RESTORING SALMONID STOCKS IN BOREAL RIVERS

Problems of passage at migratory obstructions and land-derived loading in production areas

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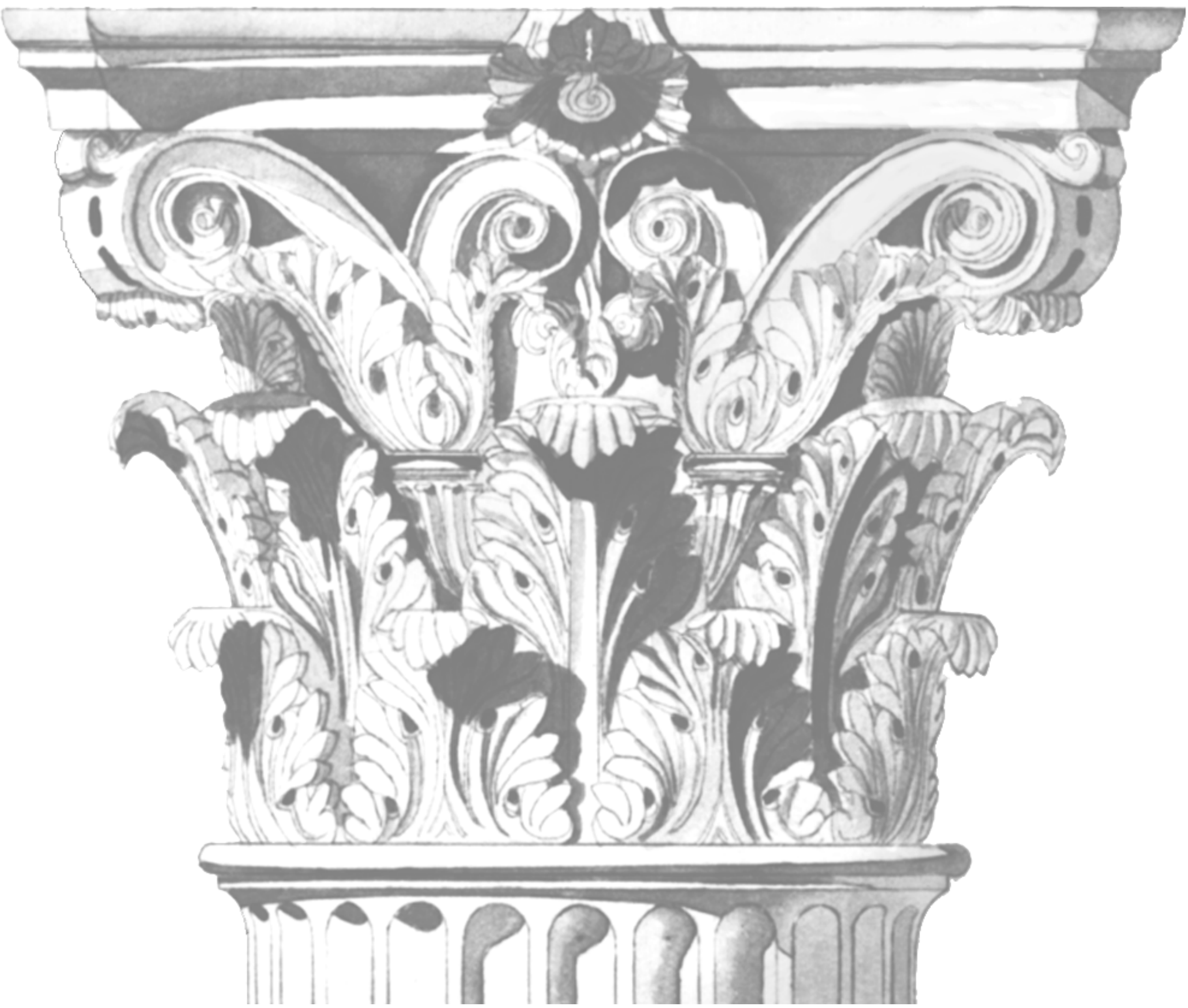

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Abstract

In this thesis, I examine two important aspects surrounding salmonid reproductive ecology, namely: (*i*) the problems with passing obstructions during migratory spawning runs and (*ii*) how the early life stages in boreal streams are influenced by increased levels of fine-grained particulate matter from drained peatlands. These aspects are not only critical to salmonid reproductive success but have grave implications regarding environmental quality and species conservation.

