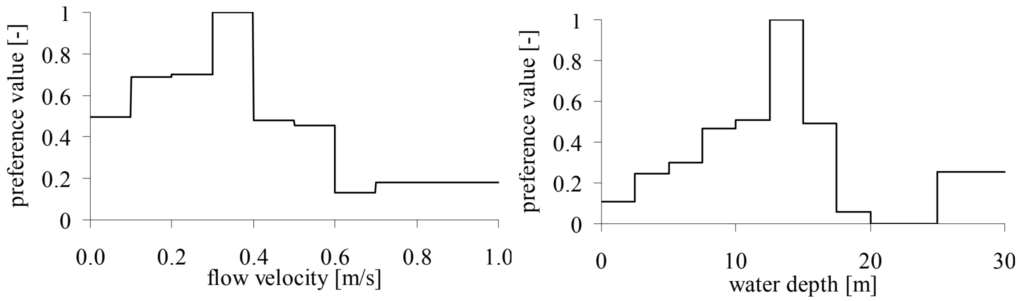


Figure 5.17 Preference curves for pikeperch made from observations June 8, 1999 to September 21, 1999 at the Pyhäkoski impoundment.

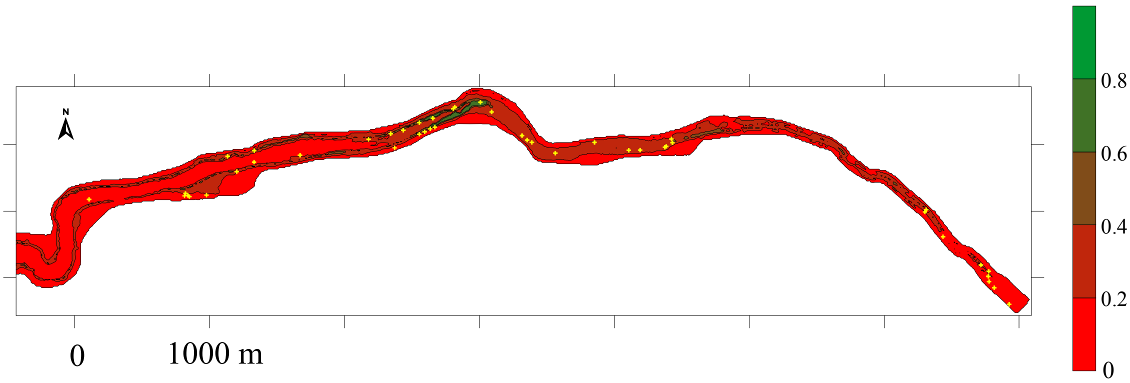


Figure 5.18 A habitat value map calculated with preference curves made from observations during June 8, 1999 to September 21, 1999 at a flow of 200 m^3/s and fish observations with flows between 160 and 250 m^3/s.

Table 5.9 Available habitat and habitat use and proportion of use to availability calculated with preference curves made from observations June 8, 1999 to September 21, 1999 at the Pyhäkoski impoundment and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2	30.56	26.69	0.87	0.49	0.37	-7.21	
0.2-1	27.36	31.22	1.14	0.54	0.41	8.24	
sum	57.91	57.91	high/low	1.03	0.78	1.03	1.02
			1.31	0.31	0.38	0.31	0.31

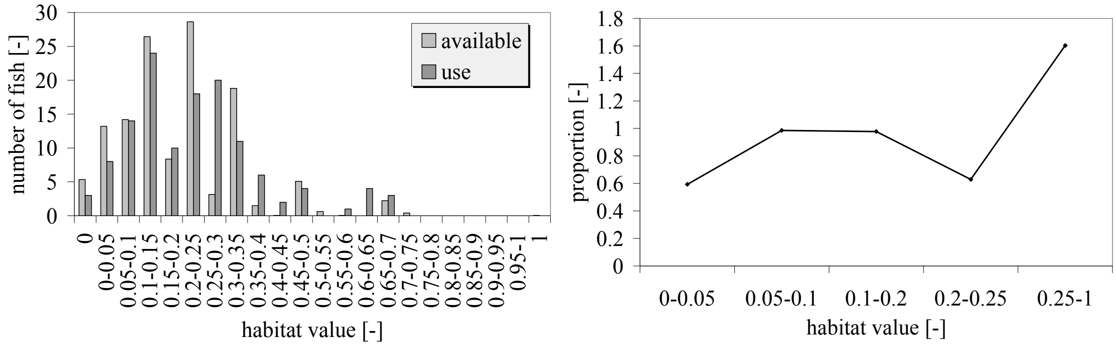


Figure 5.19 Distributions of available habitat and habitat use and proportions of available habitat to habitat use June 8, 1999 to October 2, 1999 for pikeperch calculated with preference curves made from observations during the June 8, 1999 to September 21, 1999 at the Pyhäkoski impoundment.

5.2 Crayfish model

5.2.1 Validation of a model from Lake Katumajärvi study areas 4-5 at Lamminsaari Island

Habitat modelling was carried out at Lamminsaari Island, Lake Pääjärvi (Figures 5.20 and 5.21) with the model created at Lake Katumajärvi study areas 4-5 (see 2.3), in order to validate the model. A chi-square test was then made (Table 5.10 and Figure 5.22). The prediction of abundance was weak. However, the lowest class of habitat values was avoided, and the higher classes were weakly preferred. One reason for the weak prediction might be that strong large scale water level fluctuation-induced currents hit the island changing the mechanisms of erosion (Erkamo 2002). Another explanation might be, that the positioning of the traps was not very accurate. Because of this, using moving averages of catch/effort ratios was also tested (Figure 5.23). The chi-square test was carried out again and the distributions and proportions were drawn (Table 5.11 and Figure 5.24). The prediction was weaker than without using moving averages.

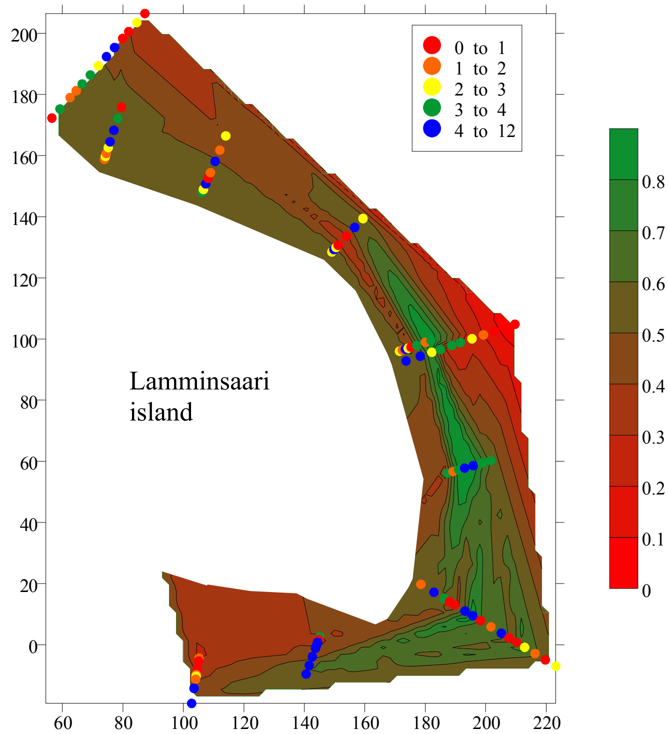


Figure 5.20 A calculated habitat preference value map and catch/effort ratios (circles) at the Lamminsaari Island study area, Lake Pääjärvi.

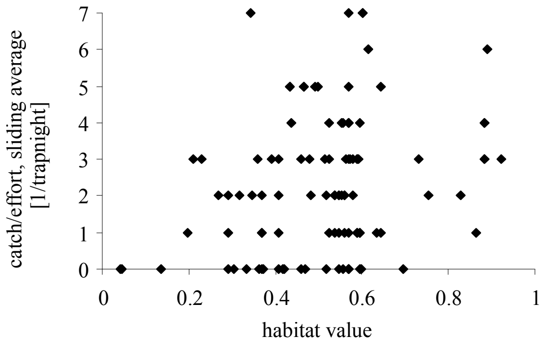


Figure 5.21 Catch/effort ratio at the Lamminsaari study area, Lake Pääjärvi, as a function of habitat value calculated on the basis of erosion rate and water temperature.

Table 5.10 Lamminsaari Island, Lake Pääjärvi, available habitat and habitat use (catch/effort ratio) and proportion of use to availability and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.5419	127.00	120	0.94	0.39	0.33	-13.61	
0.5419-1	127.00	134	1.06	0.39	0.33	14.38	
sum	254	254	high/low	0.77	0.67	0.77	0.77
			1.12	0.38	0.41	0.38	0.38

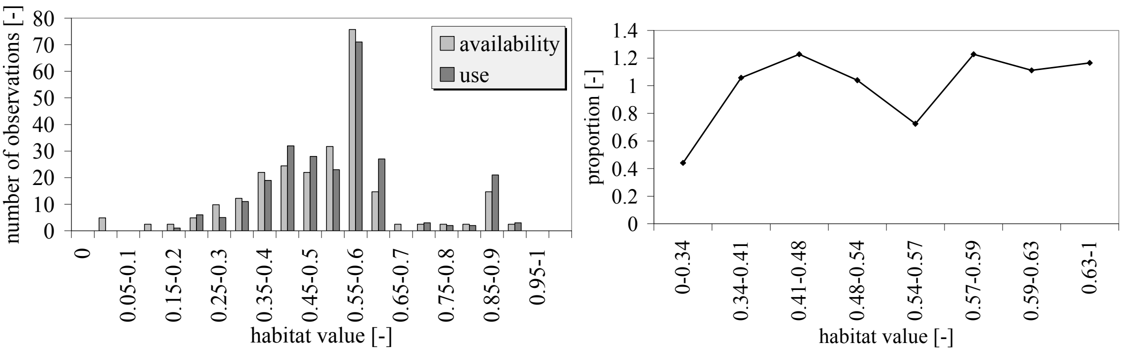


Figure 5.22 Lamminsaari Island, Lake Pääjärvi, available habitat and habitat use (catch/effort ratio) and proportion of use to availability.

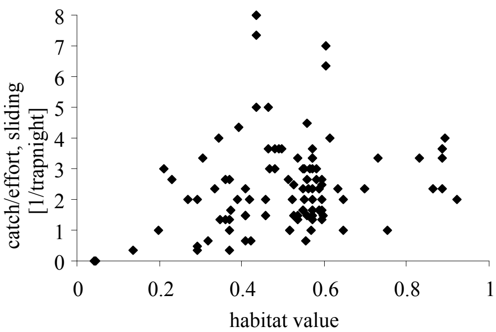


Figure 5.23 Lamminsaari island, Lake Pääjärvi, habitat value and a moving average (n+-1) of catch/effort ratios.

Table 5.11 Lamminsaari Island, Lake Pääjärvi, available habitat and habitat use (a moving average (n+-1) of catch/effort ratios) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.5419	128.17	123.83	0.97	0.15	0.11	-8.52	
0.5419-1	128.17	132.5	1.03	0.15	0.11	8.81	
sum	256.33	256.33	high/low	0.29	0.23	0.29	0.29
			1.07	0.59	0.73	0.59	0.59

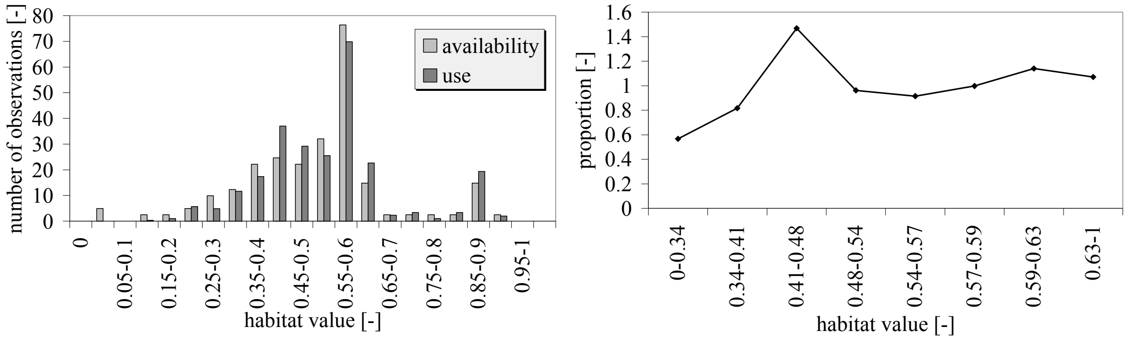


Figure 5.24 Lamminsaari Island, Lake Pääjärvi, available habitat and habitat use (a moving average (n+-1) of catch/effort ratios) and proportion of use to availability, a moving average.

5.2.2 Validation of a model from Lake Katumajärvi study areas 4-5 at Lake Slickolampi

The original model constructed with data from the Lake Katumajärvi study areas 4-5 (see 2.3) was validated at Lake Slickolampi to see whether a model calibrated with data from large lakes would work at a smaller lake. The habitat value map is shown in Figure 5.25 and the test of significance is shown in Table 5.12. Distributions of available habitat and habitat use and proportions of habitat use to habitat availability are shown in Figure 5.26. The prediction was accurate; no crayfish were observed in the lower half of habitat values. However, of the model variables, water temperature is weather-dependent and the curve for potential erosion was rough. Catch/effort ratio as a function of habitat suitability index value is shown in Figure 5.27.

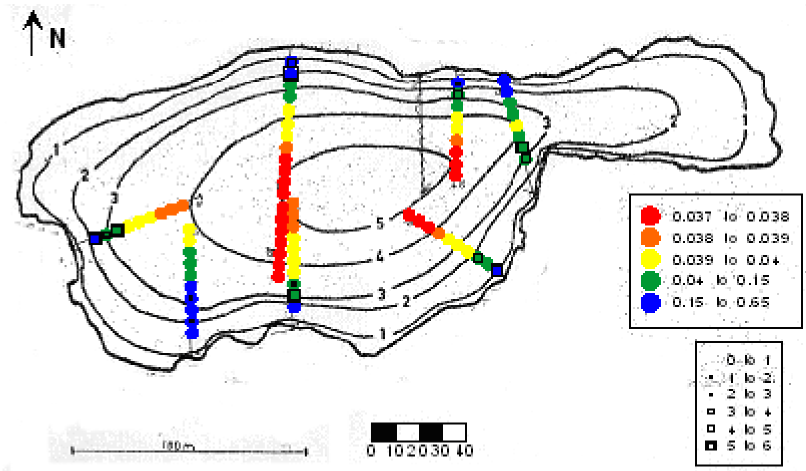


Figure 5.25 A calculated habitat map and catch/effort ratios (circles) at Lake Slickolampi with original preference curves from Lake Katumajärvi with a fixed suitability index value with small values of potential erosion. Habitat suitability index values are shown with colours. The sizes of the boxes indicate the number of crayfish caught.

Table 5.12 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with original preference curves from Lake Katumajärvi with a fixed suitability index value with small values of potential erosion and goodness of fit tests.

habitat value	available	use	proportion	chi- square	Yates
0-0.0392	25.23	0	0.00	25.23	24.24
0.0392-1	17.77	43	2.42	35.81	34.40
sum	43	43	high/low	61.03	58.64
average			large	<0.0001	<0.0001

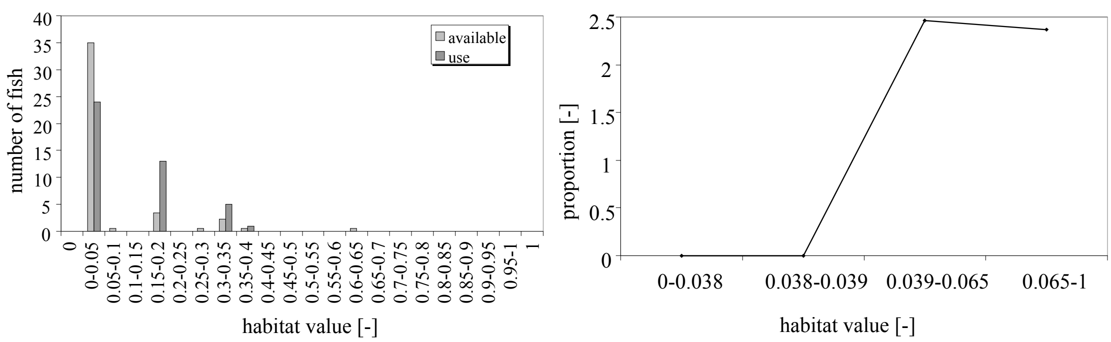


Figure 5.26 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Slickolampi with original preference curves from Lake Katumajärvi with a fixed suitability index value with small values of potential erosion.

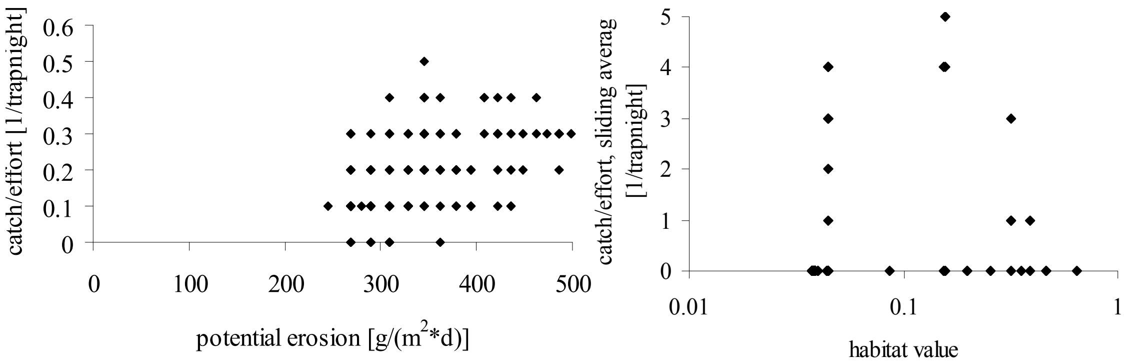


Figure 5.27 Catch/effort ratio as a function of habitat value at Lake Slickolampi with preference curves made at Lake Katumajärvi study areas 4-5 with the preference curve for potential erosion as originally.

5.2.3 Validation of a model from Lake Pääjärvi at Lake Katumajärvi study areas 4-5

The model created with data from Lamminsaari Island at Lake Pääjärvi was validated at the Lake Katumajärvi study areas 4-5. The preference curves and calculation formulas were tested first. Habitat values were calculated at the Lake Katumajärvi study areas with different combinations of preference curves from Lake Pääjärvi. Surprisingly, the lake bed material variables did not correlate with catch/effort ratio, but both the formulae, product (depth, erosion, water temperature) and product (erosion, water temperature), gave top correlations of the formulae (Table 5.12). Some data about bed material were not measured; these were marked with average habitat values.

Table 5.12 Habitat value calculations at Lake Katumajärvi study areas 4-5 with preference curves from Lake Pääjärvi, correlations between catch/effort ratio and habitat value with different habitat value calculation formulae.

habitat value calculation formula	correlation
sand/fine sand	-0.15
soft material	0.00
depth	0.48
erosion	0.24
water temperature	0.46
product of all	0.48
product (erosion, water temperature)	0.49
product (sand/fine sand, soft material, depth, erosion)	0.42
product (sand/fine sand, soft material, erosion, water temperature)	0.40
product (depth, erosion, water temperature)	0.53
product (sand/fine sand, soft material, depth, water temperature)	0.45
sum of all	0.48
sum (sand/fine sand, soft material, erosion, water temperature)	0.39

However, because the model created with data from Lamminsaari Island at Lake Pääjärvi was to be validated, the chi-square test is done with the habitat value calculation formula chosen on the basis of the study at Lake Pääjärvi: product (sand/fine sand, soft material, erosion, water temperature).

In Figure 5.28, a calculated habitat preference value map and catch/effort ratios during the summer of 2001 at the Lake Katumajärvi study areas 4-5 are shown. The exact places and directions of the trap lines were not known, so their direction was assumed to be perpendicular to the shoreline. The obvious inaccuracies and inconsistencies shown in the figures do not affect the calculations, because the habitat maps were drawn only for the purpose of visualisation; attempts were made to measure the field measurements of the habitat variables as closely as possible in situ from the same points where the traps were. In Figure 5.29, the same data are shown for the summer of 2002. In Figure 5.30, the catch/effort ratio is shown as a function of habitat value.

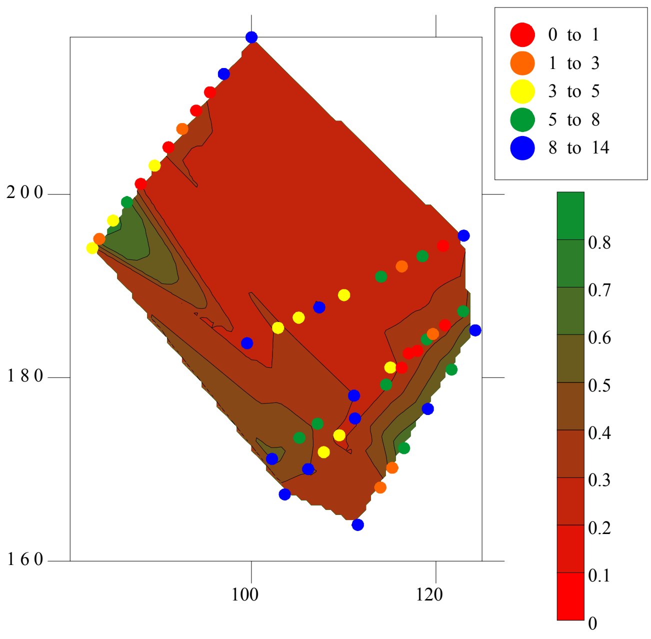


Figure 5.28 A calculated habitat suitability index value map and catch/effort ratios (circles) at Lake Katumajärvi study areas 4-5. The green colour on the map marks the best habitats and the blue and green circles mark the highest catches during the summer of 2001.

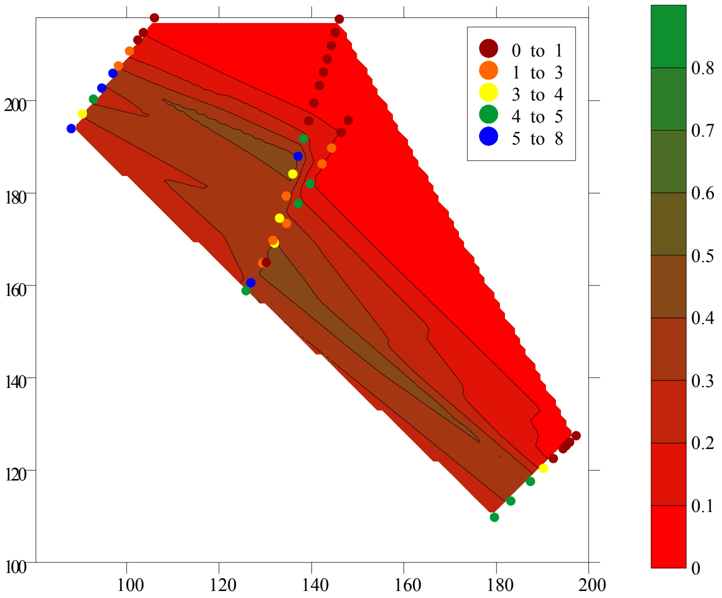


Figure 5.29 A calculated habitat suitability index value map and catch/effort ratios (circles) at Lake Katumajärvi study areas 4-5. The green colour on the map marks the best habitats and the blue and green circles mark the highest catches during the summer of 2002.

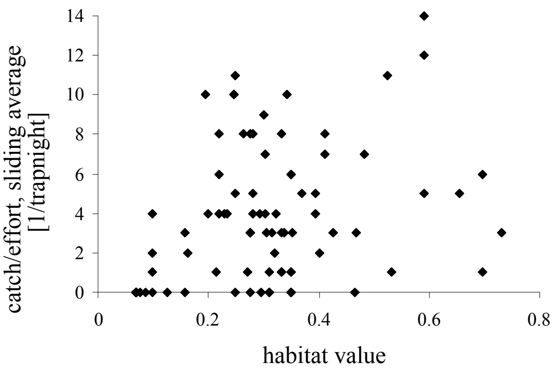


Figure 5.30 Catch/effort ratio as a funtion of habitat value at Lake Katumajärvi study areas 4-5 with preference curves from Lake Pääjärvi.

The tests of significance were calculated (Table 5.13). The prediction was found to be moderate and the difference between habitat use and available habitat was found to be highly significant. Available habitats and habitat use and proportion of use to availability are represented in Figure 5.31. The habitats with the lowest values were avoided, but there were two maxima in observed habitat preference. The strong currents hitting the shores of Lamminsaari Island induced by fluctuations in the water level of the Lake Pääjärvi might have caused that kind of behaviour of the model.

Table 5.13 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Katumajärvi study areas 4-5 with preference curves from Lake Pääjärvi and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2873	157.00	132	0.84	3.98	3.82	-45.79	
0.2873-1	157.00	182	1.16	3.98	3.82	53.78	
sum	314	314	high/low	7.96	7.65	8.00	7.98
			1.38	0.005	0.006	0.005	0.005

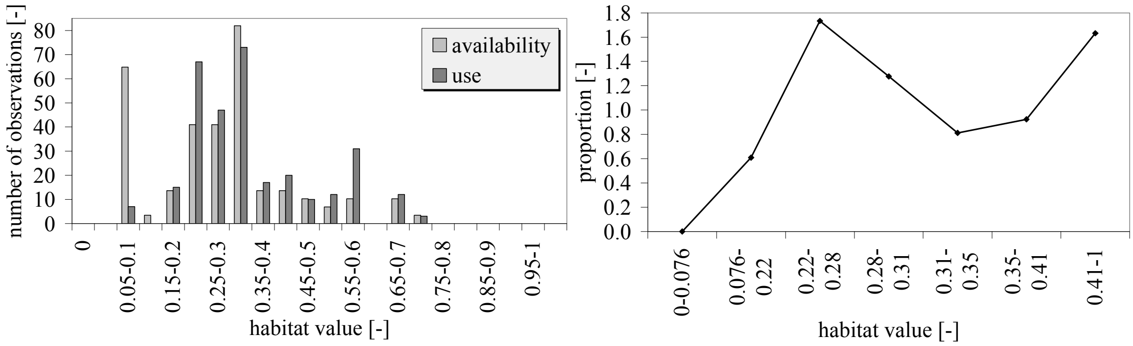


Figure 5.31 Available habitat and habitat use (catch/effort ratio) and proportion of use to availability at Lake Katumajärvi study areas 4-5 with preference curves from Lake Pääjärvi.

5.3 Vegetation modelling

5.3.1 Vegetation modelling in the delta of the River Oulujoki

Description of the area and the organism studied, measurement data and preference curves used are represented in Chapter “Calibration of the model”. The model calibrated with preference curves of Lahti & Riihimäki (2000) was validated with observations of Ulvinen (Ulvinen 2000, Väre et al. 2000).