Spawning runs can be re-established by constructing fishways at obstructions but the efficiency of fishways depends on several factors. The passage of multi-sea-winter salmon was enhanced in the Isohaara fishway by increasing its water flow and by creating a small waterfall at the entrance. The fishway, which consists of vertical slot and Denil sections, proved to be unsuitable for most freshwater fish, whitefish and river lamprey, whereas salmonids, once they had entered, successfully negotiated the fishway. In fishway design, the migratory behaviour and the demands of the species of interest should be considered. For salmonids, priority should be given to the attractiveness of the fish entrance.

When there is a migration corridor, the availability and the quality of spawning and rearing habitats has a major effect on the success of restoration projects. In the humic rivers studied, the survival of incubated brown trout eggs was lower in riffles susceptible to increased levels of fine-grained particulate matter from drained peatlands. Additionally, an increase in the Fe content of high molecular weight dissolved organic matter followed by its precipitation and sedimentation was proposed to be involved. Correspondingly, the recapture rates of stocked yearling salmon were lower in the affected riffles, individual salmon being smaller and thinner and having less food in their stomachs than reference salmon. Based on these results, it seems probable that peatland drainage, by influencing the incubation success of salmonid embryos and the foraging, growth and survival of juveniles, eventually affects the number and quality of smolts produced. In future, such water pollution control measures should be implemented that would enhance the success of natural spawning and help ensure environmental quality.

Keywords: fishways, peatland drainage, incubation success, foraging

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Bohdan Sklepkovych, although occupied with his own research, kindly revised the English of the summary of the thesis. Taina Liu and Malcolm Hicks have corrected the English of the separate papers. Helena Heikkinen helped in drawing most of the maps.

Professor Markku Orell from the Department of Biology has been my long-term companion in civil life and he has persistently encouraged me to finish this work. Our children Anna and Tuure entered their first class of primary school while I was writing the summary of this thesis. They may have suffered a bit because their mother had not much energy left to play football with them each evening. Positively thinking, they have learned to be more independent and have also made me understand that there are much more important things in life than career.

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List of original papers

This thesis is based on the following original papers, which are referred to in the text by their Roman numerals:

I Laine A, Kamula R & Hooli J (1998) Fish and lamprey passage in a combined Denil and vertical slot fishway. Fisheries Management and Ecology 5: 31-44.

II Laine A, Jokivirta T & Katopodis C (2001) Salmon and sea trout passage in a regulated northern river – fishway efficiency, fish entrance and environmental factors. Fisheries Management and Ecology, in press.

III Laine A & Heikkinen K (2000) Peat mining increasing fine-grained organic matter on the riffle beds of boreal rivers. Archiv für Hydrobiologie 148: 9-24.

IV Laine A, Heikkinen K & Sutela T (2001) Incubation success of brown trout (Salmo trutta) eggs in boreal humic rivers affected by peatland drainage. Archiv für Hydrobiologie 150: 289-305.

V Laine A (2001) Effects of peatland drainage on the size and diet of yearling salmon in a humic northern river. Archiv für Hydrobiologie, in press.

Contents

1 Introduction

1.1 Background

Throughout the world, anthropogenic alterations in habitat and water quality in river systems have had a profound effect on salmonids (L'Abée-Lund *et al*. 1992, Eaglin & Hubert 1993, Zeh & Dönni 1994, Rubin & Glimsäter 1996, Jungwirth 1998, Elliott *et al*. 1998, Parrish *et al*. 1998, Eklöv *et al*. 1999). Hydroelectric construction, which blocks migration routes, has severely affected migratory fish stocks in both large and mid-sized rivers. The resulting water level regulation has diminished the areas suitable for spawning and nursing. Tributaries and headwaters, however, often remain potential production areas and by providing access to these areas, migratory fish stocks can be supported in regulated rivers.

Restoring the reproductive cycle is a long-term process, requiring consideration and accountability for all the phases. Fishways or fish passage facilities that open or reopen streams to migratory fish have been constructed for centuries, with stronger development coming along with hydropower construction. The efficiency of a fishway depends greatly on its attraction, as well as its safe and speedy transport of fish (Katopodis 1990). However, even a completely successful fish passage facility may be of little value if few fish use it as a migration route or the habitat to which the fish are migrating is neither available or badly degraded (Northcote 1998). Runs can be re-established by stocking fish upstream of the obstacles but often supportive stockings must be continued for considerable periods of time in order to sustain the runs (Banks 1969, Saltveit 1993).

Much effort has been done to improve and restore habitats suitable for spawning and rearing in dredged and channelised rivers of the boreal region. Less attention has been paid to impacts of land use in the catchment which can, in case of increased loading, seriously impair the conditions for embryos and alevins inside the gravel and for juveniles in their first feeding habitats (Olsson & Näslund 1985, Olsson & Persson 1986, Chapman 1988, Weaver & Fraley 1993, Avery 1996). Increased mobilisation and transport of fine-grained particulate matter can be regarded as the most intensive disturbance caused by land use for rivers in the boreal region, where peatlands are commonly drained for forestry and peat mining (Sallantaus 1988, Heikkinen 1990abc, Ahtiainen 1992).

Mobilisation of high molecular weight iron-carrying humic substances have also been reported from peat mining areas (Heikkinen 1990a,c).

1.2 Fish passage at migratory obstructions

In designing fish passage facilities at migratory obstructions, the flow and water velocities suitable for the fish species involved need to be considered (Larinier 1998, Williams 1998). It has been proposed that a fishway can be regarded successful only when it enables the passage of all species that either inhabit or have previously inhabited the river system (DVWK 1996). However, biological and hydraulic criteria vary with fish species and size (Katopodis 1990, 1999). Different species may also display different migration and search patterns at the dam and downstream of a fishway (Johlander 1999) leading to various requirements for positioning fish entrances. This results in high, if not almost impossible demands in terms of successfully designing fishways that would be suitable for all potential species and serve multi-use demands.

Environmental factors, specifically water temperature, play an important role in both the timing of fish arrival and the success of river migration (Banks 1969, Smith *et al.* 1994, Smith 1995, Northcote 1998). Discharge, especially a change in the rate of flow, has also long been recognised as important in modifying both run timing and migratory success particularly in rivers with highly fluctuating water levels during the migration period (Banks 1969, Clarke *et al.* 1991, Jonsson 1991, Trépanier *et al.* 1996). Nevertheless, the relationship between river entry and discharge is highly complex (Smith *et al.* 1994, Northcote 1998) and the effects of discharge are diminished or strengthened by other hydrological, hydraulic and meteorological conditions (Banks 1969, Jensen & Aass 1995). Discharge is important also in guiding and attracting fish to enter a fishway (Larinier 1998). The nature of flows at the entrance in relation to fish attraction is, nonetheless, poorly understood, and complicated by the varying flow patterns found at different hydropower plants.

The passage of two closely related anadromous salmonids, salmon (*Salmo salar* L.) and sea trout (*S. trutta* m. *trutta* L.) have been emphasized in papers I and II as the main users of a fishway constructed close to the mouth of a large, regulated river in northern Finland. The simultaneous passage of anadromous whitefish (*Coregonus lavaretus* L.) and European river lamprey (*Lampetra fluviatilis* L.), representing species with a considerably weaker swimming ability, have been discussed briefly in paper I. The effects of improving the fishway to attract salmon that have spent multiple winters at sea (multi-sea-winter or MSW salmon) and the possible inverse effects on the ascent of smaller-sized, one-sea winter (1SW) salmon and sea trout have been assessed in paper II.

1.3 Freshwater habitats and peatland drainage

Freshwater habitats for salmonids are the products of interactions among climate, hydrologic responses of watersheds, and hillslope and channel erosion processes. Together with vegetation cover, these processes control streamflow, input of allochthonous material to the channel, channel stability and channel structures suitable for spawning, incubation and rearing of fish. In the absence of major disturbances, these processes produce small changes in the natural environment, resulting in a constant background level of habitat variability and diversity against which the modifications produced by human activity can be judged (Swanston 1991).