Habitat availability

The distribution of habitat availability of the organism was obtained by taking those cells at least a part of which were located between the depth range +-1 metres into account. 19 shore cells in which the topography model was inaccurate were removed from the data. Two of these were deleted from near the city, and the others were removed from low areas near the sea. The reason for this selection of cells was to include only appropriate cells near the shoreline, so that the study would not include deep waters or land areas with high elevations, where the plant is clearly known not to grow. Therefore, the frame of the study is to find out whether the model can be used in predicting where near the shoreline *Persicaria foliosa* is found. Average habitat values were calculated for the cells.

Observations

Results from a survey made by Ulvinen (Ulvinen 2000, Väre et al. 2000) were used as observation data. In the survey, all the shores of the delta area were mapped. The area was divided into cells of 100*100 metres. If *Persicaria Foliosa* was observed, a point was marked in that square on the map (Figure 5.7). Average habitat values were calculated for all cells. Figure 5.7 shows calculated Weighted Usable Areas marked with colours, and the cells in which *Persicaria Foliosa* was observed are shown with filled circles and the cells without observations with empty circles.

Results

The habitat map is shown in Figure 5.33 and the tests of significance in Table 5.14; the available habitat and observed distribution of occurrences of *Persicaria Foliosa* and the proportions of habitat use and available habitats in cells with different average habitat values in the delta of the River Oulujoki are shown in Figure 5.32. With the model it was possible to predict the abundance of *Persicaria Foliosa* accurately.

Table 5.14 Available habitat and habitat use and proportion of use to availability of *Persicaria Foliosa* in the delta of the River Oulujoki and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0009	44.50	8	0.18	29.94	29.12	-27.46	
0.0009-1	44.50	81	1.82	29.94	29.12	97.03	
sum	89	89	high/low	59.88	58.25	69.57	69.19
average	0.01	0.04	10.13	<0.0001	<0.0001	<0.0001	<0.0001

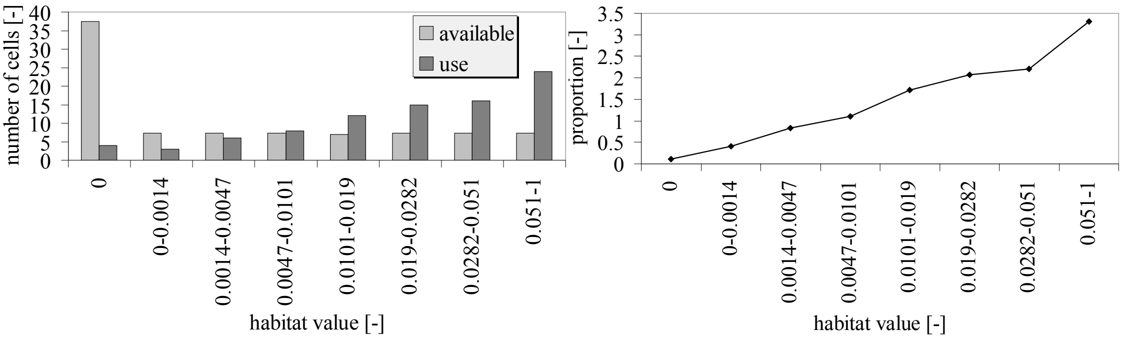


Figure 5.32 Available habitat and habitat use and proportion of habitat use to available habitat of *Persicaria Foliosa* in the delta of the River Oulujoki.

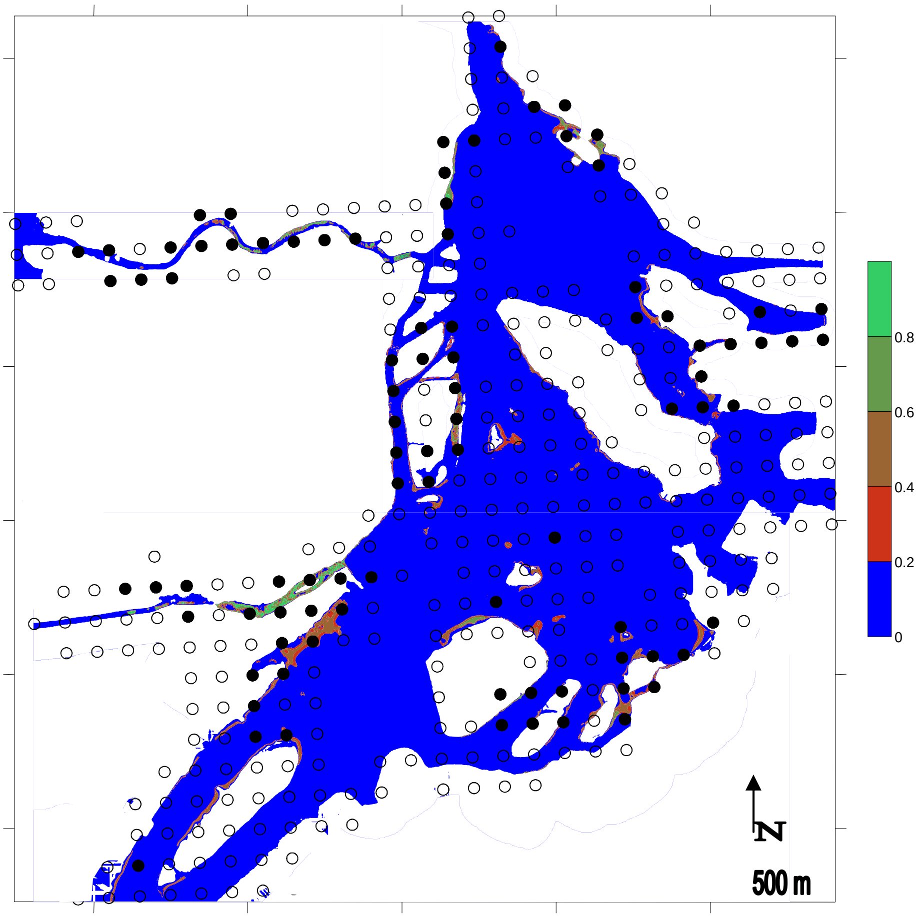


Figure 5.33 Calculated Weighted Usable Areas marked with colours and cells in shallow areas with observations of *Persicaria Foliosa* (filled circles) and without observations (empty circles) in the delta of the River Oulujoki.

6 DISCUSSION

Habitat modelling – state of the art

Two-dimensional habitat models have been started to be developed during the latest years. Methods for field measurements, data model creation and hydraulic modelling have neither been fully developed nor studied for the purpose of habitat modelling. The effect of using preference curves with different origin and methods of making curves or the effect of scale on modelling have not been studied either. Two-dimensional modelling has not been validated with large comparisons with observations.

6.1 Calibration and testing of the models

6.1.1 Fish model

The fish habitat model was run with different types of preference data at Rivers Simojoki and Ala-Koitajoki. The model residuals seemed to be randomly distributed. This would mean that the model would explain the part of the variation that is explainable, and the rest of the variation would be caused by inaccuracy in measurements of observations and by random factors of the phenomenon. The model was run also at Laukka area, and at Pyhäkoski impoundment with different types of preference data. The results showed the importance of selecting appropriate preference curves and methods of making them in model calibration. At Laukka, preference curves from a smaller river produced an accurate estimation of habitat selection of grayling. At Pyhäkoski, an accurate prediction of habitat use was achieved for pikeperch with winter preference data from the area. This was opposite to the summer situation; perhaps in winter, when the fish are more inactive, the habitat preferences are clearer, towards deeper and slower flowing areas, while in summer, the pikeperch might e.g. select their habitat based on abundance of nourishment not explained by the variables used.

Software development

To further decrease cost of labour in modelling, the software could be developed. The partly automated data processing of two-dimensional models could be automated almost fully by programming all parts of the model into one program code. For example, the model tested here is based on separate modules, e.g. a graphical hydraulic modelling interface and hydraulic and habitat value calculation models, necessitating data conversion work between the phases of modelling. Neither is printing of figures fully automated. So, the next step in technical software development should be programming all the models together so that the results could be output automatically from the same program into which the field data were input, making modelling less laborious. The automation of the printing of results is found in the models of Steffler & Blackburn (2002), but the typing of relatively simple formatted ASCII files is required for data input.

6.1.2 Herb model

The herb model was not tested, because the model is a subset of the fish model. The structure of the model is similar but there are fewer variables; only water depth and substrate. The herb model was only validated in this work.

6.1.3 Crayfish model

The crayfish model was tested at Lake Katumajärvi study areas 4-5 and at Lake Pääjärvi with preference curves from the lakes themselves. Very accurate predictions were achieved at both lakes. This may indicate that modelling of the habitats of crayfish might be possible with material from the same or similar type of lake. However, because the same data was used in the test and calibration, dependencies may have influenced the result, and final conclusions can’t be drawn.

6.2 Verification and sensitivity analysis of the model

6.2.1 Fish model

6.2.1.1 Physical model

6.2.1.1.1 Field measurements and data models

The physical model was verified by testing the effects of methods used in the different phases of the modelling with artificial data that offers unbiased comparisons. Changing the number of measurement points and grid densities resulted in an assumed response in model accuracy. By changing the densities, the model scale can be fit to the phenomenon studied. Accurate delineation of the topographic model was found to be important as also Tarbet & Hardy have (1996) concluded in their study. The number of field measurement points was found to affect the results much more than the normally used habitat model grid density. The sizes of habitat value calculation grids can usually be adjusted so that both precision and moderate calculation times are maintained.

Where there were linear forms in the channel, shore line interpolation and linear interpolation resulted in more accurate models, as assumed, while Kriging may produce more accurate models when the topography is irregular. Shore and bank measurements as lines were found to be useful. When the topography was anisotropic, use of anisotropic interpolation resulted in more accurate models as expected. The curvilinear anisotropic interpolation method is useful if the channel is curved. The model was sensitive to the density of topography measurements. This result should be generalisable, because the measurement methods in habitat hydraulic modellings are rather similar.

6.2.1.1.2 Hydraulic model

Hydraulic modelling was also studied. At a small side channel at the Hotilankoski Rapids, measured and modelled values coincided well, the overall forms being nearly identical, however, the modelled values having a smaller fine scale variation. At the Olkkakoski and Pyhäkoski Rapids, the values matched relatively well, except the shore areas, which were not measured precisely. In the study of Ghanem et al. (1994), too, two-dimensional hydraulic modelling produced a good presentation of the flow field. However, in a Canadian study (Guay et al. 2000, Guay et al. 2001), it was found out that the distribution of modelled flow velocity was smoother than that measured at 60% depth and with a measurement period of 30 s. This has also been noticed in a work with a set of data of quality that is too uncertain to be included in this work. But much of the smoothening effect may be caused by the precision of the field measurements and interpolation into a topographic model. Flow velocity distributions were modelled precisely in mid-channels, and if shore area data was precise, also near shore line. In the data of this work, no multiple sufficiently accurate topographic data combined with flow velocity cross-sections were available for accurate testing with hydraulic modelling of near bank areas. However, at Rapid Hotilankoski, the measurements continued above the shore line and the flow velocity distribution was accurately modelled.

An accurate hydraulic modelling of shallow areas is important in habitat modelling, because the youngest fish often occupy these areas. A wetting and drying -algorithm should be used if the shore line is not exactly known at every hydraulic situation to be modelled. Changes in the values of the coefficients, river bed roughness and kinematic viscosity affected results as expected. Sensitivity analyses with real field data showed similar results. If hydraulic models without vertical friction are used or the wetting and drying algorithm deletes cells from shallow areas, using higher friction coefficients for shallow areas, and higher grid densities near shore line can be used to compensate for the effect. The value of kinematic viscosity should not be used in calibration of the calculation of shallow areas, because changing it would change the flow distribution in other parts of the channel. On the other hand, hydraulic models taking vertical friction into account are available. In some models, the roughness can be set automatically according to water depth. Additionally, the position of the shore line can be initially calculated with a hydraulic model, and the model grid adjusted after that. This is often useful when gradients are steep. These mean that a good precision can be achieved even relatively near the shore line. Testing the effect of increasing the number of elements in a cross-section produced surprisingly accurate models with very few elements when the borders of the elements were set to the points of change in the cross-sections of the theoretical river topography. This means that it is important to design the model grid geometry to match the hydraulic conditions, not only to get numerical convergence. On the other hand, in nature, the topography is not regular between the points in a cross-section, which means, that a higher resolution is usually beneficial. The selection of field measurement and hydraulic modelling grid densities should take place according to the purpose of the modelling. The results from hydraulic model responded predictably to changes in parameter values and to changes in modelling methods. The sensitivity of hydraulic modelling results to changes in parameter values or geometry was low or moderate. Often other factors compensate for the changes. As a summary, hydraulic models were found to produce accurate estimations of flow velocity distributions in mid-channels. For evaluations of the distributions at the shore area no accurately measured data was available. Modelling of shallow areas should be studied further.

6.2.1.1.3 Smoothening of data models

Cumulative spatial smoothening of values of variables may occur in different phases of habitat modelling: field measurements, interpolation to a topographic model, interpolation to a hydraulic model grid, in hydraulic model calculations, and in interpolation to the habitat modelling grid. This kind of phenomenon could be caused by a low density of field measurements, measurement methods, interpolations smoothening the topography, the fact that vertical shear is not included in all two-dimensional hydraulic models, a coarse hydraulic modelling grid, missing shore areas, and numerical diffusion in hydraulic model calculation. The dynamic character of flow, e.g. pulsativity, and three-dimensionality of flow in the field may also cause deviation of observed values from modelled. The decrease in variation may be local, or cross-sectional, so that calculated flow velocities are too high near the shore. Smaller variation in modelled flow velocity values compared with observations may be expected when the substrate size is large compared with water depth values and the gradient is steep, just because of variations in scale smaller than the scale used in modelling and because of possible vertical flows. Flattening of modelled flow velocity value distributions in hydraulic modelling can be reduced by dense measurements that include measurement of large stones, not only between them, and dense topographic and especially hydraulic modelling grids, particularly near shores. The grid should be constructed taking the shore line into consideration. The model can be adjusted after an initial run. The cross-sectional flattening, if exists, can be compensated for by the calibration of flow velocities across the channel too. This should preferably be carried out by adjusting channel roughness values, if needed.

6.2.1.1.4 Spatial scales

The question about spatial scales is of importance. Habitat modelling can be performed e.g. to model the whole river to map places with good habitats or to model a river section containing different habitat mesotypes to find the location of habitats and to estimate the amount of them. Modelling can also be used to model a short reach of one mesotype for more detailed rehabilitation planning or a smaller patch for studying microhabitats or for fine-detail rehabilitation planning. Modelling is naturally more accurate if the scale of the phenomena studied is larger than the measurement density and modelling grid size. Normally, the side of a modelling cell ranges from 0.2 to 25 metres. The density of field measurements, accuracy of interpolations to calculation grids, and the density of the grids affect the ability of the model to represent the prevailing conditions. Modelled topography is usually smoother than the real geometry. For example, in rapids with big boulders and stones and if an overall picture of habitats is to be achieved, perhaps a longer river section can be modelled with coarser measurements, but the number of field measurement points and model elements should be increased from this to get more precise values if a more detailed picture is needed.

The fish may select their sites inside a suitable area on the basis of the fine details of the river bed. In very heterogeneous rapids, where the scale of the model remains too large, modelling can be used to distinct between suitable and unsuitable habitats, but the prediction of the exact positions of individual fish might be more difficult. At Rivers Simojoki and Ala-Koitajoki, the accuracy of 0.5 metres of observations was not sufficient for evaluation of modellings in the smallest microhabitat scale. In addition to model scales, an explanation might be that energetically favourable eddies and gradients and three-dimensional phenomena couldn’t be modelled with the scales and hydraulic model used. In hydraulic modelling, larger scales than the smallest-scale microhabitats are usually considered. When modelling e.g. the effect of adding or removing material or changing the water level in the river, the scales used in habitat modelling are often suitable. The fine structure of the river bed is partly included into habitat modelling by using the substrate as a variable. A good deal of preference information based on columnar flow velocities is available. Luckily, in visual habitat assessments and rehabilitation planning, the overall hydraulic conditions and geometry are often estimated or planned first. Modelling can be used in determining the hydraulic conditions with a given geometry and river bed roughness, and then the river bed substrate is selected on the basis of the preference criteria of the species being studied, and the patterns of placing the individual stones and stone groups and the small-scale geometry are designed on the basis of larger-scale modelling and small-scale preference information. When planning the smallest-scale microhabitat, e.g. the substrate and microstructure, knowledge of phenomena on that smaller scale should be utilised. The effect of average-sized boulders and holes that are also typical rehabilitation measures cannot usually be taken into account in hydraulic modelling because of the cost of labour in the field and in the office. With more advanced field measurement methods, e.g. with diagonal echo sounding connected to GPS, with laser or perhaps with photogrammetry, more data can be gathered, and with more powerful computers, the amount of elements used in hydraulic modelling can be increased. On the other hand, the scale of modelling may also be too small; the same calibrated model often cannot be used in modelling areas containing different types of mesohabitats, because preference curves may be applicable only to certain types of overall conditions.

6.2.1.1.5 Nose velocities

Habitat preference information based on nose velocities should be used in planning the smallest microhabitat details. Two sets of preference curves could be made; with mean column velocities for meso- and larger microhabitat scale assessments, and with nose velocities for planning the details of the elements of the rehabilitation. If three-dimensional hydraulic models were used, only nose velocities would then be used in modelling, but three-dimensional models require much computer time and calibration data.

6.2.1.2 Habitat preference model

6.2.1.2.1 Preference curves

The prerequisite for modelling are that the habitat preferences of the organism can be represented with variables and method used in modelling, and the existence of preference study data or knowledge. A sensitivity analysis regarding the effect of changing preference curves showed that the model is sensitive to preference material. Especially, the magnitude of the habitat values varied remarkably. The relative magnitude of habitat values inside the study area was not so sensitive; the suitable and unsuitable areas were rather clearly separated from each other.

6.2.1.2.2 Transferability of preference curves

Often the most important factor affecting the results of modelling is the selection of preference curves. The variables that are not included in models and also the other variables included affect the preferred ranges of values of variables used in modelling, e.g. water temperature may affect the flow velocity preference. These factors may be site-specific, e.g. the amount and quality of vegetation, competing and predator species, or they may also change with time; weather, time of day (Le Drew 1996), season (Mäki-Petäys et al. 1997), or amount or type of nourishment (Muotka et al. 1999). Preference curves from different kinds of conditions should not be used without careful judgement (Huusko et al. 2003). Preference curves based only on one set of conditions may not be transferable to different kinds of sites, while preference curves based on a large variety of conditions may become too general (Huusko et al. 2003) for exact predictions in a specific type of watershed or season. In the Laukka area, both local and the Swedish curves from a much smaller river gave good predictions, but the very general ones from America gave poor results. In addition to those factors external to the population studied, population density and intraspecies competition also affect habitat use. The use of slightly lower-quality but still suitable habitats depends on the amount of the competitors for the best habitats (Vehanen et al. 1999). The number of study areas from which the data for preference curves are gathered indirectly affects the results. Mäki-Petäys (2002) found out that needle figured preference curves based on a single study did not work as well as other curves (Mäki-Petäys & Huusko 2001) based on many rivers, even if the first preference curves were made in the study river. The amount of observations also affects results. Mäki-Petäys (2002) remarked that the site selection of fish is dynamic, which means that preference curves made with small samples may be defective. Many of these problems could be solved if preference curves were made for each different type of conditions. For example, according to Mäki-Petäys (2003) and Mäki-Petäys et al. (1997 & 1999), there should be separate preference curves at least for summer and winter if winter conditions may be a limiting factor for populations. The suggestion was proven valid in this work in tests with winter data. Huusko et al. (2003) concluded that for juveniles of brown trout and salmon, there exist applicable preference curves for Finnish rivers. These curves should be applied only at least relatively fast flowing river sections (Huusko et al. 2003). They also remarked that if curves are made at small rivers, it is possible that they will not work as well in large streams.

Despite differences in conditions in different parts of the world, there is some indication that at least some preference curves could be geographically transferable. Mäki-Petäys et al. (2002) studied preference criteria for juvenile Atlantic salmon (*Salmo salar*) and found it conceivable that summertime preference curves would be transferable at least on a regional scale, perhaps globally. In the present study, preference curves for salmon fry were found to be rather similar to each other, as were also their predictive powers. This might be due to the fact that substrate that offers visual shelter is important and also because the selection of water depths goes along with the size of the fish (Hunter 1991), factors which are not so easily affected by changes in conditions. This kind of transferability of curves would mean that in many cases, expensive field studies on study sites would not be required. But, on the contrary, e.g. Groshens & Orth (1994) found preference criteria for Smallmouth bass (*Micropterus dolomieu*) in some cases transferring and in some cases not in warmwater streams, and they suggested using nose velocities. Also in the present study, it was noticed that the preference curves for adult grayling for flow velocity varied greatly. Column flow velocity preference may be a more sensitive function to changes in other conditions, e.g. water depth, discharge, temperature, and the amount of nutrition. Perhaps different curves should be used for different-sized rivers. Despite that, good predictions were also achieved in the Laukka area with the preference curves made at small rivers. Nykänen & Huusko (2004) found flow velocity criteria for larval European grayling (*Thymallus thymallus*) transferring well whereas the criteria for water depth and substrate, and combined indices transferred inconsistently and vegetation did not transfer. In a single-site two-dimensional model validation by Boudreau et al. (1996), the model was found to work appropriately although there were apparent inconsistencies in the preference curves. Modelling microhabitat suitability for spawning and egg incubation is likely to be even easier than for juveniles, because some complicated factors, e.g. competition, do not affect it, and thus it should be possible to do it reliably for many species.

6.2.1.2.3 Methods of making preference functions

The methods used for making the preference curves from study data also affect the properties of the curves. If division of habitat use by availability is used, there is a linear relationship between the preference index value and density, which may be beneficial if habitat areas are to be calculated, but the preference values of different preference curves are less comparable with each other. On the contrary, with Jacobs's method, different curves may be easier comparable with each other, but the relationship with density is not linear. In the Laukka area, the modelling with curves made with Jacobs's method produced a slightly more accurate prediction. The method used for the division of the data into classes also affects results, especially if the data are scant. Grouping the data with non-uniform intervals could be advantageous, and special attention should be paid to flow velocity values near zero. Some of the problems caused by the combined effects of variables in nature could be avoided by using multivariate preferences, often visualised by surfaces. In the two-dimensional model studied, the possibility of using these has been included. At the Pyhäkoski impoundment, using multivariate preferences resulted in a rather similar prediction than when preference curves were used, but the amount of data used in making the surface was low. Guay et al. (2000) fitted a Gaussian multivariate logistic model to data with three variables and got more accurate predictions of abundance than with preference curves. Constructing multivariate preferences requires much more data, because the data are divided into classes according to the values of many variables simultaneously. If different preference curves made for different conditions are sufficiently similar, multivariate preferences may not be needed, but on the other hand, the benefit of using them should be studied especially if all factors affecting preference are not known.

6.2.1.2.4 Other preference functions and indices

So-called fuzzy logic preferences (Jorde et al. 2001) are an easier but coarser way to input multivariate preferences-type relationships into a habitat model. It is worth considering when preference curves are not considered adequate and there are not enough data to make multivariate preferences, and biological expertise about the preferences is available. To take differences in the relative importance of variables into consideration, exponents for weighing variables have been calculated by multivariate analysis (see Chapter 2).

A move in the other direction is so-called generalised instream habitat models (Lamouroux & Jowett 2005), in which habitat predictions are derived from simplified hydraulic data, based on e.g. aggregates of Froude and Reynolds numbers and relative roughness and width to depth ratio. These can't be calibrated to non-homogeneous rivers. The calculation of very simple indices describing the overall hydraulic conditions, e.g. the Froude number and printing maps e.g. of flow velocity or calculation of shear stress at river bed, in addition to modelling, could also be advantageous.

6.2.1.2.5 Adjacent habitats

Habitat models could be developed to take better into consideration the effect of adjacent microhabitats and mesohabitats on habitat quality. When using habitat models in planning of rehabilitations, the whole life cycle of the species, habitats at different seasons, the habitats of the prey, habitat connectivity and the processes forming the habitats should be taken care of (Roni et al. 2002). The availability of habitats for the early life stages, winter and low flow refuge should be taken care of (Bond et al. 2005, Cunjak 1994, Muotka & Syrjänen 2007). Energetically favourable conditions may exist in places with strong gradients in flow fields. Habitat gradients give fish the possibility to optimise energy use and availability of drift prey.

Predicting the exact positions of individual fish may not be as easy as differentiating between the suitable and unsuitable habitats. A reason could also be that energetically favourable eddies and gradients in the heterogeneous river, and three-dimensional phenomena couldn't be modelled with the scales and hydraulic model used. It would be easy to add to habitat models a feature computing gradients, but the grid cell size should correspond to the scale of heterogeneity. With a submodel of PHABSIM, indices based on combinations of user-defined flow velocities of adjacent cells can be calculated (U.S. Geological Survey 2005). Edge effects could be estimated by calculating partial derivates of the values of variables and these could be used as variables in calculation formulae. Despite the fact that grayling uses the transition zone between swift and slow flow, prediction of abundance was successful both at Laukka area and on River Simojoki. Because the fish select certain types of habitats, flow velocities in the transition zones may usually be rather similar, which reduces the need to take the effect of adjacent cells into account.

The use of models in which the behaviour of individual fish is modelled could reduce the biases discussed above, but the need for calibration data is high, and modelling may take substantial amounts of computer time. Railsback and Harvey (2001) have constructed such a model (Railsback et al. 2002) and French modellers have already applied a model in some rivers (Gouraud et al. 2004) which dynamically takes the different life stages of fish into consideration. The so-called energetic models that are based on calculations of the energy balance of fish can be included in individual fish-based models. Using three-dimensional hydraulic models could make hydraulic data more accurate. With the help of these methods, more factors can be taken into account, but the complexity of models and the work needed in modelling are increased.

6.2.1.2.6 Mesohabitats

Mesohabitats may affect microhabitat preferences. These and the mesohabitats may also be different under different hydraulic conditions. Habitat quality may also depend on e.g. predation and competition. A part of these effects can be taken into consideration by developing and using appropriate microhabitat suitability criteria on each different mesohabitat type. In calculated microhabitat values for single life stages of fish, mesohabitat quality is not always taken into consideration. Substrate is often an indicator of the mesohabitat type, which supports the capability of models also in different mesohabitat types than where the preference curves come from. Mesohabitat suitability indice values can be calculated e.g. as in Raleigh et al. (1986). The preferences could e.g. be used as multipliers of microhabitat suitability values if long river sections containing different mesohabitats are modelled.

6.2.1.2.7 Other variables; vegetation and shear stress at river bed

Vegetation could be used as a variable in the same way as substrate. In earlier studies (Heggenes et al. 1994) flow velocity and water depth were found to explain the habitat selection of salmon and trout best from seven variables examined. These and substrate (river bed material and its size), and to lesser amount cover are generally considered to be the most important factors affecting the habitat use of salmon and trout (Heggenes 1994a), e.g. because the values of other variables have been found to depend on the values of those three variables and existence of cover. All size classes of juvenile trout avoided vegetation in the Finnish Kuusinkijoki River study (Mäki-Petäys et al. 1997) in winter, while in many foreign studies contradictory observations have been made. On the basis of these, some authors have suggested that the primary factor offering wintertime shelter would be a coarse substrate. In summer, young-of-the-year trout preferred cover offered by vegetation, whereas the larger juveniles seemed to avoid it, perhaps because they were searching for deep pools (Mäki-Petäys et al. 1997). Results of preference studies in natural rivers concerning vegetation should be checked by laboratory experiments, in which different factors can be controlled. The amount of vegetation varies during the year, and the effects of different plant species are different. The type of vegetation also varies geographically. Additionally, the quantification of the amount of vegetation cover should be standardised if vegetation is used as a variable. Today, vegetation could be used on the basis of local studies at the habitat study site. It could be suggested that because it offers shelter vegetation could be a useful variable for the smallest juveniles in summer. More studies are needed concerning the effect of vegetation, its importance, and about the preferences themselves.

Shear stress on the river bed, and Froude number have been found to be important factors for habitats of lotic benthos (Extence et al. 1999, Merigouox & Dolodec 2004, Sagnes et al. 2008). The effect of erosion, sedimentation and vegetational processes on the river to be rehabilitated are often estimated. Methods based on the results of the same two-dimensional hydraulic models used in habitat modelling exist for assessing the effects of erosion and sedimentation. Habitat modelling of the prey of fish, e.g. benthos could also be carried out. Shear stress can be used to help in assessing the hydraulic conditions for the growth of benthos and vegetation. Two-dimensional habitat modellings have been carried out based on it (Jorde 1996, Kopecki 2008, Lahti & Auvinen 2009).

6.2.2 Herb model

No sensitivity analyses were specifically carried out for the herb model, because the structure of the model is a subset of the fish model.

6.2.3 Crayfish model

A sensitivity analysis was carried out for the crayfish model regarding the use of preference data from a lake of different size. When preference curves derived from larger lakes were used in modelling of a small Lake Slickolampi, varying predictions resulted. The first model from a larger Lake Pääjärvi couldn't be used without a modification of the preference curve for potential erosion to take the smaller lake size into account. Creating the preference curve for potential erosion from data from small and large lakes, a total preference of the areas with higher habitat values resulted. With the preference curves from the second lake, Lake Katumajärvi, again, a total and significant preference of the areas with higher habitat values was observed.

Potential erosion and temperature were correlated with habitat use. Potential erosion reflects the cleaning effect of water movement on lake bed material, keeping the sheltering places of crayfish free of settling material. But too-strong currents may also make the habitat unsuitable for crayfish (Jussila 2002). One assumption based on both biological literature and interviews with biologists (Jussila, Erkamo) could be that crayfish need steady bed material in which they can find or build sheltered places for resting (Tulonen et al. 2007b & 2007c), but with not too much water movement, also optimising all these together with water temperature (Tulonen et al. 2007a). According to Peay (2003), for a British crayfish species, the key features of potential refuges for crayfish are big enough to amply cover the crayfish, relatively stable and resistant to high flows but in a flow that is slow enough for a crayfish to walk in the refuge but still not too silted. Also Klosterman and Goldman (1981) concluded that crayfish *Pacifastacus Leniusculus* might have definite preferences for substrate materials which may also be affected by other factors, e.g. flow velocity and direction. Adult crayfish preferred mixed rock to small gravel. Slope may also affect site selection, being important in lakes with low wind-induced potential erosion rates, but also in windy lakes it may have a combined effect together with water movement (Erkamo). Water depth could also be used as a variable, but potential erosion rate and temperature stratification correlate with it and the importance of only depth is unknown. Bed quality could also directly be a variable, because coarse, relatively unlaborious estimations of it could be made on the basis on photogrammetric maps or by boat on the basis of the existence and quality of vegetative cover. In this study, there were not enough suitable data available to study this. The abundance of crayfish was studied on the basis of trap catches. The spatial distribution of catches may include proportionally too much habitats where crayfish move while searching for new habitats or nutrition, compared with the real relative importance of these kinds of areas for habitat quality. Instead, it may be the amount of areas offering shelter that makes the difference in importance between different areas for crayfish populations. Crayfish feed during the night and hide under light conditions. The effect of wintertime conditions should also be studied. It would be advantageous to study all these with cameras and telemetry. The effect of water level fluctuations, patterns of yearly temperature stratification, water quality, and turbidity should also be studied. The habitat requirements of young crayfish should also be studied. Measurement methods should be standardised. It seems that there exist variables useful in modelling to assess the habitat quality of crayfish, but studies directed towards a more accurate understanding and modelling of the behaviour of crayfish need to be continued. It can be concluded from the tests and validations, that the effect of wind may be different in magnitude and in the way of action on shores at different lakes. At small lakes, e.g. Lake Slickolampi, the effect may be weak, and the slope and water depth, which is correlated with water temperature, may be the deciding physical variables. At larger lakes, the action of wind may be the primary factor affecting the substrate. At Lamminsaari Island, wind-induced currents flowing from one side of the lake towards the other, hit the shores of the island (Erkamo 2002) changing the usual way of action of wind-induced erosion. At all lakes, measuring the substrate directly, could be the most reliable method of habitat modelling, but usually this is very laborious, if reliable satellite based mapping methods do not exist. Assessing the effect of wind on the composition of the substrate may give a less laborious alternative. Water temperature may also have an effect on habitat use, depending on season and temperature stratification. Further studies are needed with larger data to find the most suitable variables and the limitations for their use, because the variables are so correlated, e.g. water depth, temperature, substrate, distance from shore and potential erosion may often be intercorrelated.

6.3 Validation of the models

6.3.1 Introduction

There have not been thorough validations of two-dimensional habitat models. Critical aspects of modelling mentioned by McMahon (1992) are the biomass-WUA relationship, other factors affecting populations, and a lack of well-defined or standardised preference curves. Hydraulic modelling methods used in habitat modelling have neither been optimized nor validated. In this work a model based on a more robust hydraulic model and spatial technology was tested in order to overcome the question marks that arise from the use of PHABSIM. The usefulness of these kinds of models was studied. The tests should be used to study the ability of the model to produce new, useful and accurate information. Choosing too large study areas including too clearly unsuitable habitats may not give much information of the usefulness of the model. For this reason, e.g. only the near shore line areas outside the centrum of town Oulu were chosen to the study area of *Persicaria Foliosa* model. On the other hand, if the area consists of only the most suitable habitats, the power of the test may suffer.

The spatial heterogeneity of the study areas affects the test. The heterogeneity here is related to the habitat requirements of the organism studied. If the heterogeneity takes place only in larger scale, and is strong, this makes testing easy. However, if the heterogeneity of the study area is strong in small scale, this makes accurate observations and modelling difficult.

Different sources of variation in the validation are violations of the assumptions of the statistical test, variation caused by sampling methods, and natural variation of the phenomenon studied. The model was validated by comparing calculated habitat suitability index values against observed habitat use (Figure 6.1).

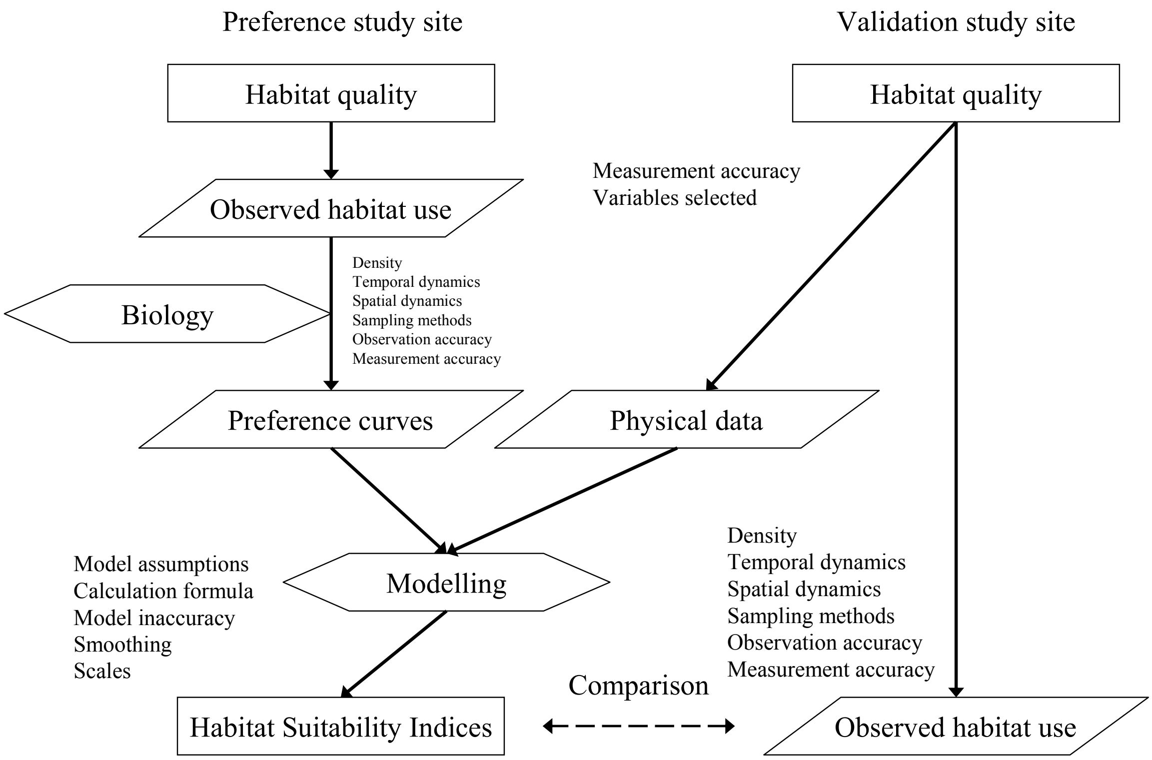


Figure 6.1. The process of model validation.

6.3.2 Requirements of the test

The null hypothesis of the test is that the event, habitat selection, does not depend on the variable, habitat suitability index, by which it is classified. In the statistical test, chi square test, it is required that the events of habitat selection are independent and have similar distributions of expected probability with each other. Assumptions necessary for the statistical test are e.g. that the fish don't interact with each other, the fish don't take space or territories; all fish can freely select their habitat from the whole study area and that the fish can swim to every place that could be suitable for them, inside the study area. These assumptions are violated to some degree. The fish take territories, which is a violation against the test. This reduces the power of the test, i.e. increases the risk of type II error when habitats are predicted well, the more the higher densities get, because then the probability that also the less suitable half of the study area gets used, gets higher. On the other hand, if densities were very low, the test would not make difference between the use of good and the best habitats. For that purpose, the proportions of use divided by availability were drawn. Anyway, the assumption of the statistical test that the events of habitat selection by individual fish would be independent is violated. But a habitat model is assumed to put the habitats in an order of habitat quality from the lowest to the highest. On the other hand, the dynamic habitat use by fish causes an effect of similar type. The combined effect of territories and densities comparably puts the areas in an order based on observed densities. If the effect of territories was small, it could be approximated that the fish would select the best habitat but the dynamic habitat use would cause the variation that puts the habitats in an order of preference. In practice, both territories and the dynamic use have an effect. Without territories or variation, all fish would choose only the best spot in the river. The accuracy of observations brings additional uncertainty to the test.

The effect of density on habitat use is included in the model by the preference curves, but the multiplication in the habitat value calculation formula changes this effect in a certain amount, because values from preference curves are multiplied together; all variables have to take optimal values simultaneously to the combined habitat suitability index value to be optimal. On the other hand, the preference curves may be based on larger data and thus more universal and less spiky than the observed habitat use.

The fish may interact with each other in other ways too; brown trout or salmon don't shoal (Koli 1990), shoaling was not observed for pikeperch, but adult grayling take territories but may be aggregated like shoaling (Koli 1990). Shoaling could reduce the effective number of events in the test, leading to higher uncertainty. These mean that the test may result in too easy conclusions at Laukka area. On the contrary, At Rivers Simojoki and Ala-Koitajoki, the high densities observed may result in an increased risk of type II error.

Inside most study areas, the habitats truly available to all fish match the study areas, because adult grayling and pikeperch can swim everywhere in the study areas and so do all salmon and trout larger than ten centimeters. It is not clear whether the smallest brown trout and salmon can also swim across the study areas at Rivers Simojoki and Ala-Koitajoki. Anyway, they can at least, select from habitats of one side of the stream, if not from whole the study area.

Additionally, at Laukka area and Pyhäkoski impoundment, the statistical test requires an assumption that if the hydraulic or other conditions change, the fish despite that have already found the most preferred habitats at the sampling moment. This is not a critical requirement, because the fish usually can select good, if not the best habitats fast, after rapid changes.

Additionally, if any observations are made from same individual fish, serial correlation may be induced by temporal adjacency, and the risk of type I error may increase. This might happen when the fish are observed by telemetry or with catch and release fishing with a log book. At Pyhäkoski impoundment, the effect of serial correlation was estimated with calculations based on assumptions of Matalas (1967). At Laukka area, the amount and effect of catch and release fishing was not known. The observations being of the same individuals having an individual behaviour, reduces the variation in the habitat selection, not only because natural variation in habitat selection is caused by the dynamic character of habitat use by individual organisms, but also by differences between individuals. The test would also require that the fishermen equally effectively fish every spot and the whole of the study area that the sampling would be carried out from the same set than the expected probabilities of the event of habitat selection are calculated from. This might not be true, because some areas are easier accessible for fishing than other areas.

Validity of tests requires assumptions regarding the sampling methods: the fish wouldn't move to fished habitats while sampling, all fish are found and caught, and the fish wouldn't escape or move because of disturbance from sampling, the position of fish could be measured accurately, and that water depth, flow velocity and substrate could be measured accurately. Additionally, at Laukka area and Pyhäkoski impoundment, if the hydraulic conditions changed during observations, and the habitat availability distributions are computed by weighting the distributions at different moments by the number of fish caught, there should still be plenty of all types of habitats used by the fish available at each moment. At Laukka area, it was assumed, that the fished individuals are in their normal habitats. At Pyhäkoski, it is assumed, that the telemetry transmitters don't change the behaviour of the fish.

In the following it is discussed to which degree these assumptions are violated. When carrying out electric fishing, normally less than half of the fish are found at the first fishing. If some fish are hiding in the substrate and these habitats differ from the habitats selected by the fish found, some difference to observed habitat use may result, but this is considered not to violently change the habitat use observed. However, it may bring some uncertainty to the tests. The accuracy of positioning the fish may affect the results more; measuring flow velocity from the right spot is important, but the accuracy estimated is only 0.5 meters. The measurement of flow velocity is affected by dynamic phenomena in the flow, heterogeneous river bed particle sizes and geometry and three-dimensionality of flow. The measurement of water depth is simpler, but a heterogeneous river bed structure may make it difficult, if the right spot is not exactly known. When measuring the substrate, decisions made by the measurer may affect the results. All these bring uncertainty to the test, and make it difficult to validate the ability of the model to accurately predict the use of the smallest microhabitats. However, on the normal microhabitat modelling scale of 1-10 meters, on which also the measurements for modelling are made, the validation test should be possible. However, when habitat quality is very heterogeneous, validations at larger spatial scale are also affected remarkably by the increased variation.

At Laukka area and Pyhäkoski impoundment, during the lowest flows, high velocity habitats weren't available, but the proportion of such events was rather low. At Laukka area, the difference between the feeding and average habitats should not be large in summer and daytime. At Pyhäkoski impoundment, the telemetry transmitters were so small compared with fish size that they are considered not to affect the behaviour of the fish. The statistical event of choosing habitats would not change, under the assumption of independence and similarity, if the number of fish inside the study area changed if the area would be sampled during a longer period. However, in practice, the effect of it would only be similar to that the density was varied, which might even be beneficial.

6.3.3 Measurement of observations

The inaccuracy of the measurements of observations may reduce the statistical power of the comparison tests. Finding the exact spot where the fish was when it was observed is not possible with electric fishing, however, the precision of the measurement of coordinates is good. In a reach, which is heterogeneous in a small scale, e.g. includes stones and boulders in a shallow riffle, conditions may vary rapidly spatially. Temporal changes in very turbulent sections may also have some effect on observed preferences as well as three-dimensionality of flow can cause variation which is not taken into consideration by the measurement method. All this may mean that the assessment of the predictive capability of the model might have resulted in a higher ability to predict habitat use if the observations had been more accurate.

In the following, the accuracy of field measurement methods used when observing fish is discussed and recommendations are given. Measuring water depth and substrate is straightforward after the position of the fish is determined. Here, only the demanding measurements of flow velocity and fish position are discussed.

The declared accuracy of the observation of the horisontal position of the fish was 0.5 metres at Rivers Simojoki and Ala-Koitajoki. The coordinates of the fish finding spots were determined with a tacheometer, and were accurate enough, but observing the position of fish is difficult. Flow velocity values may change rapidly in shallow rapids with lots of stones and boulders. If a fish swims behind a stone in a spatially and temporally varying flow with eddies optimizing energy use and availability of drifting prey, the measurement accuracy should be in an order of 10 centimeters. The accuracy of the observation data may not be sufficient for assessment of the model prediction of the smallest microhabitat details with a comparison. There are several methods of measurement. Nose velocities mean the flow velocity measured just in front of the fish. Column velocities are depth-averaged values e.g. produced by two-dimensional hydraulic models. Many flow velocity measurement methods are suggested for measuring depth-averaged flow velocities in literature, e.g. one-, two-, and three-point methods. The selection of the method depends on the water depth and accuracy desired. For shallower depths a measurement device with a smaller-sized impeller should be used. Flow velocities at 60% depth were measured directly on situ on Rivers Simojoki and Ala-Koitajoki. Most of the preference curves used were made with the same method. Column velocity values are, on average, near the values measured at 60% depth and usually 10-15% smaller than values found on the water surface. Intensive studies by Hulsing, Smith, and Cobb (1966) showed that velocities measured at 60% of depth were on average 1.02 times the mean vertical velocity. The flow velocity at 60% of depth measured from the water table is used as an estimate for average column velocity as it is the practice of the U.S. Geological Survey with shallow streams with depths between 0.09-0.76 metres (0.09-0.46 m, Price pygmy, 0.46-0.76 m Price type A or A metres). The 5 and 95% percentiles for water depth of all the data from the River Simojoki are 8 and 71 centimetres and 5 and 58 centimetres for the River Ala-Koitajoki. These mean that the measured flow velocity values at 60% of depth can be used as estimates for average column velocities. Using directly measured values in a river with a rough river bed surface is probably a more exact method, but often a more laborious one too, than hydraulic modelling with a restricted number of topography measurement points, which usually leads e.g. to a necessary interpolation and smoothening of values.

An important thing to consider is the measurement time needed. Eddies changing with time found in places with significant changes in topography may also affect flow velocity measurements. In Watson et al. (2002), a measurement time of 10 seconds to 1 minute is suggested in discharge measurements; in other sources, e.g. Rantz et al. (1982), the recommended time in the same measurements is 40 to 70 seconds. The relative pulsation of flow was largest with low flow velocities. With a flow velocity of 1 ft/s, the deviation caused by pulsation was, at maximum, only 7% as an average of 23 s, during a period of 680 s in a laboratory flume (Rantz et al. 1982). The standard error in discharge was only 2.2% with a flow velocity measurement time of 45 seconds measured with a two-point method in a study based on data from many natural rivers (Rantz et al.1982). The variation was described as being randomly distributed. The spatial and temporal variation of flow velocity should be taken into account when planning and making measurements from which the data will be used in calibration or validation or as hydraulic data in habitat modelling. To optimise the accuracy versus time used for measurements, preliminary measurement tests can be carried out with different measurement periods before measurements.

The measurement of the positions of *Persicaria Foliosa* was easy. The measurement was carried out in late summer, when the herb is clearly visible from the mud. Still it is possible, that some herbs under other vegetation were not observed.

Measurement of the positions of crayfish was partly easy, because the traps define the positions, but the exact coordinates of the traps had to be calculated afterwards for use in this work. This means there may be some displacement in the positioning.

6.3.4 Results of validation tests

The habitats of adult grayling were predicted very accurately at Laukka area with locally determined preference curves. Grayling has clear habitat preferences related to hydraulics, which may explain the result. On the other hand, the properties of the data increase the risk of type I error. The model was validated also at Pyhäkoski impoundment with a modelling of summer habitats of pikeperch. The prediction was weak, but insignificant. This may show the limits of the applicability of the model; the habitat preferences of pikeperch in summer might depend on factors not explained by the model; e.g. on availability of nutrition, because pikeperch are more actively feeding in summer. On the other hand, the fish were released to the study site in late spring, which may mean that the fish hadn't found their preferred habitats yet.

In the Simojoki and Ala-Koitajoki rivers, roughly twice as many salmon and brown trout were found in the halves of study areas with higher calculated suitability index values than in the halves with lower values. Densities increased surprisingly consistently towards higher values of suitability indices, but with a decreasing rate towards the highest values. The areas with the suitability index value in classes with the lowest value were, on average, almost empty. The difference between the uses of calculated average and high-quality habitats was not very large, but the overall ascending trend and the avoidance of the lowest class were consistent. That the difference was rather small might be caused by the relatively homogeneously good quality habitats in the study areas (Mäki-Petäys et al. 2002), the high densities observed and by inaccuracy of the positioning of the fish observed. Only the strongest competitor can select freely its habitat; the others have to select lower quality habitats that are left. The dynamic use of habitats (Mäki-Petäys et al. 2002) may cause small shifts in habitat preferences which may become significant when the differences in habitat quality inside the study area are small. In this case, also the finest microstructure of the river bed and eddies caused by it not represented precisely and other factors not included in the traditional model, e.g. shelter from banks and flow gradients may have taken effect. On the other hand, the precision of the measurements in the observation data may not have been sufficient. At these rivers, the habitat availability was sampled with constant intervals, and it may be rather precise, but when the positions of the fish were located, an accuracy of 0.5 metres is rather low if the use of microhabitat details is studied. The inaccuracy caused by this to the flow velocity values may be large. This may have caused much of the rather large random variation in the results.

The sets of data from River Simojoki for grayling, bullhead, and stone loach were too small for conclusions to be drawn. Grayling preferred areas with high habitat values, bullhead preferred weakly in three sets of data, while stone loach avoided in two and preferred in one set of data. The importance of availability of nourishment to bullhead as a factor in habitat selection as suggested by Huusko et al. (2003) may have affected the result.

In the Laukka area, both high- and low-quality habitats were abundant, which resulted in a clear difference between the uses of these areas. Both the curves from much smaller rivers and local curves resulted in a good predictions. Only the too general curves failed. These results suggest that habitat quality could be estimated with the model, and that the prediction of abundance of an organism would be stronger when the range of variation in larger scale habitat quality is greater. The clear larger scale spatial variation in topography and habitats contributed to the accurate predictions achieved.

With the herb model, the abundance of preferred habitats for *Persicaria Foliosa* was easily predicted. This was caused by the fact that water depth and substrate probably mostly define the habitat preference.

For crayfish, a model for lakes was validated. Model validation at Lamminsaari Island with preference curves from Lake Katumajärvi study areas 4-5 resulted in a weak and insignificant prediction of habitat use. Validation of the same model at Lake Slickolampi resulted in a strong prediction. The unsuitable habitats were very clearly predicted, but the moderately and most suitable habitats were not separated from each other. A modelling carried out at Lake Katumajärvi study areas 4-5 with a model created at Lake Pääjärvi resulted in a good and significant prediction of habitat use. However, the proportion of use and availability had two maxima. These imply that many variables useful for habitat modellings of crayfish have been found, but the importance and interaction of these at different lakes should be studied further with larger data in order to ensure a reliably transferring model.

6.3.5 Interpretation of the results

Next, whether these results can be used as a proof for a claim that real habitat quality could be calculated or assessed with habitat models is discussed. The question is whether the study arrangement makes this kind of claim reasonable and whether some factors in modelling could cause bias between the calculated and the real habitat quality. In fact, the real habitat quality cannot be measured directly by any means. It can only be assessed indirectly on the basis of observations of the behaviour and properties of the organism. This means a need to understand the behaviour of the organism and decisions made by them when selecting habitats. A model of the behaviour of the organism could be constructed on the basis of this information. An alternative method could be using statistics with assumptions of the relationship between abundance of organism and habitat quality. In practice, the models constructed are usually combinations of these; the first method e.g. is characteristic of models that here are called individual fish models and the second better describes the traditional habitat modelling studied here.

The difference is that in individual fish models statistics are used to construct rules for the behaviour of individual fish, while in traditional models the preference for using different types of habitats is modelled on the basis of statistics of observed habitat use. In both, the factors affecting the behaviour of fish must be known and understood, though in the first, the model is more detailed. Modelling is possible and more reliable if the behaviour of the organism is more based on irrational traits, without very much learning of different habits that would dictate the habitat selection, than rational decision-making. That would mean that the behaviour of the organism could rather be studied as a consequence of prevailing conditions and the genetic traits and properties of the fish than that the organism had a large variety of possibly culturally affected and changing and varying motives that should be understood. This assumption is the base of individual fish models. One problem existing that reduces their usability is the variety of conditions affecting behaviour, which makes these models expensive to calibrate because of the number of variables it is necessary to study. In traditional habitat modelling, a smaller number of variables are taken into account, and the role of statistics is more profound. This makes modelling less laborious, but some problems are created. If many factors affecting the behaviour of the organism remain unrecognised, when the model is applied to different places after calibration, changes in behaviour caused by different conditions cannot be taken into account in such detail. For example, the mechanisms with which competition, density, organism size distribution, and the amount of nutrition affect habitat selection are not modelled. Additionally, the preference curves are made on the basis of observations of the organism and are often calculated from densities. This means that the positions of suitable habitats and their quality proposed by the model may be biased. Before the biases can be estimated, habitat quality must be defined.