The long intragravel period of salmon and trout is considered critical, as successful incubation and emergence depends on numerous chemical, physical, and hydraulic factors within and outside the gravel (Tappel & Bjornn 1983, Chapman 1988, Bjornn & Reiser 1991, Pauwels & Haines 1994, Rubin 1998). The interstitial oxygen concentration, which is related to the respective concentration in the water and water exchange in the gravel, is regarded as the main factor influencing the survival of eggs up to hatching (Chapman 1988, Rubin & Glimsäter 1996). Redds may become less suitable for embryos if inorganic fine sediments and organic materials are deposited in the interstitial spaces between the larger particles (Bjornn & Reiser 1991, Argent & Flebbe 1999). The fine particles impede the movement of water and the organic material consumes oxygen during decomposition. Effects of increased particulate matter loading from peatland drainage areas on the quality of the riffle beds have been assessed in paper III and on the incubation success of brown trout eggs in paper IV.

Yearlings and older salmonids can survive for considerable periods even in high particulate matter concentrations (Sigler *et al.* 1984, Solbé 1988). Increased loading, however, can cause sublethal stress and reduce the capacity for fish to obtain food which may consequently reduce growth rates (Alabaster & Lloyd 1980, Redding *et al.* 1987, Lloyd 1987, Lloyd *et al.* 1987, Hicks *et al.* 1991). Macrobenthos densities can also be reduced or their communities altered by the transport and deposition of particulate matter (Rabeni & Minshall 1977, Bond 1979, Olsson & Näslund 1985, Mills 1989). Thus, deterioration of the riffle habitats may influence the foraging and growth of juvenile salmonids in riffles affected by increased levels of particulate matter from drained peatlands, which is discussed in paper V.

1.4 The aim of the study

When restoring the reproductive cycle of migratory fish in streams affected by human activities, it is essential to identify all individual factors influencing fish stocks and thus, the overall success of restoration projects. The complex interactions of river bed morphology, hydraulic regime and sedimentation processes versus the not yet fully understood physiological requirements of fish embryos and larvae in the gravel can make the outcome of rehabilitation work uncertain (Zeh & Dönni 1994). Similarly, the number and quality of smolts produced depends on the suitability of the riffle environments for rearing juveniles. In the boreal region, drainage of peatlands for peat mining or afforestation results in increased outwash of fine-grained particulate matter and may be crucial for the success of the restoration projects. The task is even more demanding in regulated rivers, where the passage of adults on their spawning run and smolts on their downstream migration also require consideration.

In the present work, I examine two aspects important for migratory fish in boreal humic rivers namely: the passage problems encountered at migratory obstructions during spawning run (I, II) and the incubation (IV) and juvenile phases (V) of stream-dwelling salmonids which are connected to the effects of increased land-derived particulate matter loading on riffle bed quality (III). In light of this context, the present work aims to find a realistic approach for restoring salmonid stocks in rivers affected by hydropower construction and peatland drainage.

2 Material and methods

2.1 Study area

Research was conducted in three boreal humic river systems running into the Gulf of Bothnia of the Baltic Sea in northern Finland (Fig. 1). The Kiiminkijoki River (MQ = 47 $m^3 s^{-1}$, MHQ = 287 $m^3 s^{-1}$) represents one of few mid-sized coastal rivers in Finland having no artificial flow regulation and largely free from industrial and domestic inputs. One third of the peatland in its catchment (3 845 km^2) has been drained for forestry since the 1970's (Heikkinen 1990b), and peat mining areas accounted for 0.6 % of the land area during this study. About half of these areas were situated in the catchment of the Nuorittajoki tributary (1 046 km^2, MQ = 14 $m^3 s^{-1}$, MHQ = 197 $m^3 s^{-1}$). There the respective percentage accounted for approximately 1.2 % of the land area.