Habitat quality could mean the quality of the habitat for all species, or it could mean its suitability for one species. In practice, habitat quality is modelled separately for different life stages of each species and the factors considered are limited to a certain number out of all those possible. In the case of models called physical habitat simulation models, water depth, flow velocity, and substrate are usually used as variables. The description of the behaviour of the organism and the effects of different factors is limited to the method of multiplication of preference values calculated together. Nor are the effects of nearby areas taken into consideration. The organisms are also either expected to stay exactly in the same position all the time or to use habitats in proportion to the importance of each of the areas for habitat quality. However, some shelter habitat might be more important for the population in comparison with the proportion of time it is used. Because so many factors are left outside the model, the variable calculated resulting from modelling is called a habitat suitability index, so as to tell it apart from habitat quality. A broader definition is used for habitat quality; in this case it could be the feasibility of habitats for a life stage of a species. Feasibility, in turn, might mean the ability of the place to sustain organism biomass growth or it could be measured by the density of organisms allowed by the habitat. Suitability indices usually tell more about the latter, because, in practice, when the model is being made and calibrated, organism density is measured and the proportional use of different habitats is used as a measure for habitat quality. This means that habitat models would be organism density distribution models.

One problem is that density affects habitat selection of fish and crayfish and therefore also the data used in making preference curves. The behaviour of fish may be territorial and the biggest salmonid fish also usually get the best habitats (Hunter 1991, Mäki-Petäys et al. 1999b) and are most strongly avoided by other fish. There was a hint of this with calculations with the River Simojoki data, in which biomass was predicted better than density, but statistically insignificantly, and the amount of data was too low and too few preference curves were used to draw conclusions about this. This could mean that the most suitable habitat could in some cases at least theoretically be used with a smaller density than some other areas. Even if the size of fish was uniform, the most suitable habitats might not be used with a higher density than other areas habitated by fish. These may be reflected in the finding in this work that the least used habitats were predicted more efficiently than the moderately and the most used habitats were separated from each other. The habitats with the lowest class calculated habitat suitability index values were very often totally empty, and starting from there the observed intensity of habitat use rose slowlier towards the highest suitability index values. Factors affecting this phenomenon negatively also exist; in the most suitable places, there may be more nourishment because of better hydraulic conditions (Hunter 1991), which allows higher densities. Shelter, in the form of stones, logs, etc., which are typical of good habitats, may provide visual cover and allow smaller-sized territories (Hunter 1991). The fish also select the most suitable spots inside their territories.

Some methods for studying those effects could be to use laboratory experiments, as in e.g. Vehanen et al. (1999). With them, it could be easier to control the effects of different factors. For example, studies could be made with individual fish to get habitats into an order of preference, and with different densities, with and without predators etc. Additionally, preference studies and curves could be made for use in different conditions; temperature, amount of nutrition, abundance of predators, density etc., but additional resources would be needed because of the resulting high number of alternative combinations. Much responsibility is usually left for biologists to make and use suitable preference curves. Preference curves are often made directly from data by dividing use by availability and smoothing the resulting curve.

Another problem in this study design is caused by the dynamic character of the site selection of fish and crayfish; habitat use observed varies temporally, and it is compared against habitat quality. The observations represent habitat use only at certain moments. This may not be a good point of comparison for modelled habitat quality. Habitat quality on field should be tried to be defined better. According to Gore et al. (1996), it has not been clearly demonstrated that habitat models would predict biomass or its position, but there still would be a significant correlation between habitat quality and density. Gore's statement could be explained by the fact that factors such as e.g. population history and the territorial behaviour of fish affect densities. But, as concluded earlier, modelling might, for other reasons, also reflect densities or biomass, which means that in the study design, instead of modelled and real habitat quality being compared, modelled measures of density and observed organism density may be compared with each other instead. This may not be a problem, because it is obvious that real habitat quality and densities correlate. But this and the dynamic nature of the behaviour of fish and crayfish mean that the amount of data used in validation must be high enough and the observation time long enough and that the data must include different conditions. The more studies that are carried out, the stronger the assessment becomes. The prediction of the abundance of organisms, i.e. given an area, what is the probability of the abundance of organisms, may not be as easy with models, because of the usual modelling scales, and because of there may be factors that affect habitat other than the variables used in modelling. The site selection of fish is dynamic (Mäki-Petäys et al. 2002). But a prediction of an abundance of organisms at a certain spot at a certain moment is not so important for river habitat assessments; what is more important is the average habitat use and quality.

However, good predictions of habitat use have been achieved with these habitat suitability calculation principles in many cases, with new two-dimensional habitat models, and even with the old PHABSIM model as earlier mentioned. This despite the fact, that there have also been less successful efforts and criticism. Compared with a single electric fishing as a habitat assessment method, modelling is usually based on a validated, much larger, set of observation data. Population history, fish movements, the weather, the time of day etc. affect the temporal site selection observed on the spot. Additionally, factors that are not usually included in models, e.g. water temperature variations and vegetation, also act on the study site. The effect of these can be averaged by using large preference study data from several places. Additionally, the effects of e.g. different organism densities in study data become averaged. Combined with biological knowledge, this type preference curves have been created for e.g. juvenile brown trout and salmon. Because good predictions of fish biomass differences between river reaches have been achieved, e.g. in France with EVHA modelling sharing the basic habitat value calculation principles with two-dimensional models, it is probable that good predictions can be achieved at least with some conditions. Fish biomasses in separate reaches are usually affected by a variety of factors over a period of many years, which means that the variable used in comparisons made in France and based on fish biomass must be near some concept of habitat quality. Added to the results of microhabitat scale validations with two-dimensional habitat models this also means that a relationship between modelled habitat quality and fish density or biomass has been found both on the micro and mesohabitat scales. In a single-site Canadian study, Boudreau et al. (1996), habitat quality modelled with a two-dimensional model and fish density correlated strongly. Because factors, often e.g. water temperature or vegetation causing bias act with varying power on different spatial scales, and good predictions have been achieved despite that on both scales, it hints that the variables used in modellings and the calculation principles should be at least partly valid. Those variables have also been found to be important in earlier fish habitat preference studies. Because calculated habitat suitability and observed density have been found to correlate in the carefully conducted studies of the present study, so that the values of both the variables ascend together, and it is evident that real habitat quality and fish densities usually correlate in this way too, and both of these occur on both scales, it is reasonable to suggest the existence of a similar kind of relationship between real habitat quality and modelled habitat suitability too. And no matter, whether the model was a density model, because density and habitat quality correlate. The question is only one of under what conditions reliable results can be achieved; at least careful application of modelling is needed to assure the relationship between modelled and real habitat quality in each study case.

With the validation of specific models e.g. for a size class, for each season, mesohabitat type, and possibly for the size class of river, generally applicable models may be achieved for organisms with habitat preferences suitable for this kind of modelling. Because of good results in this and earlier works, it can be assumed that relatively reliable habitat modelling may already be possible at least for salmon and trout fry, and possibly for the next size class of juveniles too, at least in Nordic countries. Habitat preferences of different species should be studied further these for as e.g. Mäki-Petäys (1999) has done for brown trout. Because the behaviour of trout and salmon changes consistently with fish size and a comparison of preference curves from different countries showed relatively little variation, modelling these species seems to be possible with no or relatively few local adjustments on preference curves. In many other countries, e.g. in France, local preference curves based on large amounts of data have also been created the applicability of which could be tested. The findings of this work could further be verified by additional modellings with data including sites with more varying habitats than the River Simojoki and River Ala-Koitajoki study areas representing mostly nearly optimal habitats (Mäki-Petäys et al. 2002), and possibly also with data from more southerly conditions. Studies for other life stages and species should be conducted. In modelling, important things to consider are the sensitivity of the variables used in modelling relative to those factors excluded from modelling, and of course, whether other factors, possibly vegetation or shelter in the form of eroded banks, should also be used.

6.3.6 The capabilities of the model and suggestions for future studies

In the study, the model was first tested, and after that verification and a sensitivity analysis were carried out. Finally, the model was validated with observations of habitat use. The measurement methods of observation data allowed studying the ability of the model to predict habitat use at scales normally used in modelling. However, the finest micro details of habitats are smaller than the scale of observation accuracy. This brought uncertainty into the comparison tests in addition to the variation caused by the model.

The capability of two-dimensional modelling to address the problem of interest, the prediction of habitat quality, was discussed. Model residuals seemed to be random.

Certain limitations in the applicability and accuracy of predictions exist. The limitations are e.g. on the spatial and time scales. The effect of adjacent habitats is not taken into account, but it can be estimated visually from maps. Some species can be modelled, but some not, and the availability of preference information may be a problem. The basic principle of modelling leaves many factors without recognition, and it is important to evaluate the effect of these. The interactions of different variables are taken into account only by multiplication of preference values from preference curves, or by preference surfaces. In practice, the resolutions of measurements and modelling are limited. These must be selected so that the phenomenon studied can be addressed. In practice, the habitat use during the life cycle of an organism can be taken into consideration by modelling the habitats of different life stages of organisms at different seasons. The dynamics of habitat use caused e.g. by varying hydraulic conditions can be studied by comparing the positions of habitats from habitat maps drawn for different hydraulic situations. The physical habitats under rapidly varying flow can be modelled with dynamic hydraulic models. Three-dimensional flow is usually not modelled, because vertical flow velocities are usually relatively small, but in steep rapids three-dimensional phenomena may become significant.

The reasonableness of the model structure and individual model mechanisms were studied and they were found to be suitable for the purpose of the model. The modelling is relatively straightforward. Changes in the measurement or grid densities or parameter values, e.g. when making data models and carrying out hydraulic modelling, leads to a predictable response. Near bank areas can rather completely be included in models with different methods, which can be adjusted to achieve the precision needed. Additionally, hydraulic models with vertical friction exist. The variables used, are practical to measure and to model. Modelling is usually used for habitat assessments and for planning of habitat rehabilitations, and maps of habitats and the possibility to model the effects of different physical habitat rehabilitation alternatives and hydraulic conditions make the model suitable for its purpose and useful.

A sensitivity analysis was made for the habitat model. The selection of preference data was the most important thing to consider. First, it must be checked that the habitat preferences of the organism can be described by the variables selected. The densities in the study areas where the curves were made and the range of available habitat types affect the form of the preference curves. Low-quality habitats were usually easily found with different types of curves. It is important to verify the applicability of preference curves to the study areas. Field measurement density and measurement methods affected the results remarkably, but are controllable. Changing the parameter values when they were set originally sensibly, did not affect results much and were easily controllable.

The overall model behaviour corresponded well with expectations. Relatively consistent quantitative correspondence between the overall model behaviour, i.e. the modelled habitat quality and real system behaviour, i.e. the density of organisms as an estimation of real habitat quality, was found. In the studies with the high-quality data at River Simojoki and River Ala-Koitajoki, the observed habitat use followed modelled habitat quality rather consistently. Because the observed habitat use of juveniles of salmon and brown trout ascended together with modelled habitat suitability values, and fish were significantly more abundant in the cells with the higher half of modelled habitat suitability index values, and the model residuals were random, the behaviour of the model, and the model structure of the fish model should be appropriate. Modelling of areas with larger spatial habitat quality variations, as was e.g. Laukka area, should be even easier. At Laukka area, before rehabilitation, all the 31 fish used the higher half of habitat values. However, the data may suffer from spatial and temporal dependencies of events. That some observations may be of the same individuals may also reduce the effective sample size. Additionally, the observations may have been drawn from a smaller subset of the set of available values. However, the cross-section at the bridge might moderately represent the habitats of the study area. Grayling preferred a restricted combination of water depths and flow velocities available inside the area. This and the total preference for the higher habitat values indicate that the result, an accurate prediction, would probably have been duplicated with unbiased data, too.

Modelling the habitats of *Persicaria Foliosa* was easy because of their clear preferences for just some variables; substrate and water depth. It was also easy to collect data of the habitats of the herb accurately. Very good predictions were achieved. The statistical test of the model for *Persicaria Foliosa* indicated a very accurate model. This was probably caused by an accurate positioning of the organism in the field data, and by the clear habitat preferences. The herb is well known to prefer mud as substrate and to grow near the water line. If other factors affecting the habitat selection, e.g. related to water quality or spreading were controlled, the model might be generalizable.

Modelling of the habitats of crayfish seems to be possible also with less laborious variables than the clearest habitat quality variable, substrate. Modelling of the habitats was tested with variables potential erosion, water temperature and abundance of sand and abundance of soft material. The habitat selection of crayfish and modelled habitat suitability were significantly correlated, usually positively. In most cases, but not in all, more crayfish were found at traps with modelled habitat suitability index values being in the higher half. The trend of habitat use versus suitability was clearly ascending in some cases but in some not. These imply that many important variables have been found. Whereas the models transferred between other lakes, modellings of habitats at Lamminsaari Island, and transferring the models calibrated there to other lakes were in most cases unsuccessful. At Lamminsaari Island on Lake Pääjärvi, wind-induced currents flowing from one side of the lake towards the other might have changed the usual way of action of wind-induced erosion. The effect of wave induced currents and other variables, and the combined effects of these at different sized lakes should be studied further.

As a summary, two-dimensional habitat modelling seems to be a useful alternative in habitat assessments on certain scales and in planning habitat rehabilitations if used and applied in such a manner that the limitations of the methodology are remembered. The applicability of the methodology to each new case must be checked, e.g. variables suitable for predictions with the methodology must exist and reliable preference knowledge of those must be available, and if modelling the species under conditions of this kind has not been validated, a comparison with observations is recommended.

The data used in this work were almost totally measured for other purposes than for validation of habitat models. To check the results of this work, measurements of topography, substrate, flow velocity and water depth, and fish observations should be carried out covering the whole of a couple of study areas. The tests carried out in this work should be duplicated with this material. Modelled two-dimensional flow fields and flow velocities could be validated based on flow velocities measured at different depths covering the areas. Three-dimensional modelling could also be compared with both of these. A comparison with PHABSIM-modelling carried out within the same study area would also be interesting. Validation of habitat modellings for different species, life stages and seasons should be carried out. The relationship between observed fish densities and habitat quality should be studied further.

The accuracy of measurements and spatial and temporal representativeness of the observation data should be studied and developed so that the results from modellings could be validated reliably. Because of the dynamic habitat use by fish, observed habitat use at a certain moment and in a certain place, may not offer fully relevant data for comparison. A more reliable indicator of habitat quality should be developed than fish observations at a single moment. It might be that making a good model could be easier than validating it, because preference curves can be made based on many data, experiments and reasoning, while the observation set of data represents only momentary habitat use, and getting the accurate flow velocity values at the position of the fish may be difficult. Even if the model would describe habitat quality accurately, the dynamic habitat use and observation accuracy would result in much weaker results in tests with snapshot habitat observations in spatially heterogeneous areas. This kind of a result was possibly achieved at Rivers Simojoki and Ala-Koitajoki. Perhaps, the habitat quality of the validation study area should be studied and mapped with a spatial precision higher than that of the observations, based on several observation data and other physical and biological information, and a comparison be made against that.

7 CONCLUSIONS

Prediction of abundance of salmon, brown trout and grayling with a two-dimensional aquatic habitat model was found to be possible. A consistently ascending trend of greater abundance towards higher habitat values was found. The structure of the model was found to be adequate, because also the model residuals were random.

The predictions produced with the model were found to be useful, because predictions were possible also inside good-quality habitats inside in which the river bed had a heterogeneous microstructure. The prediction was stronger when the habitat structure was divided clearer to suitable and unsuitable habitats, still the difference not being too evident without modelling.

With the model, habitat quality can be assessed, because habitat quality and abundance are usually correlated. The definition of habitat quality varies. The scale might be from habitat quality for a life stage of a species at a season to the quality for the whole ecosystem. When we extract a restricted function from an ecosystem, e.g. spawning of trout, the habitat requirements can be defined for it. The complicated system is divided to smaller parts that are handled separately. Important interactions are ignored. However, by modelling the life stages of an organism at different seasons, and by comparing the maps of habitats produced, the direct physical habitat quality can be assessed. By modellings of the habitats of the prey, e.g. benthos, the scale can be further widened.

The model was found to be an important improvement on previous models. The model data is in coordinates, which makes transferring, processing and using data easy and positioning is exact. Two-dimensional hydraulic modelling enhances the description of hydraulics. The effects of changes in geometry or hydraulic conditions can be modelled.

However, the abundance of organisms the preferences of which don’t depend on variables used in modelling can’t be predicted. Neither can spatial scales smaller than measurement density nor vertical currents be modelled.

With different types of preference curves, the suitable and unsuitable habitats could be found. The most avoided areas were predicted most accurately. The curves from different parts of the world for brown trout fry were found to be similar to each other, they transferred well and produced a good prediction of abundance.

With two-dimensional hydraulic modelling, flow velocity distributions can be modelled accurately, if the in shore areas are densely measured and properly included in the model grid. Many types of adjustment are possible for ensuring accurate modelling, especially near shore line.

The accuracy of topographic models can be adjusted by changing the methods and density of measurements and grid densities. With methods of anisotropic and line interpolation, the quality of models can be further enhanced.

In sensitivity analyses, the model was found to be most sensitive to the density of field measurements of topography and to the selection of preference curves. The methods of interpolation affected the results remarkably if the data was sparse. The roughness coefficient was found to considerably affect cross-sectional flow distributions in shore.

Additionally, important and useful findings were made of separate factors in modelling.

Preference curves made from similar type of conditions and from large data produced the most accurate results. Preference curves to be used should be suitable for modelling in the mesohabitat type and conditions of the area to be modelled. Separate preference curves should be used for at least summer and winter. Substrate may often be an indicator of the mesohabitat type in addition to being a microhabitat parameter. This increases the accuracy of the modelling when the modelled area consists partly of different mesohabitats.

The method of making preference curves affects the form of the curves remarkably. Preference functions should be constructed by comparing habitat use with habitat availability as has been suggested. The results of this work also brought out that in classification of values in construction of preference curves, a constant interval normally used, would not be the optimal method of division. The number of data available to construct the curves in each interval should be considered so that the sample is statistically large enough but that the interval doesn't include too different habitats. Special attention should be paid to flow velocity values close to zero.

The methods of field measurements and interpolation into topographical model should cohere. Measurement methods based on echo sounding should be used when possible while areas inaccessible by boat are usually measured with tacheometer at carefully selected points. Generally, of the basic interpolation methods, triangulation should be used where linear forms are found in the channel while Kriging estimates rounder, irregular forms more accurately. With the measurement and interpolation of linear forms in topography before the main interpolation, data models can be enhanced with the same or even reduced number of measurement points. Anisotropic interpolation can be used to enhance data models where anisotropy exists. With coordinate conversions, presented for the first time ever in habitat modelling, anisotropic interpolation can be used also when the shape of the channel is curvilinear. Topographic models of channels with regular cross-sections can be created effectively with the methods of anisotropic interpolation, even from a few cross-sections.

Shallow areas should be properly included in hydraulic models. This should be carried out by using a wetting and drying algorithm, if the shore line is not exactly measured at every hydraulic situation to be modelled. The model grid should be coherent with the shore line and flow directions. Based on an initial model run, the model grid should be adjusted. Using proper coefficients of roughness and kinematic viscosity is important. To take the effect of flow rate dependence of Manning's coefficient, algorithms adjusting the coefficient after water depth can be used. If needed, the cross-sectional flow velocity distributions can be manually calibrated adjusting the roughness too. Kinematic viscosity should be set by using automatic algorithms taking the effect of flow velocity and element size on it into account. Smoothening of detail can be decreased by increasing the density of field measurements and model grids, and by avoiding interpolations when possible.

A totally new two-dimensional habitat modelling of an herb, *Persicaria Foliosa*, based on substrate and water depth, produced a very good prediction of habitat use. This was due to clear habitat preferences and accurate observations. The model may be transferrable if other factors, e.g. temperature, soil and water quality are controlled.

Two-dimensional habitat modelling for crayfish based on hydromorphological variables was tried for the first time, and it seems to be possible. The effect of wind-induced water flow on the substrate described by e.g. potential erosion might be a practical variable in modelling, while the substrate may be the most accurate indicator of habitat quality. The effect of wind is more important at larger lakes with longer free wind reaches. Promising correlations between model results and observations of habitat use were found, but the behaviour of the model was not consistent in every test. The model transferred rather well between all other but one lake. At that lake, currents induced by larger scale water level fluctuations might have caused that. Common to all data was that the positioning of trap sites was not very accurate. Many important variables were found but the importance and interaction of variables need further studies and development to ensure a wide transferability.

Two-dimensional habitat models were found to work consistently if appropriately applied and used, in prediction of abundance of organisms despite a large natural variability and dynamics of habitat selection and the difficulty to accurately observe habitat selection making the validation of habitat models difficult. Because of these, the observed habitat use at a single moment and in a certain place, may not offer fully relevant data for comparison. A more reliable indicator of habitat quality should be developed for model validations with a higher spatial accuracy and taking more temporal and spatial variation into consideration.

8 SUMMARY

For the evaluation of the quality of aquatic habitats of different organisms, different methods have been developed. As a consequence of easier and faster methods and equipment for numerical hydraulic modelling than before, introduction of two-dimensional habitat models has been the latest development, based on an older IFIM-methodology. Two-dimensional hydraulic models can effectively be used e.g. in assessments of the effects of habitat rehabilitations, construction works, changes in flow rates on hydraulic conditions. If the habitat preferences of an organism are known and depend on these and the substrate, habitat suitability indices describing habitat quality can be calculated and mapped with this type of a habitat model.

In this work, different two-dimensional models of aquatic habitats of fish, an herb and crayfish were developed. In fish habitat modelling, two-dimensional hydraulic modelling was used, where only water depth and substrate were used in modelling of the habitats of an herb, *Persicaria Foliosa*, and wind induced potential lake bed erosion and other variables were calculated for crayfish. The habitats and abundance of salmon, brown trout, grayling, pikeperch, stone loach, bullhead, crayfish and *Persicaria Foliosa* were modelled.

Models were calibrated with many types of biological material and tested. The models for salmonids and the herb were found out to work consistently. Model residuals were random. Changes in parameter values lead to a predictable response. Preference curves made from similar type of conditions and from large data produced the most accurate results.

The effect of different methods of using biological information, of carrying out field measurements and hydraulic modelling were analysed. Line measurements and methods of anisotropic interpolation were found to be useful. It is important to include shallow areas in hydraulic models. In modelling of these, a wetting and drying algorithm, adjustment of roughness coefficient and of the form and size of elements are useful. Flow velocity distributions were modelled accurately, if the shore areas were densely measured and properly included in the model grid. Smoothening of detail can be decreased by increasing the density of field measurements and model grids, and by avoiding interpolations when possible.

A sensitivity analysis of the whole model was carried out. The selection of habitat preference curves and the density of field measurements were found to have the greatest effect on results. Preference curves made from similar type of conditions and from large data produced the most accurate results. The density of field measurements and model grid should be adjusted to the phenomenon studied. A precise description of the smallest micro details of flow in shallow, heterogeneous rapids, e.g. behind individual stones may require a higher detail in field measurements and modelling.

The model was validated against observed habitat use. With the models, the abundance of the juveniles of salmonids and *Persicaria Foliosa* could be predicted. The observed habitat use of juveniles of salmon and brown trout ascended together with modelled habitat suitability values. Based on the statistical test, the fish were significantly more abundant in the cells with the higher half of modelled habitat suitability index values. At Rivers Simojoki and Ala-Koitajoki, the location of the most avoided habitats was found more efficiently than the most preferred areas were predicted. This might be due to the methods, detail and scales used in modelling and the high densities, but on the other hand, the dynamic habitats use of salmonids and the accuracy of fish observations affect the observations. A more reliable indicator of habitat quality than momentary observations of fish should be developed against which the models could be validated.

The habitat use of bullhead might depend also on other factors than used in the model, e.g. the abundance of its prey. The same might be true for summer habitats of pikeperch, or the fish were searching for habitats at the study time, however the winter habitats were predicted more accurately. For predictions of abundance of these species, modelling of the habitats of the prey could be considered. The prediction of the abundance of stone loach was poor. The data for making the preference curves and for validation of the predictions of abundance of bullhead and stone loach were small.

Habitat modelling of an herb, *Persicaria Foliosa*, based on substrate and water depth, produced a very good prediction of abundance, due to clear habitat preferences and accurate observations. The model may be transferrable if other factors, e.g. temperature, soil and water quality are controlled.

Two-dimensional habitat modelling for crayfish based on hydromorphological variables was tried for the first time. Correlations between variables and observed abundance were found. In tests, the model transferred rather well between all other lakes but one. Many important variables were found but the importance and interaction of variables need further studies and development to ensure a wide transferability.

Two-dimensional habitat models were found to work consistently if appropriately applied and used, in prediction of abundance of organisms despite a large natural variability and dynamics of habitat selection and the difficulty to accurately observe habitat selection making the validation of habitat models difficult.

REFERENCES

Allan, J.D. 1995. Stream Ecology. Structure and function of running waters. Chapman & Hall, Lontoo. 388 p.

Arthington, A.H. 2002. Environmental flows: ecological importance, methods and lessons from Australia. Mekong Dialogue Workshop“International transfer of river basin development experience: Australia and the Mekong Region”, 2 September 2002. 8 p.

Bartsch, N., Gubala, C.P. & Hardy, T.B. 1996. Determining Habitat Criteria for the Endangered Fountain Darter Through Aquatic Mapping and Hydrologic Modeling. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 251-262.

Binns, N.A. & Eiserman, F.M. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish.Soc. 108(3), 215-228.

Binohlan, C. 1995. In: Froese, R. and D. Pauly. Editors. 2005. FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2005).

Binns, N.A., 2004. North American journal of fisheries management, American Fisheries Society ISSN 0275-5947 2004, vol. 24, no 3, 911-921.

Bird, D.J. 1996. Problems with the use of IFIM for salmonids and guidelines for future UK studies. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X.

Bond, N. R. & Lake, P. S., 2005. Ecological restoration and large-scale ecological disturbance: The effects of drought on the response by fish to a habitat restoration experiment. Restoration Ecology, Volume 13, Number 1, March 2005, 39-48.

Boudreau, P., Bourgeouis, G., Leclerc, M., Boudreault, A. & Belzile, L. 1996. Two-Dimensional Habitat Model Validation Based On Spatial Fish Distribution: Application to Juvenile Atlantic Salmon of Moisie River (Québec, Canada). Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 365-380.

Bourgeois, G., Caissie, D. & El-Jabi, N. 1996. Sensitive Analysis of PHABSIM in a Small Atlantic Salmon Stream. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 381-394.

Bovee, K. D., Milhous R.T. (1978). Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper no 5. FWS/OBS 78/33. U.S. Fish and Wildlife Service, Fort Collins, Colorado, 125 p.

Bovee, K. D. 1982: A Guide to stream habitat analysis using the Instream Flow Incremental Methodology. Washington DC, U S. Fish and Wildlife Service, Instream Flow Information Paper No 12, FWS/OBS-82/26. 248 p.

Bovee, K.D. 1985. Evaluation of effects of hydropeaking on aquatic macroinvertebrates using PHABSIM. Olson, F. W., White, R. G. & Hamre, R, H. (editor) Proceedings of the symposium on small hydropower and fisheries. The American fisheries society, Denver, CO, 236-242.

Bovee, K.D. 1988. Use of Instream Flow Incremental Methodology to evaluate influences of microhabitat variability on trout populations in four Colorado streams. Proceedings of Annual Conference Western Association Fish and Wildlife Agencies 68, 227-257. From Designing and negotiating studies using IFIM. National Ecology Research Center, U.S. Fish and Wildlife Service. IF 200 Readings.

Bovee, K. 1996. Perspectives on Two-Dimensional River Habitat Models: the PHABSIM Experience. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 149-162.

Bowlby, J.N. & Roff, J.C. 1986. Trout biomass and habitat relationships in southern Ontario streams. Trans. Am. Fish. Soc. 115, 503-514.

Bozek, M.A. & Rahel, F.J. 1991. Assessing habitat requirements of young Colorado River cutthroat trout by the use of macrohabitat and microhabitat analyses. Trans. Am. Fish. Soc. 120, 571-582.

Bridger, C.J. & Booth, R.K. 2003. The effect of Biotelemetry Transmitter Presence and Attachment Procedures on Fish Physiology and Behaviour. Reviews in Fisheries Science, 11(1), 13-34 (2003).

Brigham Young University, 1997. SMS Surface-Water Modeling System. Reference manual. Version 5.0. Engineering Computer Graphics Laboratory.

Brookes, A. 1996. River restoration experience in northern Europe. Teoksessa: River channel restoration: guiding principles for sustainable projects. John Wiley, Chichester. 440 p. ISBN 0-471-96139-6.

Capra, H., Breil, P. & Souchon, Y. 1995a. A new tool to interpret magnitude and duration of fish habitat variations. In book: Capra, H. 1995. Amélioration des modèles prédictifs h'habitat de la truite fario. A doctoral thesis, University of Lyon 1. 281 p. Also published in Regulated Rivers: Research & Management, Vol. 10, 281-289 (1995).

Capra, H., Souchon, Y. & Breil, P. 1995b. Relationships between time series of natural brown trout population dynamics and physical habitat conditions of life stages. In book: Capra, H. 1995. Amélioration des modèles prédictifs h'habitat de la truite fario. Literature study. A doctoral thesis, University of Lyon 1. 281 p.

Cochran, W.G. 1954. Some methods for strengthening the common tests. Biometrics; December 1954, 4l7-45l.

COST ACTION 626 Habitat modelling Workgroup 2 members, 2002. State-of-the-art in data sampling, modelling analysis and applications of river habitat modelling. habitat modelling. COST Action 626 Report, March 2004. http://www.eamn.org/, final report. 313 p.

Cowx, I.G. & Welcomme, R.L. 1998: Rehabilitation of rivers for fish. Food and Agriculture Organisation of the United Nations (FAO). Fishing New Books. 260 p.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. 53(Suppl. 1), 267–282.

Dittrich, A. & Schmedtje, U. 1995. Indicating shear stress with FST-hemipheres - effects of stream-bottom topography and water depth. Freshwater Biology, 34, 107-121. ISSN 0046-5070.

DVWK 1996. Fluss und Landschaft- ökologische Entwicklungskonzepte. Merkblätter 240. Deutscher Verband für Wasserwirtschaft und Kulturbau e.V. 285 p. ISBN 3-89554-046-3.

Eisner, A., Young, C., Schneider, M. & Kopecki, I., 2007. MesoCASiMiR – new mapping method and comparison with other current approaches. Manuscript.

Elliott, G. V. 1980. First interim report on the evaluation of stream crossings and effects of channel modifications on fishery resources along the route of the trans-Alaska pipeline. U.S. Fish and Wildlife Service, Special Studies, 1011 E. Tudor Road, Anchorage, Alaska. 77 p.

Elliott, J. M. 1994. Quantitative ecology and brown trout. Oxford University Press, Oxford. 286 p.

Elliot, C.R.N., Willis, D.J. & Acreman, M.C. 1996. Application of the physical habitat simulation (PHABSIM) model as an assesment tool for riverine habitat restoration teqhniques. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X. 11, (B), 607-618.

Erkamo, E. 2002. Crayfish data: crayfish *Pacifastacus leniusculus* at Lamminsaari Island in Lake Pääjärvi, Lake Katumajärvi study areas 4-5 and Pukettisaari Island, Lake Slickolampi, crayfish *Astacus astacus* Lake Valkjärvi in the Lake Haarajärvi area. Finnish game and fisheries research institute.

Extence, C.A, Balbi, D.M. & Hadd, R.P. 1999. River flow indexing using British benthic macroinvertebrates: a framework for setting hydroecological objectives. Regul. Rivers: Res. Mgmt. 15, 543–574.

Forsius, J. 1983. Vesivoimalaitosten lyhytaikaissäädön vaikutukset. VH:n koulutustilaisuuden 17.-18.5.1983 esitelmät. (The hydraulic peculiarities of short term regulation. In book: The effects of short term regulation of hydro power plants. The papers of a training course of National Board of Waters). Vesihallituksen monistesarja (The publishment series of National Board of Waters) 1983:177. Helsinki 1983. In Finnish. 6 p.

Forsius, J. 1984. Computing Unsteady Flow and Tracer movement in a River. Helsinki, Vesihallitus. Vesientutkimuslaitoksen julkaisuja (National Board of Waters, Water Research Institute) No 60, 3-15.

Forsius, J. 2001. Valajaskosken ADCP-mittausten tulokset. (The results of ADCP-measurements at Valajaskoski). Fortum Engineering / Hydro and wind power. 4 p.

Ghanem, A., Steffler, P., Hicks, F. & Katopodis, C. 1994. Two-dimensional finite element flow modeling of physical fish habitat. Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 84-98.

Gibson, R. J. 1993. The Atlantic salmon in freshwater: spawning, rearing and production. Rev. Fish. Biol. Fish. 3, 39-73.

Ginot, V. 1995. EVHA, un logiciel d'evaluation de l'habitat du poissons sous Windows. Laboratoire d'Hydroecologie Quantitative, Division Biologie des Ecosystemes Aquatiques, CEMAGREF, 3 bis quai Cavveau, 69336 Lyon cedex 09, France. Bull. Fr. Peche Piscic. 337/338/339, 303-308.

Ginot, V. 1998: EVHA, version 2.0. Evaluation de l'habitat physique des poissons en riviere. Guide de l'Utilisateur. Lyon, France: CEMAGREF-Lyon.

Golden Software, Inc. 1999. User's Guide, Surfer 7. August 1999.

Gore, J.A., Crawford, D.J. & Addison, D.S. 1996. An Analysis of Artificial Riffles and enhancement of Benthic Community Diversity by Physical Habitat Simulation (PHABSIM) and Direct Observation. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X. 11 p.

Gouraud, V., Sabaton, C. and Capra, H. 2004. Role of habitat variability in trout populations dynamics: Application of a dynamic population model to three french rivers. Hydroécologie Appliquée, 14(1), 221-244.

Greenberg, L., Svendsen, P. & Harby, A. 1994. Availability of Microhabitats and their Use by Brown trout (*Salmo trutta*) and grayling (T*hymallus thymallus*) in the River Vojmån, Sweden. Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 294-304.

Groshens, T. P. & Orth, D.J. 1994. Tranferability of habitat suitability criteria for smallmouth bass, *Micropterus dolomieu*. Department of Fisheries and wildlife sciences, Virginia polytechnic institute and state university, Blacksburg, Virginia 24061-0321. In: Rivers, volume 4, number 3, 194-212.

Guay, J. C., Bosclair, D., Rioux, D., Leclerc, M., Lapointe, M & Legendre, P. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 57, 2065-2075.

Guay, J. C., Bosclair, D., Leclerc, M., Lapointe, M & Legendre, P. 2001. Science on the edge of spatial scales: a reply to the comments of Willliams (2001). Can. J. Fish. Aquat. Sci. 58, 2108-2111.

Hardy, T. B. 1996. The Future of Habitat Modeling. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 447-463.

Harvey, B.,C. & Nakamoto, R.J. 1996. Effects of Steelhead Density on Growth of Coho Salmon in a Small Coastal California Stream, Transactions of the American Fisheries Society 125: 237-243, 1996

Heggenes, J. 1988. Physical habitat selection by brown trout (*Salmo trutta*) in riverine systems. Nordic Journal of Freshwater Research (1988) 64, 74-90.

Heggenes, J. 1990. Habitat utilization and preferences in brown trout (*Salmo trutta*) and juvenile Atlantic salmon (*Salmo salar*) in streams, Oslo, Agricultural University of Norway, Department of Nature Conservation.

Heggenes, J. 1994a. Physical habitat selection by brown trout (*Salmo trutta*) and young Atlantic salmon (*S. salar*) in spatially and temporally heterogegeous streams: Implications for hydraulic modelling. Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 12-30.

Heggenes, J., Saltveit, S.J., Vaskinn, K.A. & Lingaas, O. 1994b. Predicting fish habitat use responses to changes in waterflow regime: modelling critical minimum flows for atlantic salmon, Salmo salar, and brown trout, S. trutta, in a heterogeneous stream. Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 124-142.

Heggenes, J., Harby, A. & Bult, T. 1996. Microposition choice in stream-living Atlantic salmon (*Salmo salar*) parr and brown trout (*Salmo trutta*): Habitat-hydraulic 3-dimensional model and test. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X· S, (B), 353-361.

Hellsten, S. & Juntura, E., 2000. Effects of the wave-induced shoreline erosion on the littoral zone; case studies in northern Europe. Workshop on hydrologic and environmental modelling in Mekong basin, Phnom Penh, Cambodia 11-12 September 2000, Mekong river comission, 302-312.

Hubert, W.A., Helzner, R.S., Lee L. A. & Nelson, P.C. 1985. Habitat suitability index models and instream flow suitability curves: Arctic grayling riverine populations. U.S. Fish and Wildlife Service. Biological Report 82(10.110). 34 p.

Hulsing, H., Smith, W. & Cobb, E.D. 1966. Velocity-Head Coefficients in Open Channels. U.S. Geological Survey Water Supply Paper No. 1869-C, U.S. Geological Survey, 45 p.

Hunter, C.J. 1991. Better trout habitat. A Guide to stream restoration and management. Island Press, Washington D.C. 320 p.

Huusko, A. & Korhonen, P. 1995. Elinympäristömallin soveltuvuus uittoväylien kunnostuksen arvioimiseen ja kehittämiseen. (The suitability of a habitat model in assessing the success of rehabilitations of logging route channels and in development of rehabilitations). In book: Yrjänä, T. (editor). Entisten uittojokien kunnostaminen - esimerkkinä Iijoen vesistöalue. Vesi- ja ympäristöhallitus. Oulun vesi- ja ympäristöpiiri, Helsinki. ISBN 951-53-0091-6, ISSN 0786-9592, 67-88. In Finnish.

Huusko, A., Kreivi, P., Mäki-Petäys, A., Nykänen, M. &Vehanen, T. 2003. Virtavesikalojen elinympäristövaatimukset. Perustietoa elinympäristömallisovelluksiin. Paltamo. (The habitat requirements of fluvial fish. base information for habitat model applications.) Kala- ja Riistaraportteja nro 284. Paltamo. 42 p.

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.

Huusko, A. & Yrjänä, T. 1997. Effects of instream enhancement structures on brown trout habitat availability in a channelized boreal river: a PHABSIM approach. Fisheries Management and Ecology (4), 453-466. Also in Yrjänä (2003).

Huusko, A. Kreivi, P., Mäki-Petäys, A., Nykänen, M. & Vehanen, T. 2003. Virtavesikalojen elinympäristövaatimukset. Perustietoa elinympäristömallisovelluksiin. Kala- ja riistaraportteja nro 284. Paltamo. 42 p.

Hynes, H.B.N. 1972. The ecology of running waters. Liverpool University Press, Liverpool, UK.

Jacobs J. 1974. Quantitative measurement of food selection. A Modification of the Forage Ratio and Ivlev's Electivity Index. Oecologia (Berl.) 14, 413–417. In the end of the collection book for year 1973.

Janauer, G. A. 1994. Habitat hydraulics: an essential tool for assessing aquatic terrestrial ecotones. Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 199-206.

Joensuu I., Vuori, K.-M. & Nieminen, M. 1996. Vesistörakentamisen ja lyhytaikaissäännöstelyn vaikutus Perhonjoen koskien elinyhteisöihin. (The effects of water construction and short time regulation on the communities of of the rapids of Perhonjoki River. Suomen Ympäristö 79.) Keski-Pohjanmaan ympäristökeskus, Edita, Helsinki. ISSN 1238-7312. ISBN 952-11-0110-5. 90 p. In Finnish.

Jorde, K. 1996. Ecological evaluation of instream flow regulations based on temporal and spatial variability of bottom shear stress and hydraulic habitat quality, proceedings of the second International Symposium on Habitat Hydraulics, Ecohydraulics 2000, Quebec City, Volume B, 163-174.

Jorde, K., Schneider, M., Peter, A. & Zoellner, F. 2001. Fuzzy based models for the evaluation of fish habitat quality and instream flow assessment. Proceedings of the 2001 International Symposium on Environmental Hydraulics. 6 p.

Jowett, I.G. 1992. Models of the Abundance of Large Brown Trout in New Zealand Rivers. North American Journal of Fisheries Management 12, 417-432.

Jungwirth, M.& Winkler, H. 1983. Die Bedeutung der Flussbettstruktur für Fischgemeinschaften. Österreichische Wasser- und Abfallwirtschaft (ÖWW), 35, 9/10, 229-234. ISSN 0945-358X.

Juntura, E. 2000. A calculation sheet for calculating wave induced shore erosion. Unpublished.

Jussila, J., 2002. (Enhancing the regulation of central lakes of Pirkanmaa. The effects of water level regulation on stocks of *Pacifastacus leniusculus*. Local environmental publications 266. Pirkanmaa Regional Environment Centre.) In Finnish. ISSN 1238-8610, ISBN 952-11-1154-2. 48 p.

Jutila, E. 1987. Lohenpoikastuotannon ja kalansaaliiden kehitys Simojoessa koskien kunnostuksen jälkeen vuosina 1982-1985. Riista- ja kalatalouden tutkimuslaitos, Kalantutkimusosasto. Monistettuja julkaisuja 71, 47-96.

Jutila E., Karttunen V. & Niemitalo, V. 1994. Parempi kivi koskessa kuin kymmenen rannalla - Erilaisten kunnostusmenetelmien vaikutus taimenten poikasmääriin Iijoen sivujokien koskissa. Riista- ja kalatalouden tutkimuslaitos, Kalatutkimuksia 87, Helsinki. 29 p. ISBN 951-8914-80-X, ISSN 0787-8478.

Järvelä, J. 1998. Luonnonmukainen vesirakennus. Periaatteet ja näkökohdat virtavesien ennallistamisessa ja uudisrakentamisessa. Teknillinen korkeakoulu. Teknillisen korkeakoulun vesitalouden ja vesirakennuksen julkaisuja, TKK-VTR-1. Helsinki University of Technology Water Resources Publications. 1, 129 p. ISBN 951-22-4296-6, ISSN 1456-2596. In Finnish.

Järvelä, J. & Vakkilainen, P. 1996a. Luonnonmukaisuus Keski-Eurooppalaisessa vesirakentamisessa. Vesitalous 37, 5, 10-16. ISSN 0505-3838.

Järvelä, J. & Vakkilainen (ed.), P. 1996b. Luonnonmukaistavesirakentamista ja agrohydrologiaa Keski-Euroopassa - matkakertomus. Teknillinen korkeakoulu, Vesitalouden laboratorio, Otaniemi. Monistesarja 1996:1. In Finnish.

Karlström, Ö. 1977. Habitat selection and population densities of salmon (Salmo salar L) and trout (Salmo trutta) in Swedish rivers with some reference to human activities. Acta Univ. Upsaliensis 402. 12 p.

Koli, L. 1990. Suomen kalat. WSOY. ISBN 951-0-16337-6. 357 p.

Klosterman, B.J. & Goldman C.R., 1981. Substrate selection behaviour of the crayfish *Pacifastacus Leniusculs.* In: Freshwater Crayfish V. Goldman, C.R., Papers from the fifth international Symposium on Freshwater Crayfish, Davis, California, USA, 254-263.

Kopecki, I. 2008. Calculational Approach to FST Hemispheres for Multiparametrical Benthos Habitat Modelling, Heft 169 Institut für Wasserbau der Universität Stuttgart. 265 p.

Kuosa, H., Arvola, L, Bärlund, I., Ekholm, P., Hietanen, S., Kaipainen, H., Lehtoranta, J., Leivuori, M., Lukkari, K., Pitkänen, H., Rask, M., Tallberg, P. & Tulonen, T. 2006. Itämeren rehevöitymiseen on vaikutettava maalla ja merellä. Vesitalous 2/2006, 20-25.

Kuusela, K. 1995. Virtavesien kunnostuksen ekologiset perusteet. In book: Yrjänä, T. (editor). Entisten uittojokien kunnostaminen - esimerkkinä Iijoen vesistöalue. Vesi- ja ympäristöhallitus. Oulun vesi- ja ympäristöpiiri, Helsinki, 14-20. ISBN 951-53-0091-6, ISSN 0786-9592.

Kylmänen, I. 1999. Flow measurements at Pyhäkoski impoundment. Unpublished data.

Laasonen, P., Muotka, T., Tikkanen, P., Huhta, A. & Kuusela, K. 1995. Kunnostuksen lyhyen ja pitkän aikavälin vaikutukset. In book: Yrjänä, T. (editor). Entisten uittojokien kunnostaminen - esimerkkinä Iijoen vesistöalue. Vesi- ja ympäristöhallitus. Oulun vesi- ja ympäristöpiiri, Helsinki, 29-38. ISBN 951-53-0091-6, ISSN 0786-9592.

Lahti, M., Riihimäki J., 2000. Modelling of the habitats of *Persicaria foliosa* (H.Lindb.) Kitag. in the delta of river Oulujoki. Report, Fortum Technology for Town of Oulu.

Lahti, M., 1999. Elinympäristömalli vesistöjen kunnostusten suunnittelussa. (A habitat model for planning of water system rehabilitations.) Diplomityö. (A work for the master's thesis.) Rakennus- ja ympäristötekniikka/Vesitalous. Department of Civil and Environmental Engineering/Water resources engineering .105 p. In Finnish, abstract in English.

Lahti, M., 1999. Elinympäristömalli vesistöjen kunnostusten suunnittelussa. (A habitat model for planning of water system rehabilitations.) Fortum Power and Heat Oy/ Teknologia. Tutkimusraportteja (Research Reports) 02/99.105 p. In Finnish, abstract in English. ISBN 951-591-071-4. ISSN 1238-6006.

Lahti, M., 2000. Pälli-Pyhäkoski virtauslaskennat (Pälli-Pyhäkoski flow calculations. Fortum Technology/Environment and chemistry. For Finnish Game and Fisheries Research Intitute.) Report. 8 p.+ appendices. In Finnish.

Lahti, M. 2002. Modelling of Siltapuro B river reach after rehabilitation. Fortum Service Oy. Report. 6 p.

Lahti, M. & Auvinen, H. 2009. Pohjaeläinten elinympäristön mallinnus, Kollaja-hankkeen ympäristövaikutusten arviointiselostus. Pohjolan Voima Oy.

Lambert, T. R. & Hanson, D. F. 1989. Development of habitat suitability criteria for trout in small streams. Regulated rivers: Research & management, vol. 3, 291-303.

Lamouroux, N., Capra, H., Pouilly, M & Souchon, Y. 1999. Fish habitat preferences in large streams of southern France. Freshwater Biology 42(4), 673-687.

Lamouroux, N. & Jowett, I. G. 2005. Generalized instream habitat models. Canadian Journal of Fisheries and Aquatic Sciences 62, 7-14 (2005).

Leclerc, M., Boudreault, A. Bechara, J. & Corfa, G. 1995. Two-dimensional Hydrodynamic Modeling: A Neglected Tool in the Instream Flow Incremental Methodology. Transactions of the American Fisheries Society 124, 645-662.

LeDrew, L .J. 1996. A Comparison of Habitat Suitability Indices Developed From Daytime Versus Nighttime Observations for Atlantic Salmon in a Regulated Newfoundland Stream. In: Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 33-44.

Leinonen, A.-L. 1999. Laukan alueen kalataloudelliseen kunnostukseen liittyvät kalastustiedustelun tulokset vuodelta 1998 ja kirjanpitokalastajien tulokset vuosilta 1996-1998. (The results of a fishing inquiry connected to the fisheries rehabilitation of Laukka area from year 1988 and the results of book keeping fishings 1996-1998. Report. North Ostrobothnia Regional Environment Centre. 19 p.

Lepori, F., Palm, D., Brännäs, E., and Malmqvist, B. 2005. Does restoration of structural heterogeneity enhance the diversity of fish and macroinvertebrates? Ecological Applications 15, 2060-2071.

Macklin, M.G. & Lewin, J. 1997. Channel, Floodplain and Drainage Basin Respomse to Environmental Change. In: Thorne, C.R., Hey, R.D. & Newson, M.D. (ed.): Applied Fluvial Geomorphology for River Engineering and Management. 1997, 15-45.

McMahon, T.A. 1992 Hydrologic Desingn For Water Use, in Handbook of Hydrology, ed. Maidment, D. R., Mc Graw-Hill, ISBN 0-07-039732-5, 51 p.

Maddock, I., Bird, D., 1996. The application of habitat mapping to identify representative Phabsim sites on the River Tavy, Devon, UK. 2nd international symposium on habitat hydraulics, Proceedings, Quebec, June 1996.

Malavoi, J.R. & Souchon, Y. 1989. Methodologie de description et quantification des variables morphodynamiques d un cours d eau a fond cailloutex: exemple d une station sur la Filliere (Heute-Savoie). In Book: Revue de Geographie de Lyon, 64, 252-259. In French.

Matalas, N., C. 1967. Time Series Analysis. Water Resources Research, Vol 3, No 3. 817-829.

Matzusaki, H.& Tamai, N. 1996. A Study on the method of evaluating fish habitat environment by PCA under various river environmental factors. Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 27-32.

Merigoux, S. & Doledec, S. 2004. Hydraulic requirements of stream communities: a case study on invertebrates, Freshwater Biology 49, 600–613.

Milhous, R.T. 1990. Insteam habitat considering hydro-peaking. In book: Khanbilvardi, R.M. & Gooch, T.C. (ed.). Optimizing the resources for water management. American society of civil engineers. New York, 593-598.

Milhous, R.T. 1991. Insteam flow needs below peaking hydroelectric projects. In book: Darling, D.D. (ed.). Proceedings of the international conference on hydropower. American society of civil engineers. New York, 163-172.

Mills, D. 1989. Ecology and Management of Atlantic Salmon. Chapman & Hall. London. 351 p.

Muhar, S. 1996. Habitat improvement of Austrian rivers with regard to different scales. In book: Regulated Rivers: Research and Management, 12, 5, 471-482. ISSN 0886-9379.

Muotka, J. 1991. Vesivoima sähköntuotantojärjestelmässä ja ympäristönäkökohdat Oulujoen vesistön säännöstelyjen käytössä. In: Vesi- ja ympäristöhallituksen monistesarja nro 306. 1. Säännöstelyjen vaikutuksia, muutostarpeita ja lupien hallintaa käsittelevä neuvottelupäivä 3.4.1991. 2. Päätösanalyysi ympäristövaikutusten arvioinnin apuvälineenä - koulutustilaisuus 4.4.1991. ed. Vähäsöyrinki, E & Marttunen, M. (Hydro power in electricity production system and environmental aspects in the use of the regulation at Oulujoki watershed. In book: A conference on the effects of regulation, on the needs for changes and the management of licences 3.4.1991. National Board of Waters and the Environment, Publications, number 306. National Board of Waters and the Environment, Helsinki.), 69-94. In Finnish.

Muotka T, Syrjänen J (2007). Changes in habitat structure, benthic invertebrate diversity, trout populations and ecosystem processes in restored forest streams: a boreal perspective. – Freshwater Biology 52: 724-737.

Muotka T. & Tikkanen P. 1995. The communities in stream waters and the factors affecting them. In book: Yrjänä, T. (editor). The rehabilitation of former logging rivers - Iijoki watershed area as an example. National Board of Waters and the Environment, Water and Environment District of Oulu, Helsinki, 21-27. ISBN 951-53-0091-6, ISSN 0786-9592.

Muotka, T., Mäki-Petäys, A., Kreivi, P. & Högmander, H. 1999. Spatial associations between lotic fish, macroinvertebrate prey and stream habitat: a multi-scale approach. Boreal Environment Research 3, 371-380.

Mäki-Petäys, A. Muotka, T., Tikkanen, P. Huusko, A., Kreivi, P. & Kuusela, K. 1994. The differences in the use of microhabitats between different size classes of trout juveniles. Finnish Game and Fisheries Research Institute. Fish studies 80. 38 p.

Mäki-Petäys, A., Muotka, T., Tikkanen, P. & Kreivi, P. 1997. Seasonal changes in habitat use and preference by juvenile Brown trout *Salmo trutta* in a northern boreal river. In book: Can. J. Fish. Aquat. Sci. 54, 520-530.

Mäki-Petäys, A., Muotka, T. & Huusko, A. 1999. Densities of juvenile brown trout (Salmo trutta) in two subarctic rivers: assessing the predictive capability of habitat preference indices. Canadian Journal of Fisheries and Aquatic Sciences 56(8),1420-1427. From and also in Mäki-Petäys 1999.

Mäki-Petäys, A. 1999. Habitat Requirements of Juvenile Salmonids, doctoral thesis, A 322, The department of biology at the university of Oulu, Oulu. approx. 73 p. ISBN 951-42-5219-5, ISSN 0355-3191.

Mäki-Petäys, A. 2000. Preference information database of salmon, 29.11.2000. Finnish Game and Fisheries Research Institute, Oulu.

Mäki-Petäys, A. 2001. Preference information database, general preference curves for brown trout, 13.6.2001. Finnish Game and Fisheries Research Institute, Oulu.

Mäki-Petäys, A. & Huusko, A. (2001): Taimenen poikashabitaatit kesällä - yleiskriteerit syvyydelle, virrannopeudelle ja kivikoolle. (Summertime habitat use by juvenile brown trout - generalized habitat suitability criteria for depth, velocity and substrate.) Riista- ja kalatalouden tutkimuslaitos. (Finnish Game and Fisheries Research Institute.) Research report. 14 p.