The Iijoki and Kemijoki rivers are large systems harnessed for hydropower production. The Iijoki River (MQ = 174 $m^3 s^{-1}$, MHQ = 907 $m^3 s^{-1}$) and its tributaries drain 14 385 km^2. The Siuruanjoki River (MQ = 34 $m^3 s^{-1}$, MHQ = 378 $m^3 s^{-1}$) is one of the major tributaries (Fig. 1). Its catchment (2 410 km^2) has been efficiently drained for forestry and peat mining during the last decades. The percentage of peat mining areas accounted for approximately 1.5 % of the land area during this study.

The Kemijoki River has a watershed area of 51 000 km^2 (MQ = 556 $m^3 s^{-1}$, MHQ = 3 370 $m^3 s^{-1}$). The first dam was constructed at Isohaara, 3 km from the river mouth, in 1949. Subsequently, four hydropower dams have been completed in the 100-km-long downstream reach of the main stem and twelve dams in the upper reaches. Access to the potential production areas in this large northern river system requires at least one, ideally four additional fishways.

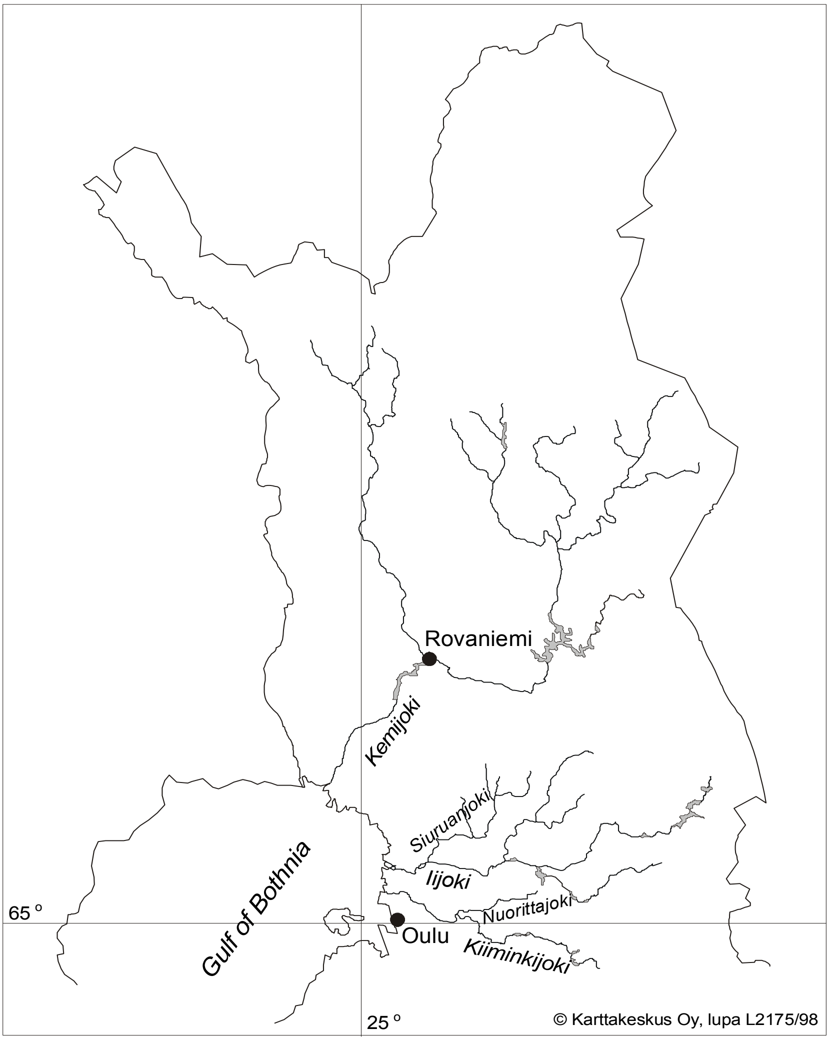

Fig. 1. The study area.

2.2 The fish species studied

Salmon (*Salmo salar L.*), sea trout (*S. trutta* m. *trutta* L.) and brown trout (*S. trutta* m. *lacustris* L.) are the primary species considered in this thesis (I, II, IV, V) although paper I includes two other species, anadromous whitefish (*Coregonus lavaretus* L.) and European river lamprey (*Lampetra fluviatilis* L.).