Mäki-Petäys, A., Huusko. A., Erkinaro, J. & Muotka., T. 2002. Transferability of habitat suitability criteria of juvenile Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 59, 218-228 (2002).

Mäki-Petäys, A., Erkinaro, J., Niemelä, E., Huusko, A. & Muotka., T. 2004 Spatial distribution of juvenile Atlantic salmon (Salmo salar) in a subarctic river: size-specific changes in a strongly seasonal environment. Canadian Journal of Fisheries Aquatic Sciences 61, 2329-2338 (2004).

Mäki-Petäys, A. 2005. Preference curves for salmon 4-6 cm in different seasons at Mantokoski Rapids on the River Utsjoki. Unpublished material.

Northcote, T. G. 1995. Comparative biology and management of Arctic and European grayling (Salmonidae, *Thymallus*). Reviews in Fish Biology and Fisheries, 5, 141-194.

Nehring, R.B., Anderson, R.M. 1993. Determination of Population Limiting Critical Salmonids Habitats in Colorado Streams Using Physical Habitat Simulation System. Rivers 4, 1-19.

Nestler, J.M., Milhous, R.T. & Layzere, J. P. 1989. Instream habitat modelling techniques. In book: Gore, J.A. & Petts, G.E. (editor) Alternatives in regulated river management. Boca Raton FL: CRC Press, 295-395. From Designing and negotiating studies using IFIM. National Ecology Research Center, U.S. Fish and Wildlife Service. IF 200 Readings.

Nuhfer, A. J. & Baker, E. A. 2004. A Long-term Field Test of Habitat Change Predicted by PHABSIM in Relation to Brook Trout Population Dynamics During Controlled Flow Reduction Experiments. Michigan Department of Natural Resources, Fisheries Research Report 2068, 2004. 39 p.

Nykänen, M. & Huusko, A. 1999. Harjuksen elinympäristövaatimukset virtavesissä. (Habitat requirements and habitat use of riverine European grayling (*Thymallus thymallus* (L.)) - a review). Kirjallisuusselvitys. Kalatutkimuksia 156. Riistan- ja kalantutkimus. 23 p.

Nykänen, M. & Huusko, A. 2004. Transferability of habitat preference criteria for larval European grayling (*Thymallus thymallus*). Can. J. Fish. Aquat. Sci. 61, 185-192 (2004).

Nykänen, M. 2004. Habitat selection by Riverine Grayling, *Thymallus thymallus L.* Academic Dissertation. University of Jyväskylä. Jyväskylä studies in biological and environmental science 140. 40 p. + original publications.

Orth, D.J. & Maughan, O.E. 1982. Evaluation of incremental methodology for recommending instream flows for fishes. Trans. Am. Fish. Soc. 111, 413-445.

Oswood, M.E. & Barber, W.E. 1982: Assesment of fish habitat in streams: goals, constrains and a new technique. In book: Fisheries 7(3), 8-11.

Palm, D., Brännäs, E., Lepori, F., Nilsson, K., and Stridsman, S. 2007. The influence of spawning habitat restoration on the density of juvenile brown trout (Salmo trutta L.). Canadian Journal of Fisheries and Aquatic Sciences 64, 509-515.

Payne, T.R., 1994. RHABSIM: User-Friendly Computer Model to Calculate River Hydraulics and Aquatic Habitat. In book: Proceedings of the 1st international symposium on habitat hydraulics. August 18-20, 1994, The Norwegian Institute of Technology, Trondheim, Norway, 254-267.

Peay, S. 2003. Monitoring the White-clawed Crayfish *Austropotamobius pallipes*. Conserving Natura 2000 Rivers Monitoring Series No. 1, English Nature, Peterborough. ISBN 1 85716 727 9. 52 p.

Pieterse, A.H. & Murphy, K.J., 1990. Aquatic weeds. The ecology and management of nuisance aquatic vegetation. Oxford science publications, 2483-2489.

Piironen, J., Makkonen, J. & van der Meer, O. 1999. Järvilohelle ja -taimenelle soveltuvan elinympäristön määrä Ala-Koitajoella mikrohabitaatimallin perusteella. In Book: Saimaan järvilohen elinolosuhteiden parantaminen (The amount of habitats suitable for lake salmon and trout at Ala-Koitajoki River according to a micro habitat modelling. In book: Makkonen, J. (editor). The improvement of the living conditions of the Saimaa lake salmon. Fish studies - Fiskundersökningar 155. Finnish Game and Fisheries Research Institute) Helsinki, 3-44. In Finnish.

Pohjonen, M. 1991. Vesivoimalaitosten lyhytaikaissäädön ekologiset vaikutukset. (The ecological effects of short term regulation of hydro power plants.) Imatran Voima Oy, T&K-tiedotteita (R&D announcements) IVO-B-01/91, Helsinki. 44 p. ISBN 951-8928-47-9, ISSN 0782-9221.

Rabeni, C. F. & Jacobson, R. B. 1993. The importance of fluvial hydraulics to fish habitat restoration in low-gradient alluvial streams. In book: Freshwater Biology 29, 211-220.

Railsback, S. F., Harvey., B.C, 2001. Individual-based model formulation for cutthroat trout, Little Jones Creek, California. General Technical Report PSW-GTR-182, Pacific Southwest Research Station, Forest Service, U. S. Department of Agriculture. 80 p.

Railsback, S. F., Harvey., B.C, Lamberson, R.H., Lee, D.E., Claasen, N.j. & Youshihara, S., 2002. Population-level analysis and validation of an individual-based cutthroat model. Natural Resource Modeling, Volume 15, Number 1, Spring 2002. 83 p. http://www.fs.fed.us/psw/rsl/projects/water/sfr02a.pdf.

Raleigh, R.F., Zuckerman, L.D. & Nelson, P.C. 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised. U.S. Fish and Wildlife Service Biological Rep. 82(10.124). 65 p. (First printed as: FWS/OBS-82/10.71, September 1984).

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: volume 2. Computation of discharge, Chapter 5, Measurement of discharge by conventional current meter -method, U.S. Geological Survey Water-Supply Paper 2175. Taken from Internet:
http://wwwrcamnl.wr.usgs.gov/sws/SWTraining/FlashFandR/rantz2_files/rantz2.htm

Riihimäki, J., Yrjänä, t. & van der Meer, O. 1996. Lyhytaikaissäädön elinympäristövaikutusten arviointimenetelmät. Suomen ympäristö 4, Suomen ympäristökeskus, Helsinki. 83 p. ISSN 1238-7312, ISBN 952-11-0011-7.

Roni, P., Beechie, T. J., Bilby, R.E., Leonetti, F.E., Pollock, M.M. & Pess, G.R. 2002. A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. North American Journal of Fisheries Management 22, 1–20, 2002. American Fisheries Society.

Rosenfeld, J. S., Leiter, T., Lindner, G. & Rothman, L. 2005. Food abundance and fish density alters habitat selection, growth, and habitat suitability curves for juvenile coho salmon (*Oncorhynchus kisutch*). Canadian journal of aquatic sciences 62, 1691-1701.

Rossoll, A. & Werth, W. (ed.) 1992. Schutzwasserbau, Gewässerbetreuung, Ökologie. Grundlagen für wasserbauliche Massnahmen an Fliessgewässern. Wien, Bundesministerium für Land- und Forstwirtschaft, Österreichischer Wasserwirtschaftsverband. 232 p.

Ruohomäki J. 1984. Lyhytaikaissäännöstelyn vaikutus joen kasvillisuuteen. Vesihallituksen monistesarja 1984:281 (The effects of short term regulation on the vegetation of a river. National Board of Waters, copy series. National Board of Waters), Helsinki. 71 p. In Finnish.

Sagnes, P. Merigoux, S. & Peru, N. 2008. Hydraulic habitat use with respect to body size of aquatic insect larvae: Case of six species from a French Mediterranean type stream. Limnologia 38, 23-33.

Schiechtl, H. M. 1982. Grundlagen der Grünverbauung. Wien, Österreichischen Staatsdrückerei.

Schneider, L.T. & Nestler J.M. 1996. Using hydraulic and water quality modeling output for instream flow studies. In book: Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X. 7 p.

Schneider, M., Noack, M. & Gebler, T. 2008. Handbuch fuer das habitatsimulationmodell CASiMiR. Modul CASiMiR-Fish. Schneider & Jorde Ecological Engineering GmbH & Universität Stuttgart, Institut fuer Wasserbau. 49 p.

Sinisalmi, T. (editor), Forsius, J., Muotka, J., Riihimäki, J., Soimakallio, H., Vehanen, T. & Yrjänä, T. 1996. Vesivoimalaitosten lyhytaikaissäädön vaikutustutkimukset. Suomen ympäristö 66. Pohjois-Pohjanmaan ympäristökeskus. (The studies on the effects of short term regulation of hydro power plants. North Ostrbothnia Regional Environment Centre.) Oulu. 130 p. ISBN 952-11-0096-6, ISSN 1238-7312.

Sirniö, V-P., 1999. Oulujoen suiston mittausraportti. (The measurements of topography at the delta of Oulujoki River). Report. Kemijoki Oy.

Solazzi, M.F., T.E. Nickelson, S.L. Johnson, and J.D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences. 57, 906-914.

Souchon, Y., Trocherie, E., Fragnoud, E. & Lacombe, C. 1989. Les modeles numeriques des microhabitats des poissons: application et nouveaux developpements Revue des Sciences de l'Eau 2, 807-830.

Spiegel, M. R., 1972. Schaums outline of theory and problems of statistics in SI units. SI Edition adapted by Boxer, R.W., McGraw-Hill International Book Company, New York, 201-216.

Steffler, P. & Blackburn, J. 2002. Two-dimensional depth averaged model of river hydrodynamics and fish habitat, introduction to depth averaged modeling and user's manual. University of Alberta. September, 2002. From Internet: http://bertram.civil.ualberta.ca/software/River2D.pdf, now at www.river2d.ualberta.ca/software/River2D.pdf 119 p.

Stenberg, L. 2007. Lammin Pääjärven ja Lahden Vesijärven vesitase: Maankäytön vaikutus valuntaan ja haihduntaan. Diplomityö. Teknillinen korkeakoulu. Rakennus- ja ympäristötekniikan osasto. 85 p.

Talvensaari, M., 2000. The flow modelling of the delta of Oulujoki River. Unpublished data. Kemijoki Oy.

Tamai, N., Kim, H.R. & Kawahara, Y. 1996. Application of the Instream Methodology to Conservation Flow for Freshwater Fishes in Japan. In book: Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 239-250.

Tarbet, K., Hardy, T. B., 1996. Evaluation of one-dimensional and two-dimensional hydraulic modeling in a natural river and implications in instream flow assessment methods. In book: Quebec, Ecohydraulics 2000, 2nd International Symposium on Habitat Hydraulics, Proceedings. ISBN 2-89146-379-X, (B), 395-406.

Tulonen, J., Erkamo, E. & Jussila, J. 2007a. Rapujen aktiivisuus ja esiintymissyvyys eri vuodenaikoina. (The activity of crayfish and depth of habitat use during the year) In: Tulonen, J. (ed.) Vesistösäännöstelyn vaikutuksista rapuihin ja niiden elinpiiriin. Kala- ja riistaraportteja nro 404. Helsinki 2007. In Finnish.

Tulonen, J., Erkamo, E. & Jussila, J. 2007b. Suojapaikkojen sijainnin vaikutus jokirapuihin kohdistuvaan predaatioon säännöstellyissä olosuhteissa. (The effect of location of refuges on the predation of *Astacus Astacus* in water level regulated environment) In: Tulonen, J. (ed.) Vesistösäännöstelyn vaikutuksista rapuihin ja niiden elinpiiriin. Kala- ja riistaraportteja nro 404. Helsinki 2007. In Finnish.

Tulonen, J., Erkamo, E., Jussila, J. & Mannonen, A. 2007c. Keväisen vedenpinnan laskun ja kalapredaation vaikutus pienten täplärapujen kuolleisuuteen.(The effect of water level decline in spring and fish predation on mortality of small *Pacifastacus Leniusculus*) In: Tulonen, J. (ed.) Vesistösäännöstelyn vaikutuksista rapuihin ja niiden elinpiiriin. Kala- ja riistaraportteja nro 404. Helsinki 2007. In Finnish.

Ulvinen, T. 2000. Mapping of Persicaria Foliosa at the delta of River Oulujoki. University of Oulu. Botanical Museum. Unpublished field material. Previous mapping and additional mappings from week 31 year 2000. Results shown only partly in Väre et al. (2000).

US Army Corps of Engineers - Waterways Experiment Station Hydraulics Laboratory, 1996. Users Guide To RMA2 Version 4.3.

U.S. Geological Survey 2005. http://www.mesc.usgs.gov/products/Publications/15000/chapter4.html. Habitat modelling. Page Last Modified: Tuesday, April 12, 2005. Page Contact Information: USGS Web, tel. (1-888-275-8747)

Valentin, S., Souchon, Y. & Wasson J.-G. 1994. Evaluation of hydropeaking effects on fish community and habitat. In book: Cowx, I.G. (editor) Rehabilitation of freshwater fisheries. Blackwell Scientifis Publications Ltd. Oxford, 139-151.

Valovirta, I., approx.1998. Preference curves for freshwater pearl mussel. Unpublished.

Vaskinn, K., A. & Saltveit, S., J., 1995. Habitat - a model to simulate physical habitat in rivers. User's Manual. In Alfredsen, K., Bakken, T.H. & Killingveit, A. (editor). The River System Simulator. User's Manual, Volume II. SINTEF NHL. 1995.

Watson, F., Newman, W., Anderson, T., Kozlowski, D., Hager, J. & Casagrande, J. 2002. Protocols for Water Quality and Stream Ecology Research. Central coast watershed studies. The watershed Institute. Earth Systems Science and Policy California State University, Monterey Bay. Report No. WI-2001-05c. Draft: October 25th June, 2002. 95 p. science.csumb.edu/~ccows/pubs/reports/CCoWS_Protocols_020625_VersionC.pdf

Vehanen, T., Mäki-Petäys, A., Yrjänä, T., Lahti, M., Huusko, A. & Hirvonen, S. 1998: Movements of grayling (*Thymallys thymallus*) in a restored hydropeaking impondment. Poster.

Vehanen, T., Huusko, A., Yrjänä, T. Kylmänen, I., Sirniö, V.-P. & Lahti, M. 2000. Habitat restoration in large hydropeaking impoundments in Finland - problems and solutions. In: Tsihrintzis, V.A., Korfiatis, G.P., Kastsifratis, K.L. & Demetracopoulos, A.C. (eds.) Proceedings of an International Conference: Protection and Restoration of the Environment V. Greece, Thassos 2.-6. July 2000, 683-690.

Vehanen, T. 2003. Oral announcement.

Vehanen, T., Huusko, A., Yrjänä, T., Lahti, M. & Mäki-Petäys, A. 2003. Habitat preference by grayling (*Thymallus thymallus*) in an artificially modified, hydropeaking riverbed: a contribution to understand the effectiveness of habitat enhancement measures. Journal of Applied Ichthyology 19 (1), 15-20. Blackwell Verlag, Berlin. ISSN 0175-8659.

Vehanen, T., Lahti, M. 2003. Movements and habitat use by pikeperch (*Stizostedion Lucioperca* (L.)) in a hydropeaking reservoir. Ecology of Freshwater fish 2003: 12 (3), 203-215.

Vehanen, T., Mäki-Petäys, A., Aspi, J & Muotka, T. 1999. Intercohort competition causes spatial segretation in brown trout in artificial streams. Journal of Fish Biology 54. 12 p. From and also in Mäki-Petäys 1999.

Virta, H., 2003. Geophysics department at Helsinki University. Internet pages.

Voos, K.A. 1981. Simulated use of the exponential polynomial/maximum likelihood technique in developing suitability of use functions for fish habitat. PhD Dissertation. Utah State University, Logan. 85 p.

Väre, H., Ulvinen, T., Vilpa, E. & Kalleinen, L. 2000. Oulujoen suiston kasvisto ja uhanalaislajisto. (Vascular flora of the River Oulujoki estuary, northern Finland.) Lutukka 16, 67-87. In Finnish.

Wesche, T.A., Goertler, C.M. & Hubert, W. A. 1987. Modified habitat suitability index model for brown trout in Southeastern Wyoming. North American Journal of Fisheries Management. Volume 7, 232-237.

Wesche, T.A. & Rechard, P.A. 1980. A Summary of Instream Flow Methods for Fisheries and Related Research Needs. In book: Designing and negotiating studies using IFIM. National Ecology Research Center, U.S. Fish and Wildlife Service, IF 200 Readings. 122 p.

Yrjänä, T. 1992. Virtavesien kalataloudelliset kunnostusmenetelmät ja niiden vaikutusten arviointi. In book: Sorva, I. & Savolainen M. (editor). Lisensiaattiseminaarin esitelmät lukuvuonna 1990-1991. Ympäristövaikutusten arviointi. University of Oulu, laboratory of hydraulic and water resources engineering, series A. Publication 52. 31 p.

Yrjänä, T. 1995a. Introduction. In book: Yrjänä, T. (editor). Entisten uittojokien kunnostaminen - esimerkkinä Iijoen vesistöalue. Vesi- ja ympäristöhallitus. Oulun vesi- ja ympäristöpiiri, Helsinki. 1995 P. 9-13. ISBN 951-53-0091-6, ISSN 0786-9592.

Yrjänä, T. 1995b. Kunnostustöiden toteuttaminen ja työmenetelmät. (Implementation of rehabilitation works and field methods.) In book: Yrjänä, T. (editor). Entisten uittojokien kunnostaminen - esimerkkinä Iijoen vesistöalue. Vesi- ja ympäristöhallitus. Oulun vesi- ja ympäristöpiiri, Helsinki, 39-49. ISBN 951-53-0091-6, ISSN 0786-9592.

Yrjänä, T. 1995c. Siikajoen säännöstelyn vaikutukset kalastoon ja kalastukseen ja säännöstelyn kehittämisvaihtoehtojen vertailu. Oulun vesi- ja ympäristöpiiri. (The effects of the regulation of Siikajoki on the fisheries and fishing and a comparison of development alternatives of regulation. Water and Environment District of Oulu.) 66p. In Finnish.

Yrjänä, T. 1998a. Efforts for In-stream Fish Habitat Restoration within the River Iijoki, Finland - Goals, Methods and Test Results. Rehabilitation of Rivers: Principles and Implementation. Ed. Waal, L.C., Large, A.R.G. & Wade, P.M. John Wiley & Sons Ltd. Also a copy in Yrjänä 2003.

Yrjänä, T. 1998b. Virtavesien kalataloudelliset kunnostusmenetelmät ja niiden vaikutusten arviointi. Licensiate study. University of Oulu. (The restoration methods of fisheries in stream waters and evaluation of the effects) In Finnish.

Yrjänä, T., Lahti, M. & Kamula, R. 1999. Kunnostustoimien vaikutus virtakalojen elinalueeseen ja saaliiseen Oulujoen Laukassa (Effects of a habitat enhancement experiment in the Laukka area of the River Oulujoki, Finland). Oulun yliopiston vesi- ja ympäristötekniikan laboratorion julkaisuja sarja A:5. Oulu 1999. 35 p. + app. 39 p. ISBN 951-42-5148-2, ISSN 1456-3770.

Yrjänä, T., Lahti, M. & Kamula, R. 2003: Enhancement of fish habitat in a hydro peaking river impoundment. In Yrjänä 2003.

Yrjänä, T. 2001. Oral announcement. Habitat selection of grayling.

Yrjänä, T. 2002. Oral announcement. Estimate of the deviation the fish positioning on the map by the book keeping fishers in the study.

Yrjänä, T. 2003. Restoration of riverine habitat for fishes - analyses of changes in physical habitat conditions. Academic Dissertation, Department of Process and Environmental Engineering, C Technica 188, University of Oulu, 2003.

Appendices 1-5

A1 HARRIKOSKI RAPIDS

Salmon <10 cm, general preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000)

Salmon <10 cm, general preference curves according to Heggenes (1990)

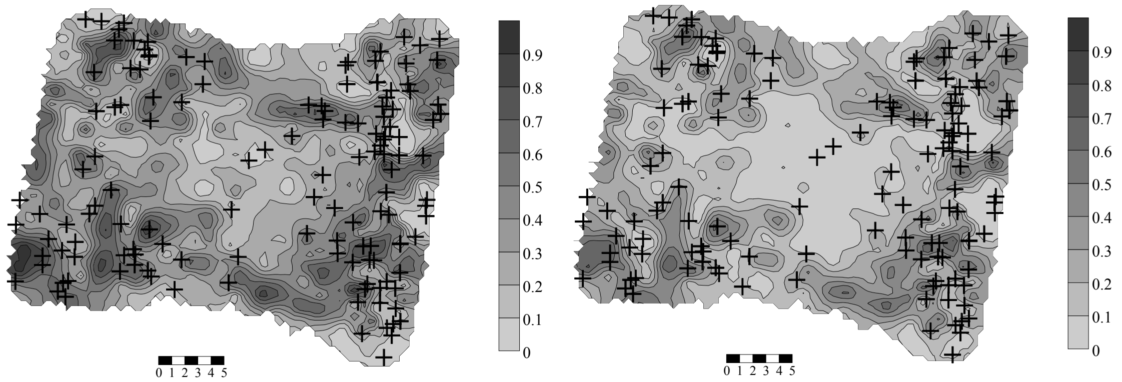


Figure A1.1 Habitat suitability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), general preference curves by Heggenes (1990), and fish observations.

Table A1.1 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2995	68.86	51	0.74	4.63	4.38	-30.63	
0.2995-1	69.14	87	1.26	4.61	4.36	39.98	
Sum	138	138	high/low	9.25	8.74	9.36	9.32
Average	0.35	0.40	1.70	0.002	0.003	0.002	0.002

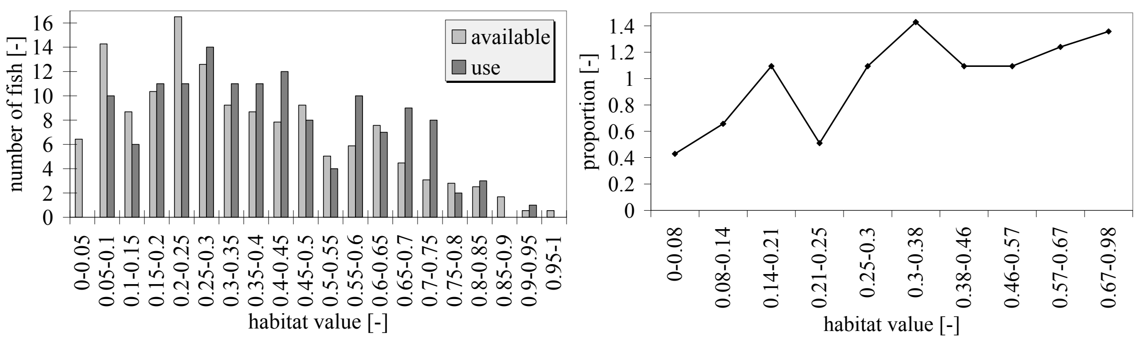


Figure A1.2 Habitat availability and use and proportion of use to availability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Table A1.2 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with general preference curves by Heggenes (1990) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1792	68.86	53	0.77	3.65	3.43	-27.75	
0.1792-1	69.14	85	1.23	3.64	3.41	35.11	
sum	138	138	high/low	7.29	6.84	7.36	7.33
average			1.60	0.007	0.009	0.007	0.007

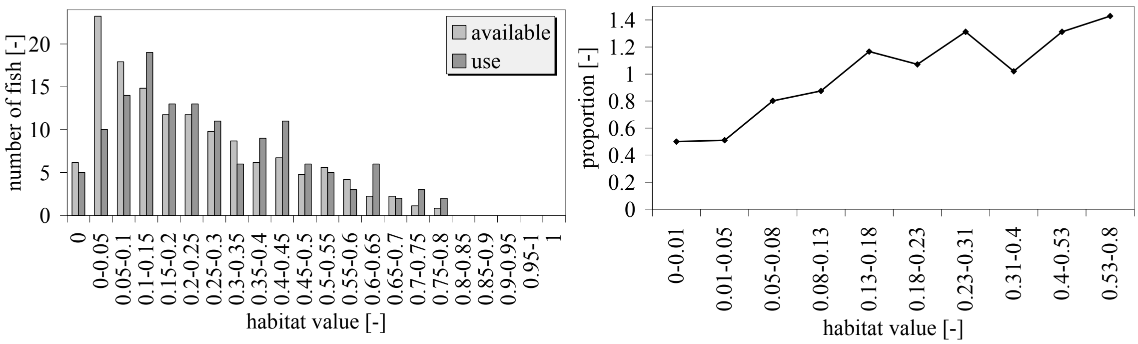


Figure A1.3 Habitat availability and use and proportion of use to availability for salmon <10 cm with general preference curves by Heggenes (1990).

Salmon >10 cm, general preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000)

Salmon >10 cm, general preference curves according to Heggenes (1990)

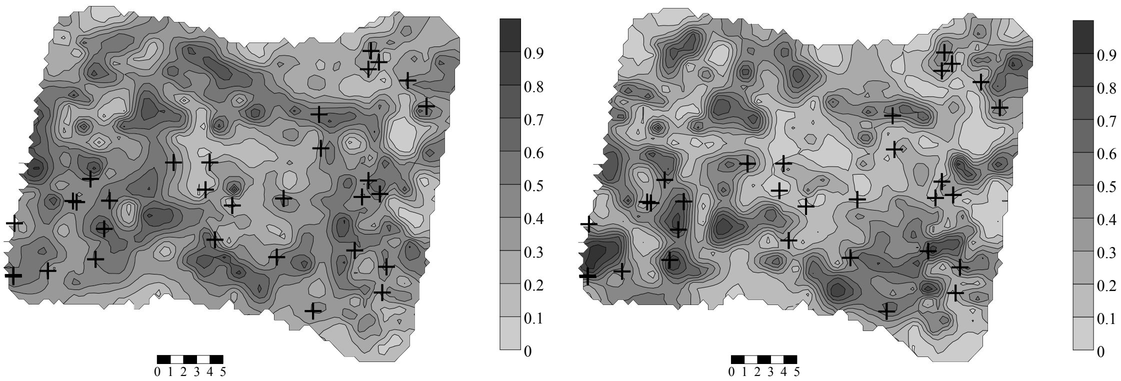


Figure A1.4 Habitat suitability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), general preference curves by Heggenes (1990), and fish observations.

Table A1.3 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1792	15.47	9	0.58	2.70	2.30	-9.75	
0.1792-1	15.53	22	1.42	2.69	2.29	15.32	
sum	31	31	high/low	5.40	4.60	5.57	5.48
average			2.43	0.02	0.03	0.02	0.02

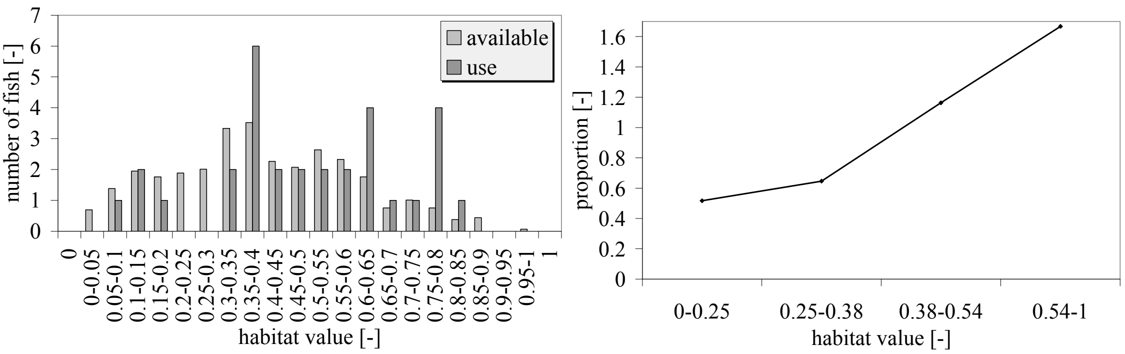
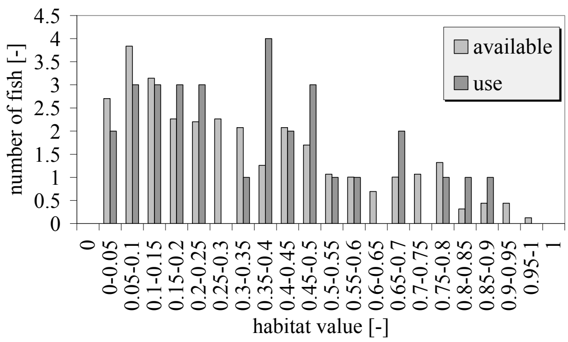


Figure A1.5 Habitat availability and use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Table A1.4 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with general preference curves by Heggenes (1990) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2825	15.47	14	0.91	0.14	0.06	-2.79	
0.2825-1	15.53	17	1.09	0.14	0.06	3.07	
Sum	31	31	high/low	0.28	0.12	0.28	0.27
Average			1.21	0.6	0.73	0.6	0.6



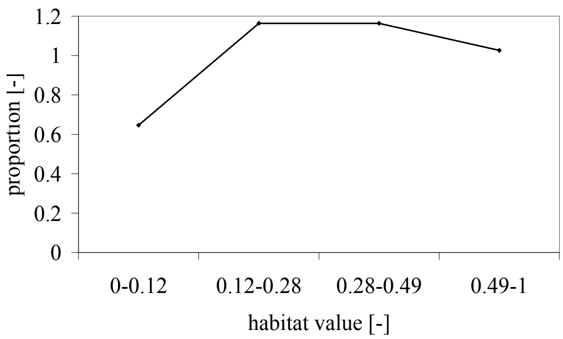


Figure A1.6 Habitat availability and use and proportion of use to availability for salmon >10 cm with general preference curves by Heggenes (1990).

Stone loach (*Noemacheilus barbatulus*), preference curves based on data (*Barbatula barbatula* (L., 1758)) of Lamouroux et al. (1999)

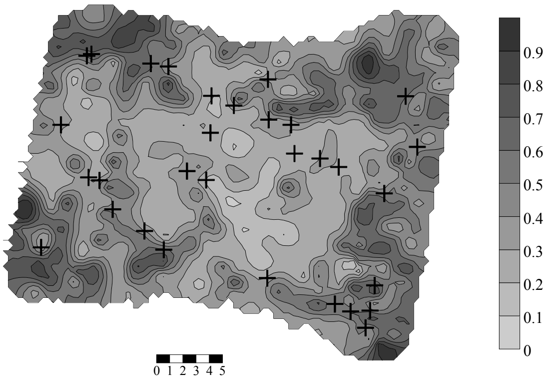


Figure A1.7 Habitat suitability for stone loach with preference curves based on French data and fish observations.

Table A1.5 Available habitat and habitat use and proportion of use to availability for stone loach based on Lamouroux et al. (1999) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3336	15.97	21	1.31	1.58	1.28	11.50	
0.3336-1	15.03	10	0.67	1.68	1.36	-8.15	
sum	31	31	high/low	3.27	2.65	3.35	3.30
average	0.43	0.37	0.51	-0.07	-0.1	-0.07	-0.07

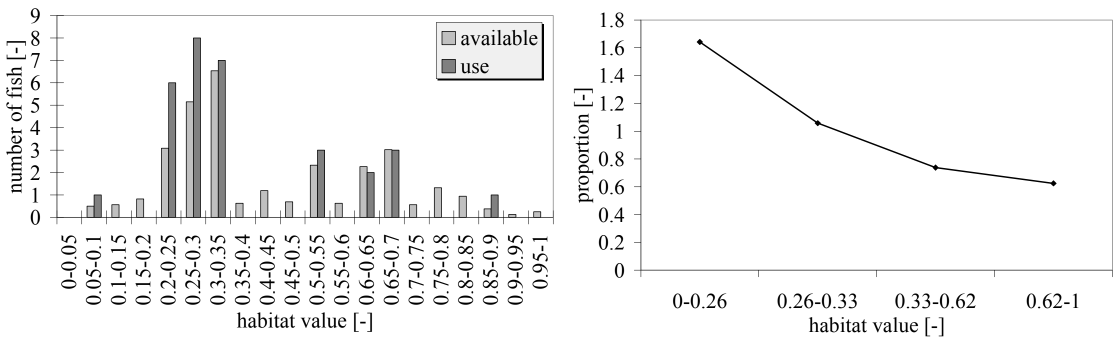


Figure A1.8 Habitat availability and use and proportion of use to availability for stone loach based on Lamouroux et al. (1999).

Bullhead (*Cottus gobio*), preference curves based on data of Lamouroux et al. (1999)

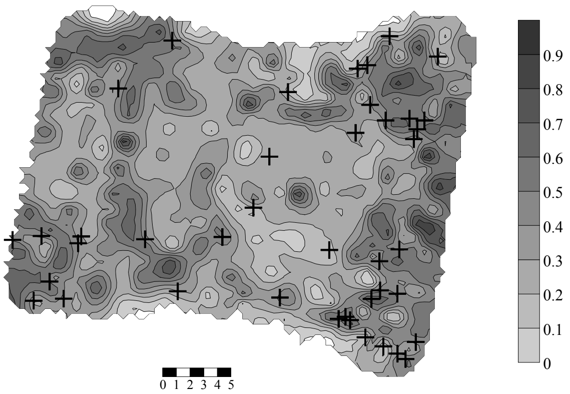


Figure A1.9 Habitat suitability for bullhead with preference curves based on Lamouroux et al. (1999) and fish observations.

Table A1.6 Available habitat and habitat use and proportion of use to availability for bullhead based on Lamouroux et al. (1999) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3122	20.38	16	0.79	0.94	0.74	-7.74	
0.3122-1	20.62	25	1.21	0.93	0.73	9.62	
sum	41	41	high/low	1.87	1.47	1.88	1.86
average	0.37	0.40	1.54	0.17	0.23	0.17	0.17

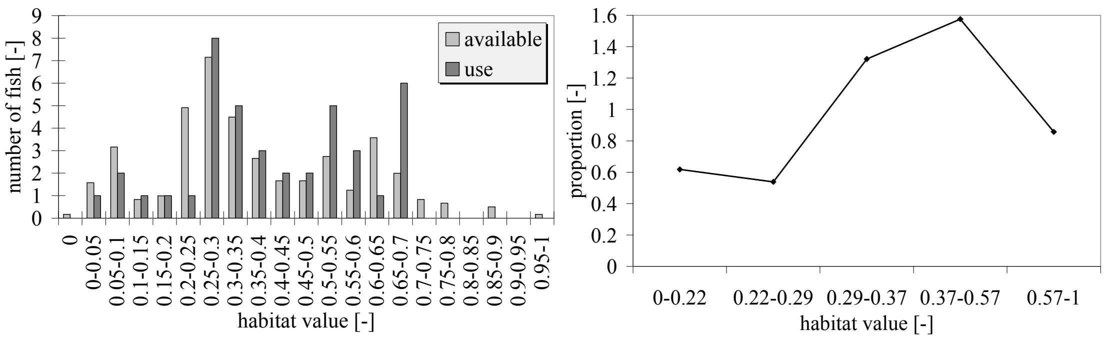


Figure A1.10 Habitat availability and use and proportion of use to availability for bullhead based on Lamouroux et al. (1999).

A2 ISO TAINIKOSKI RAPIDS, LOWER SIDE AREA

Salmon <10 cm, general preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000)

Salmon <10 cm, general preference curves by Heggenes (1990)

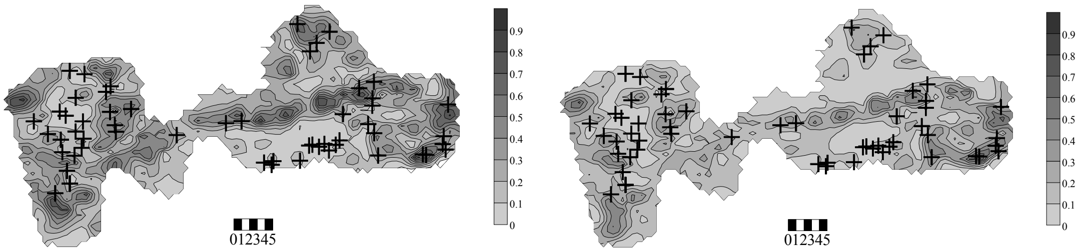


Figure A2.1 Habitat suitability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), general preference curves according to Heggenes (1990), and fish observations.

Table A2.1 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1993	28.44	14	0.49	7.33	6.83	-19.85	
0.1993-1	28.56	43	1.51	7.30	6.81	35.19	
sum	57	57	high/low	14.64	13.64	15.35	15.21
average			3.06	0.0001	0.0002	<0.0001	<0.0001

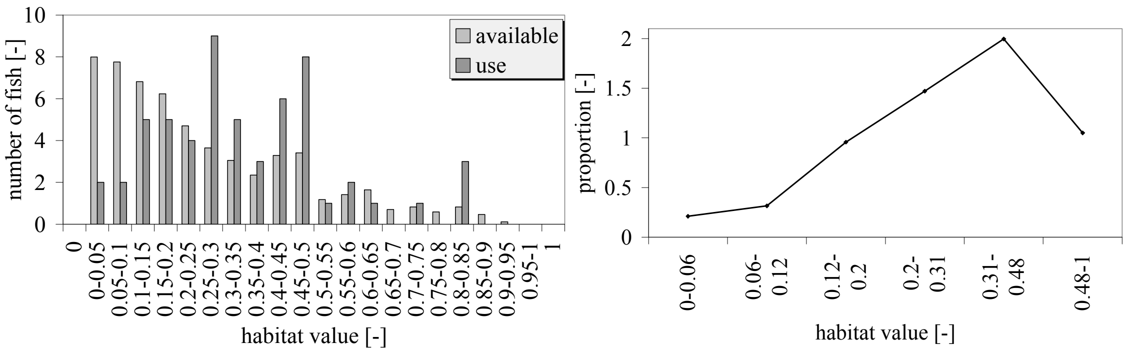


Figure A2.2 Habitat availability and use and proportion of use to availability for salmon <10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Table A2.2 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with general preference curves by Heggenes (1990) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1239	28.44	12	0.42	9.50	8.94	-20.71	
0.1239-1	28.56	45	1.58	9.47	8.90	40.92	
sum	57	57	high/low	18.97	17.83	20.21	20.04
average			3.73	<0.0001	<0.0001	<0.0001	<0.0001

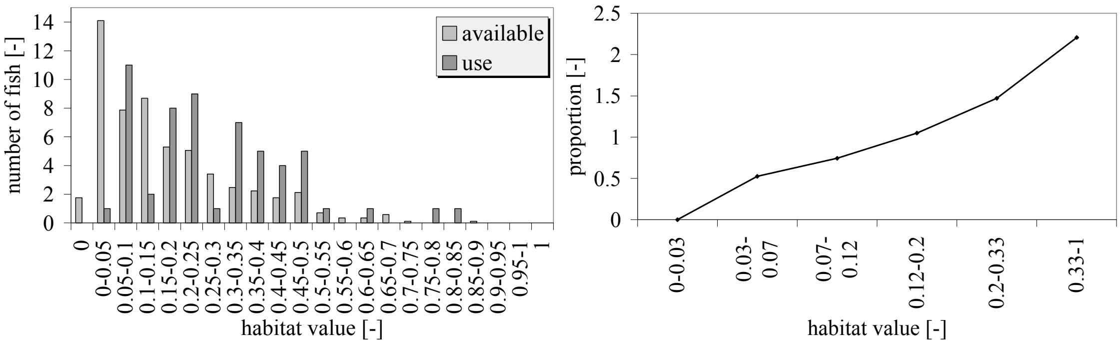


Figure A2.3 Habitat availability and use and proportion of use to availability for salmon <10 cm with general preference curves by Heggenes (1990).

Salmon >10 cm, general preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000)

Salmon >10 cm, general preference curves according to Heggenes (1990)

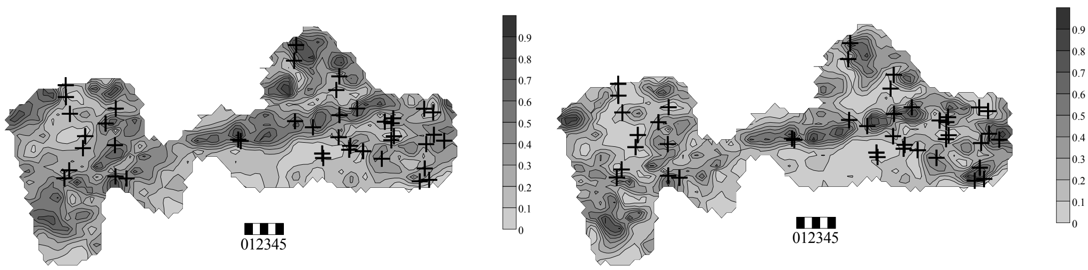


Figure A2.4 Habitat suitability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), general preference curves by Heggenes (1990), and fish observations.

Table A2.3 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1239	21.46	11	0.51	5.10	4.62	-14.70	
0.1239-1	21.54	32	1.49	5.07	4.60	25.32	
sum	43	43	high/low	10.17	9.22	10.62	10.50
average			2.90	0.001	0.002	0.001	0.001

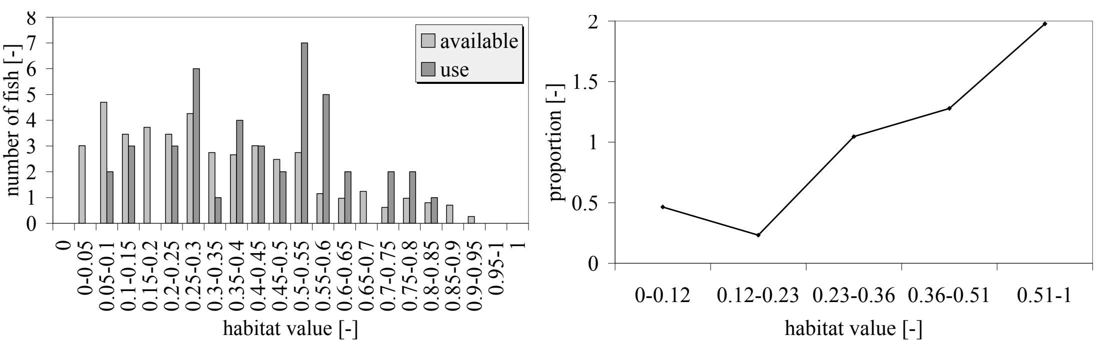


Figure A2.5 Habitat availability and use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Table A2.4 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with general preference curves by Heggenes (1990) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.1781	21.46	11	0.51	5.10	4.62	-14.70	
0.1781-1	21.54	32	1.49	5.07	4.60	25.32	
sum	43	43	high/low	10.17	9.22	10.62	10.50
average			2.90	0.002	0.003	0.002	0.002

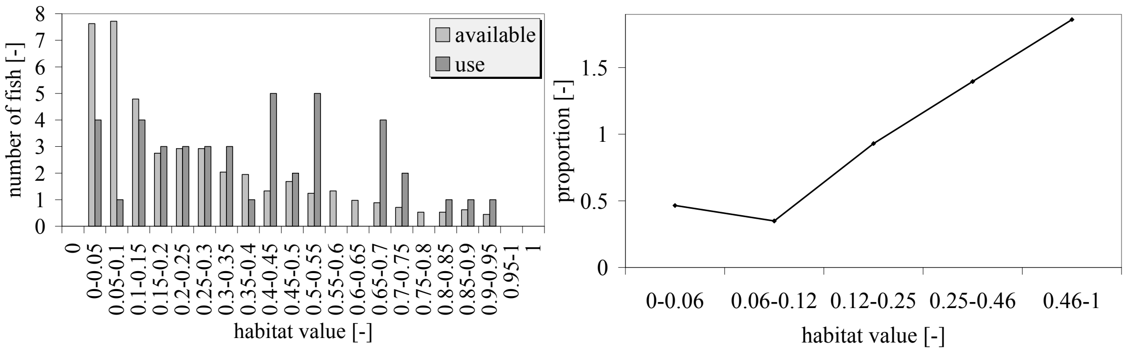


Figure A2.6 Habitat availability and use and proportion of use to availability for salmon >10 cm with general preference curves by Heggenes (1990).

Grayling 5.1-25.4 cm, preference curves of Hubert et al. (1985), summer

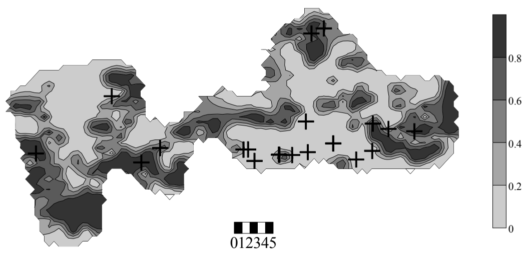


Figure A2.7 Habitat suitability for grayling 5.1-25.4 cm with the preference curves of Hubert et al. (1985) and fish observations.

Table A2.5 Available habitat and habitat use and proportion of use to availability for grayling 5.1-25.4 cm with the preference curves of Hubert et al. (1985) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0872	10.48	4	0.38	4.01	3.41	-7.70	
0.0872-1	10.52	17	1.62	3.99	3.40	16.31	
sum	21	21	high/low	7.99	6.81	8.61	8.41
average			4.23	0.005	0.009	0.003	0.004

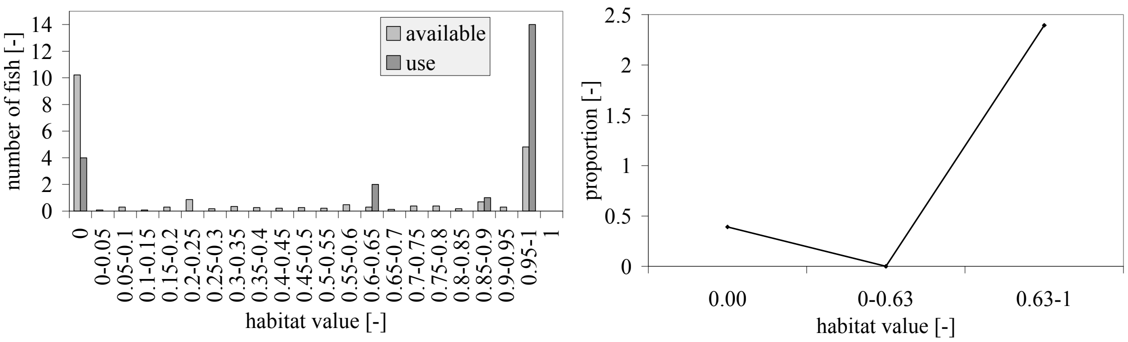


Figure A2.8 Habitat availability and use with uniform interval and proportion of use to availability for grayling 5.1-25.4 cm with the preference curves of Hubert et al. (1985).

Stone loach, preference curves from Harrikoski Rapids

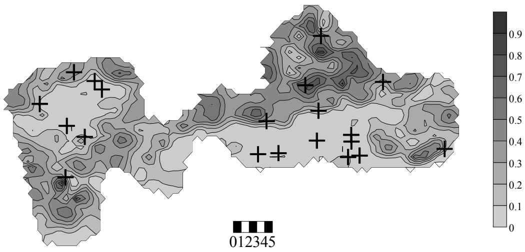


Figure A2.9 Habitat suitability for stone loach with preference curves from Harrikoski Rapids and fish observations.

Table A2.6 Available habitat and habitat use and proportion of use to availability for stone loach with preference curves from Harrikoski Rapids and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2115	9.98	12	1.20	0.41	0.23	4.43	
0.2115-1	10.02	8	0.80	0.41	0.23	-3.60	
sum	20	20	high/low	0.82	0.46	0.82	0.80
average			0.66	-0.37	-0.5	-0.36	-0.37

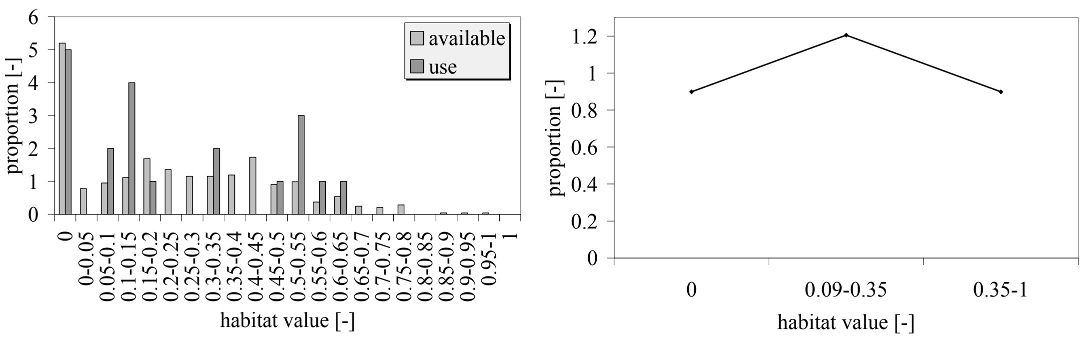


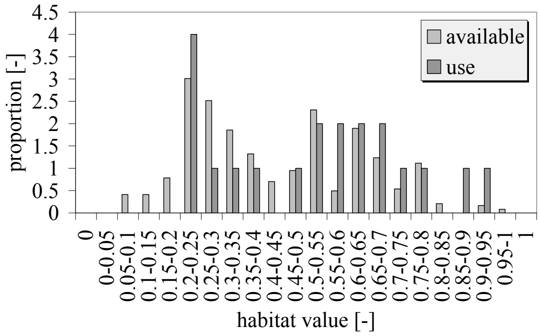
Figure A2.10 Habitat availability and use with uniform interval and proportion of use to availability for stone loach with preference curves from Harrikoski Rapids.

Stone loach (*Noemacheilus barbatulus*), preference curves based on data (*Barbatula barbatula* (L., 1758)) of Lamouroux et al. (1999)

Figure A2.11 Habitat suitability for stone loach with preference curves based on data (*Barbatula barbatula* (L., 1758)) of Lamouroux et al. (1999) and fish observations.

Table A2.7 Available habitat and habitat use and proportion of use to availability for stone loach with preference curves based on data (*Barbatula barbatula* (L., 1758)) of Lamouroux et al. (1999) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3934	9.86	6	0.61	1.51	1.14	-5.96	
0.3934-1	10.14	14	1.38	1.47	1.11	9.02	
sum	20	20	high/low	2.97	2.25	3.06	2.99
average			2.27	0.08	0.13	0.08	0.08



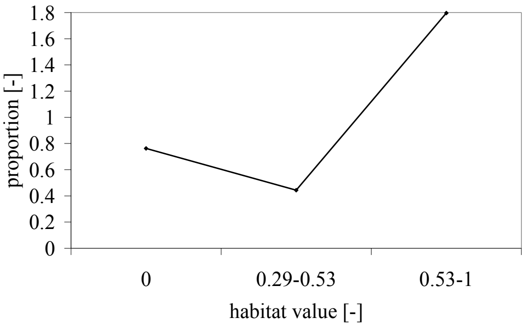


Figure A2.12 Habitat availability and use with uniform interval and proportion of use to availability for stone loach with preference curves based on data (*Barbatula barbatula* (L., 1758)) of Lamouroux et al. (1999).

Bullhead, preference curves from Harrikoski Rapids

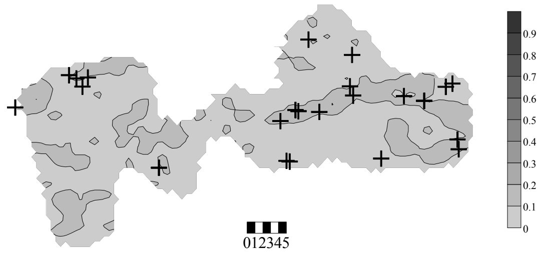


Figure A2.13 Habitat suitability for bullhead with preference curves from Harrikoski Rapids and fish observations.

Table A2.8 Available habitat and habitat use and proportion of use to availability for bullhead with preference curves from Harrikoski Rapids and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0789	12.47	8	0.64	1.60	1.27	-7.11	
0.0789-1	12.53	17	1.36	1.60	1.26	10.38	
sum	25	25	high/low	3.20	2.53	3.28	3.21
average			2.12	0.002	0.003	0.002	0.002

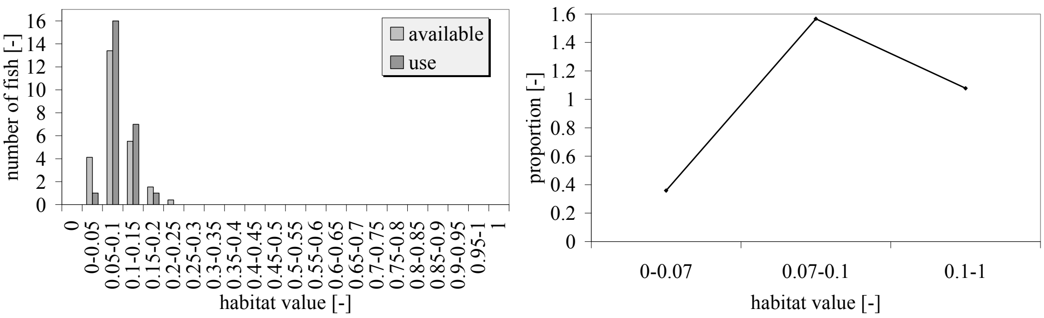


Figure A2.14 Habitat availability and use with uniform interval and proportion of use to availability for bullhead with preference curves from Harrikoski Rapids.

Bullhead (*Cottus gobio*), preference curves based on data of Lamoroux et al. (1999)

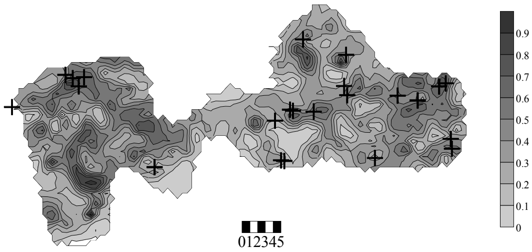


Figure A2.15 Habitat suitability and fish observation map for bullhead with preference curves based on data of Lamoroux et al. (1999).

Table A2.9 Available habitat and habitat use and proportion of use to availability for bullhead with preference curves based on data of Lamoroux et al. (1999) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3219	12.84	10	0.78	0.63	0.42	-4.99	
0.3219-1	12.16	15	1.23	0.66	0.45	6.28	
sum	25	25	high/low	1.29	0.87	1.29	1.27
average			1.58	0.26	0.35	0.26	0.26

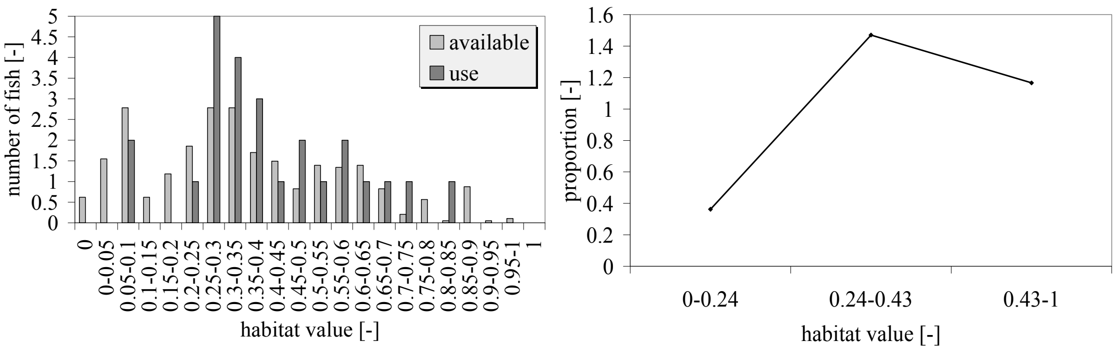


Figure A2.16 Habitat availability and use with uniform interval and proportion of use to availability for bullhead with preference curves based on data of Lamoroux et al. (1999).

A3 ISO TAINIKOSKI RAPIDS, UPPER SIDE AREA

Salmon >10 cm, general preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000)

Salmon >10 cm, general preference curves according to Heggenes (1990)

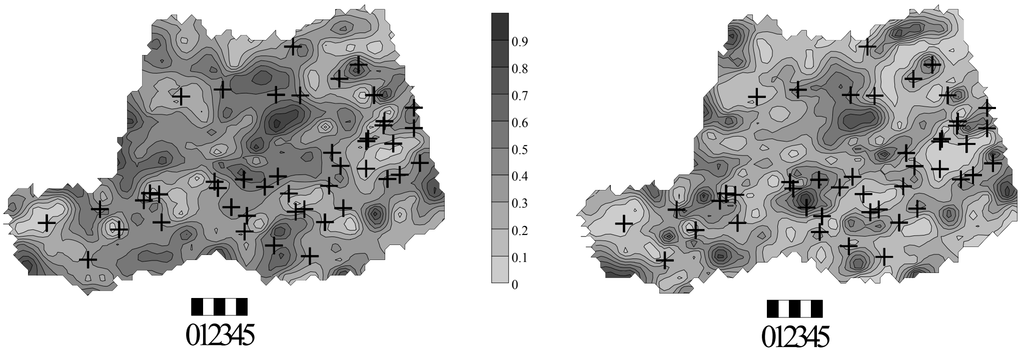


Figure A3.1 Habitat suitability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), general preference curves by Heggenes (1990), and fish observations.

Table A3.1 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3913	22.43	19	0.85	0.52	0.38	-6.31	
0.3913-1	22.57	26	1.15	0.52	0.38	7.36	
sum	45	45	high/low	1.05	0.76	1.05	1.04
average			1.36	0.31	0.38	0.31	0.31

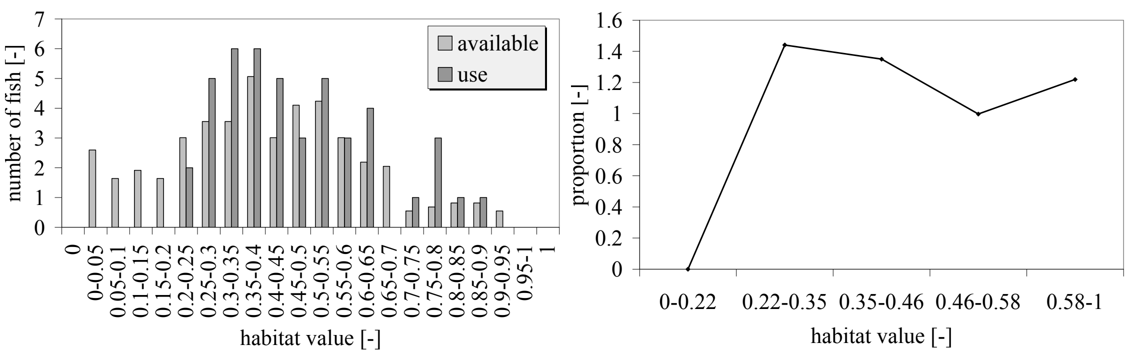


Figure A3.2 Habitat availability and use with uniform interval and proportion of use to availability for salmon >10 cm with preference curves from Rivers Koitajoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Table A3.2 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with general preference curves according to Heggenes (1990) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.02392	22.43	10	0.45	6.89	6.35	-16.16	
0.02392-1	22.57	35	1.55	6.85	6.31	30.72	
sum	45	45	high/low	13.74	12.65	14.56	14.40
average			3.48	0.0002	0.0004	0.0001	0.0001

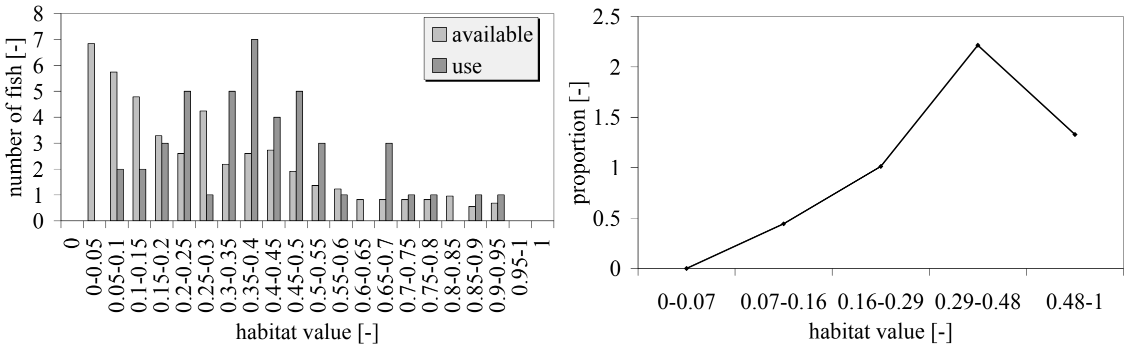


Figure A3.3 Habitat availability and use with uniform interval and proportion of use to availability for salmon >10 cm with general preference curves by Heggenes (1990).

A4 HIISKOSKI RAPIDS

Salmon >10 cm, general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), season 1, summer

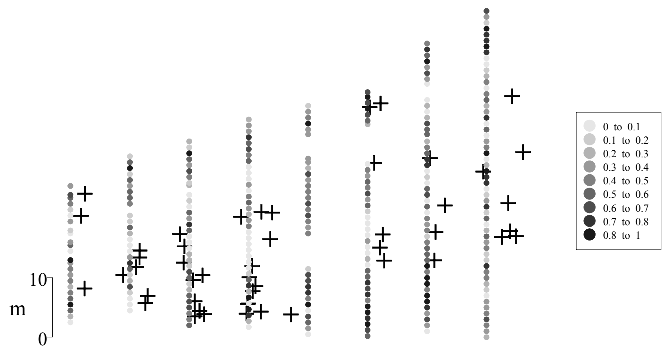


Figure A4.1 Habitat suitability measurement lines for salmon >10 cm with preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), marked with coloured circles and fish observations marked with crosses.

Table A4.1 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki, (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.4194	23.92	19	0.79	1.01	0.82	-8.75	
0.4194-1	24.08	29	1.20	1.00	0.81	10.78	
sum	48	48	high/low	2.02	1.63	2.03	2.01
average	0.40	0.53	1.52	0.16	0.20	0.15	0.16

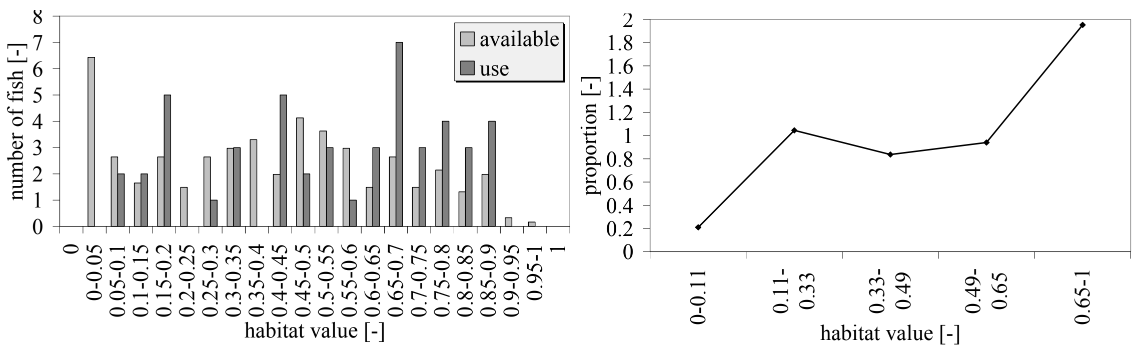


Figure A4.2 Habitat availability and use with uniform interval and proportion of use to availability for salmon >10 cm with preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Salmon >10 cm, general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), season 2, warm autumn

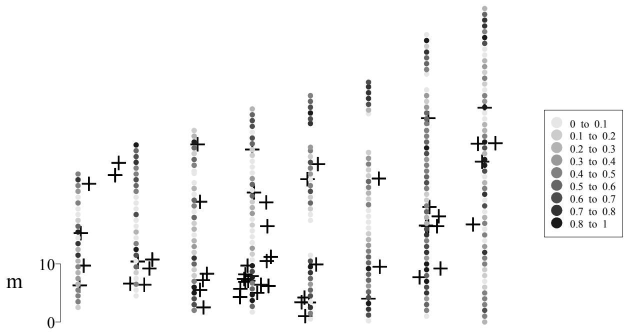


Figure A4.3 Habitat suitability measurement lines for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), marked with coloured circles and fish observations marked with crosses.

Table A4.2 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.4644	32.39	24	0.74	2.17	1.92	-14.39	
0.4644-1	32.61	41	1.26	2.16	1.91	18.77	
sum	65	65	high/low	4.33	3.83	4.38	4.35
average	0.40	0.52	1.70	0.04	0.05	0.04	0.04

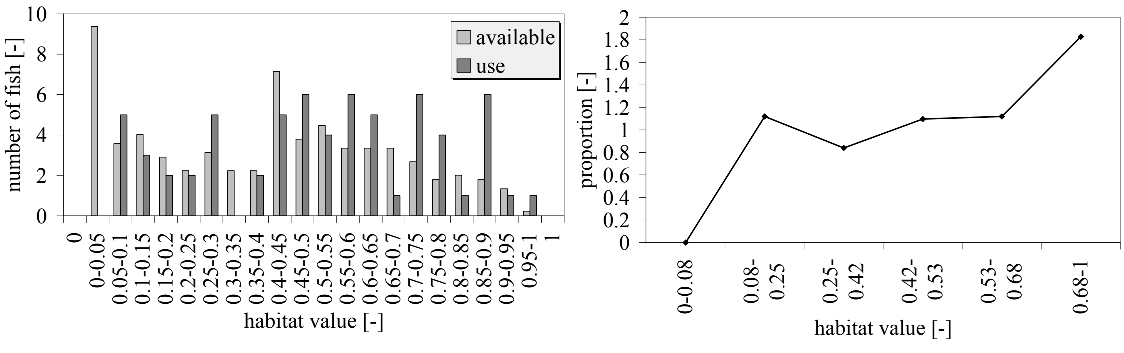


Figure A4.4 Habitat availability and use and proportion of use to availability for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Brown trout <10 cm, general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001), season 1, summer

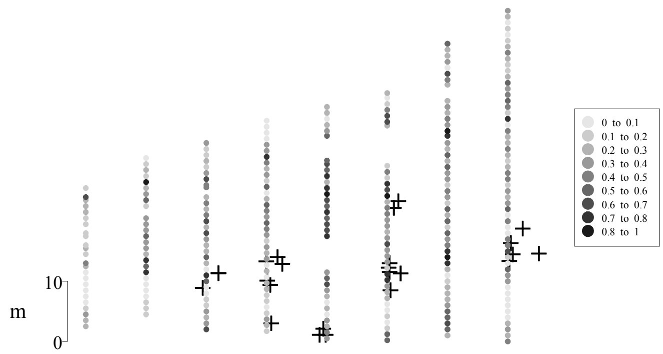


Figure A4.5 Habitat suitability measurement lines for brown trout <10 cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001), marked with coloured circles and fish observations marked with crosses.

Table A4.3 Available habitat and habitat use and proportion of use to availability for brown trout <10 cm cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.3304	12.46	6	0.48	3.35	2.85	-8.77	
0.3304-1	12.54	19	1.51	3.32	2.83	15.78	
sum	25	25	high/low	6.67	5.68	7.01	6.88
average	0.33	0.45	3.14	0.01	0.02	0.008	0.009

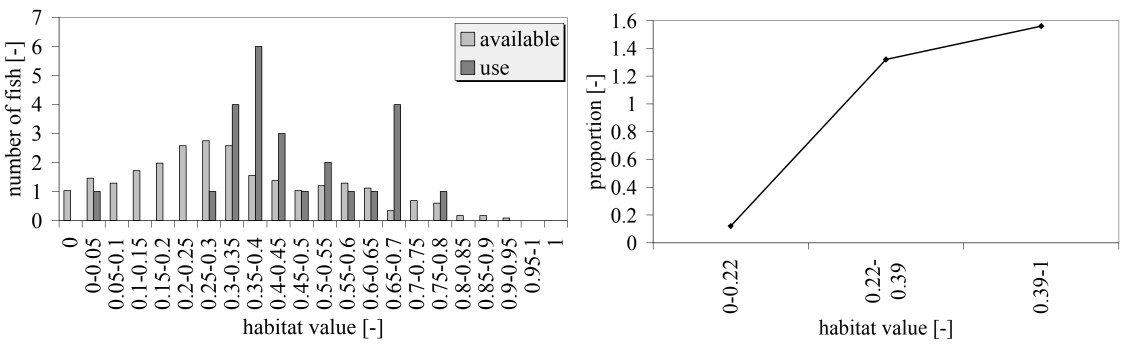


Figure A4.6 Habitat availability and use and proportion of use to availability for brown trout <10 cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001).

Brown trout, 16-25 cm, general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001), season 1, summer

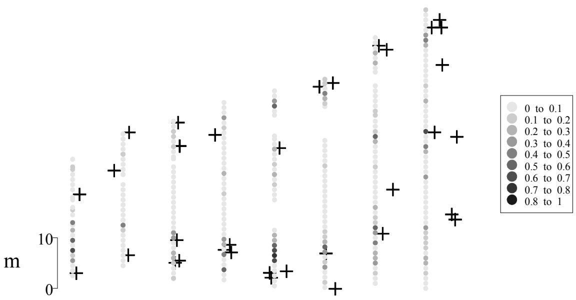


Figure A4.7 Habitat suitability measurement lines for brown trout 16-25 cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001), marked with coloured circles and fish observations marked with crosses.

Table A4.4 Available habitat and habitat use and proportion of use to for brown trout 16-25 cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.0610	16.94	10	0.59	2.84	2.45	-10.54	
0.0610-1	17.06	24	1.41	2.82	2.43	16.39	
Sum	34	34	high/low	5.67	4.88	5.84	5.76
Average	0.10	0.17	2.38	0.02	0.03	0.02	0.02

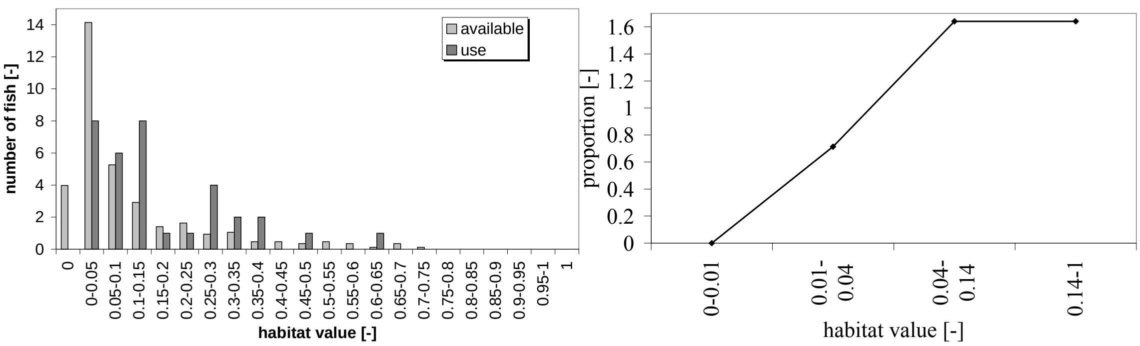


Figure A4.8 Habitat availability and use and proportion of use to availability for salmon >10 cm with general preference curves from Rivers Astervajoki, Kutijoki, Kuusinkijoki, Loukusajoki, Rutajoki, and Varisjoki (Mäki-Petäys 2001).

A5 TYLTSYKOSKI RAPIDS

Salmon <10 cm, general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), season 1, summer

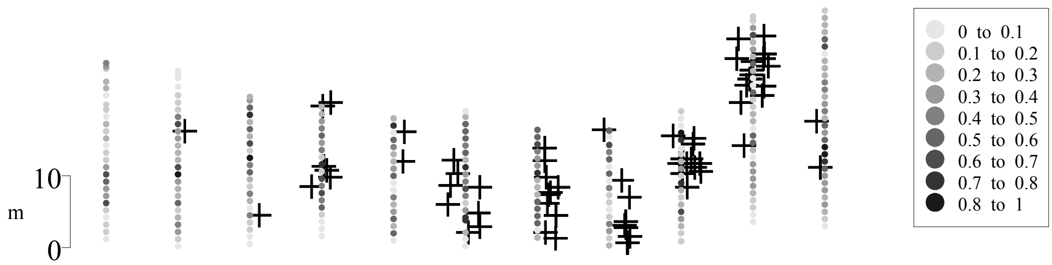


Figure A5.1. Habitat suitability measurement lines for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) marked with coloured circles and fish observations marked with crosses.

Table A5.1 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.2907	38.50	25	0.65	4.73	4.39	-21.59	
0.2907-1	38.50	52	1.35	4.73	4.39	31.26	
sum	77	77	high/low	9.47	8.78	9.67	9.61
average	0.32	0.40	2.08	0.002	0.003	0.002	0.002

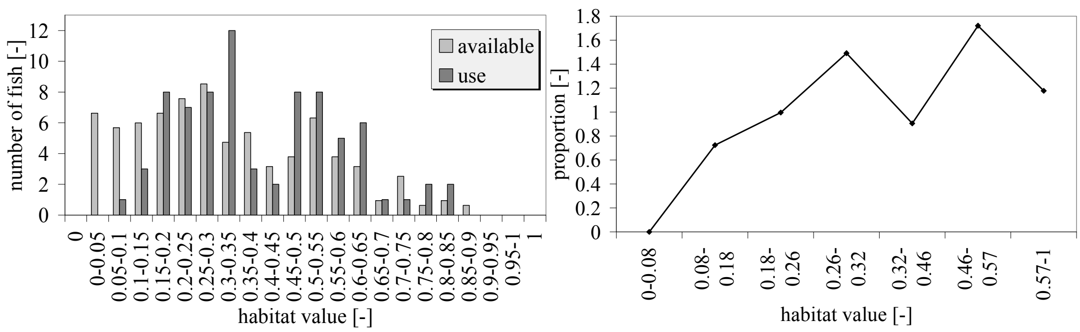


Figure A5.2 Habitat availability and use and proportion of use to availability for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Salmon <10 cm, general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), season 2, warm autumn

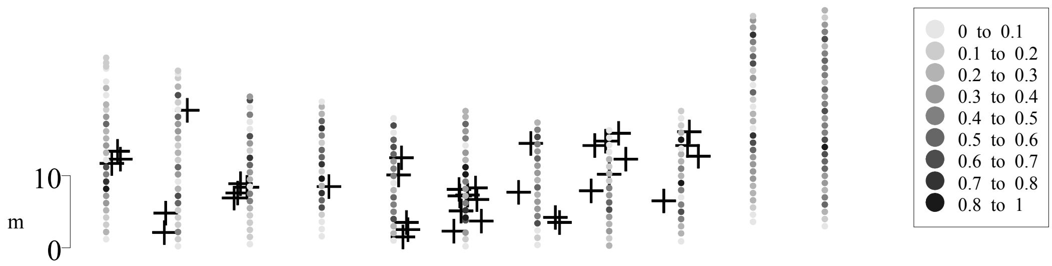


Figure A5.3 Habitat suitability measurement lines for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) marked with coloured circles and fish observations marked with crosses.

Table A5.2 Available habitat and habitat use and proportion of use to availability for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	Proportion	Pearson	Yates	log-likelihood	Williams
0-0.3029	20.00	15	0.75	1.25	1.01	-8.63	
0.3029-1	20.00	25	1.25	1.25	1.01	11.16	
sum	40	40	high/low	2.50	2.03	2.53	2.50
average	0.34	0.37	1.67	0.11	0.15	0.11	0.11

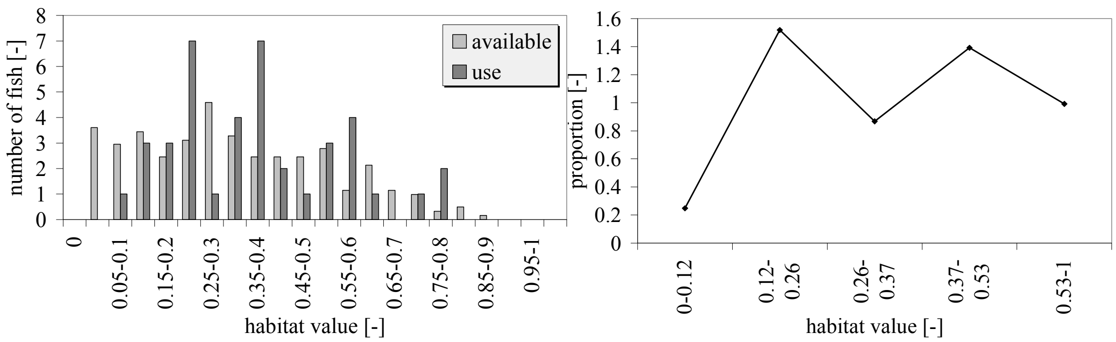


Figure A5.4 Habitat availability and use and proportion of use to availability for salmon <10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

Salmon >10 cm, general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000), season 1, summer

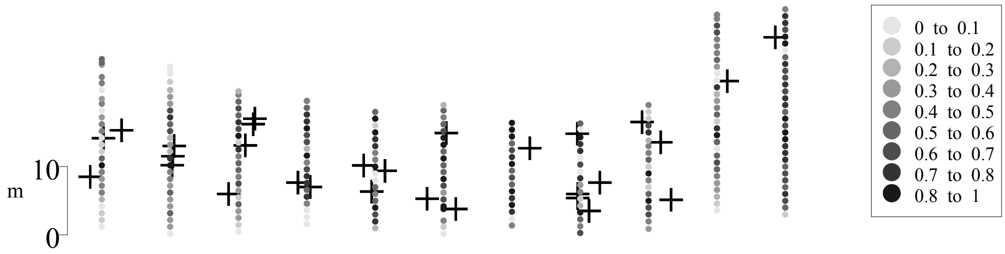


Figure A5.5 Habitat suitability measurement lines for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) marked with coloured circles and fish observations marked with crosses.

Table A5.3 Available habitat and habitat use and proportion of use to availability for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000) and goodness of fit tests.

habitat value	available	use	proportion	Pearson	Yates	log-likelihood	Williams
0-0.5211	14.50	11	0.76	0.84	0.62	-6.08	
0.5211-1	14.50	18	1.24	0.84	0.62	7.78	
sum	29	29	high/low	1.69	1.24	1.71	1.68
average	0.50	0.60	1.64	0.19	0.27	0.19	0.2

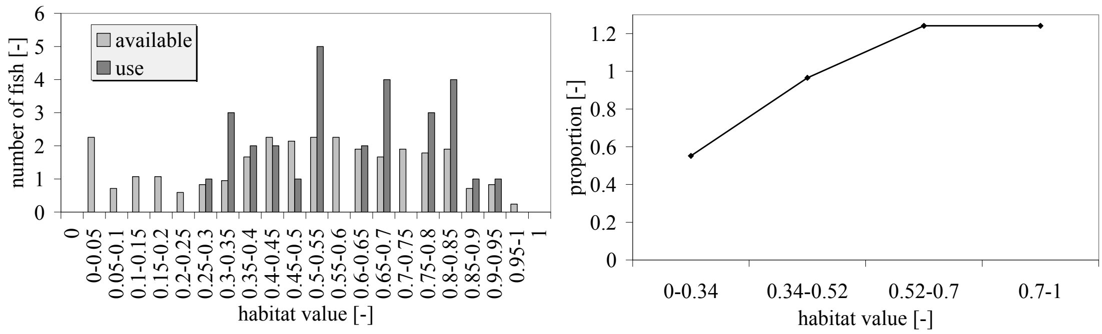


Figure A5.6 Habitat availability and use and proportion of use to availability for salmon >10 cm with general preference curves from Rivers Simojoki, Pyhäjoki, and Tenojoki (Mäki-Petäys 2000).

ISBN 978-952-248-026-2
ISBN 978-952-248-027-9 (PDF)
ISSN 1795-2239
ISSN 1795-4584 (PDF)