In the Kemijoki River, salmon returning from the feeding migration at sea have initially been raised in hatcheries receiving river water from upstream the Isohaara dam and have been stocked as smolts at the river mouth or the nearby sea. Sea trout are stocked in the same areas annually, but in addition, large numbers of brown trout migrate from the river (Vehanen 1997). This results in the number of ‘sea trout’ recorded in the fishway consisting of an undefined proportion of brown trout.

The incubation success in riffles affected by peatland drainage was studied using brown trout eggs (IV). The results may be applicable to sea trout and salmon although different salmonid species probably tolerate different levels of fine sediment, depending on inherited adaptations to substrate conditions (Tappel & Bjornn 1983). Yearling salmon parr, which were stocked in the riffles of the Nuorittajoki River in early summer, were captured by electrofishing in late summer for investigation into growth and diet with respect to peatland drainage (V). Natural salmon production was nil in the Nuorittajoki River and negligible in the Kiiminkijoki River during the study.

2.3 Field methods and laboratory measurements

2.3.1 Fish passage

The efficiency of a combined Denil and vertical slot fishway for passing various species and sizes of fish under differing water levels and flow conditions was studied at the Isohaara dam, 3 km from the mouth of the Kemijoki River, during 1993-1999. The attraction of the original discharge of the fishway, 0.5 ± 0.1 m^3 s^{-1}, was improved by an auxiliary flow of 0.4 m^3 s^{-1}, produced by a pump at the southern entrance (I). The fishway discharge was increased by an additional 0.2 - 0.3 m^3 s^{-1} and the vertical slots were widened during the fourth year of fishway operation, in 1996 (II). In the late summer of 1997, the Denil-chute of the northern entrance was removed and replaced by a pool forming a small waterfall at the entrance, to stimulate the ascent of MSW salmon.

The yearly numbers of passed salmon and sea trout were compared with the respective catches at sea and on the Finnish coast (I), and with the catch per unit effort by seine and by nets in the river (II). A stepwise multiple regression was used to test the combined effect of river discharge, water temperature and water level variables at the dam on the numbers of salmon and trout passed on the exact day of ascent (I, II). The analyses were restricted to the main period of upstream migration for salmon and sea trout in the Isohaara fishway. Additionally, an autocorrelation analysis was used for studying the effect of consecutive days on the environmental variables, on the number of fish caught outside the river mouth and on the number of fish passed in the fishway in more detail in 1998 (II). For these data, the relationships between the environmental variables and the catch outside the river mouth or the number of fish passed in the fishway were identified by using cross correlation analysis designed for time series (Systat 1992). The delay between arriving at the river mouth from their feeding migration and entering the fishway was evaluated for salmon in 1998.

2.3.2 Riffle bed quality

The effects of peatland drainage on riffle bed quality were assessed in the tributaries of the Siuruanjoki River by sampling particulate matter from the bottom using a hand-operated bilge pump (III). In each sampling area, the coverage of the moss *Fontinalis* sp. was assessed and current velocities and the roughness of the riffle bottom were measured (Statzner *et al*. 1988). To describe the ability of the water to move particles, stream power per unit channel area was calculated. Physical characteristics close to the riffle bottom were described in terms of the boundary Reynolds number (Statzner *et al*. 1988, see III).

The samples were washed through a set of sieves and the fractions were diluted and filtered through fibreglass filters (III). For the finest fraction, water having passed through the sieves was used. Dry weights and ash-free dry weights of the retained fractions were measured before and after combustion. The results for the two finest size categories, 0.25 - 0.075 mm, and <0.075 mm, of particulate organic matter were emphasised, as most particles in the runoff water from peat mining are organic (Ihme *et al*. 1991) and have a diameter less than 0.25 mm (Ihme 1994). The Fe content of the smallest size category was determined by a photometric method (National Board of Waters 1981). Repeated measures Anova was used in assessing the temporal variation in fine-grained particulate organic matter and in the environmental variables monitored, and multiple regression was used to find the environmental variables that would best predict the amount of fine-grained particulate organic matter on the riffle beds (III).

2.3.3 Early life stages

The incubation success of brown trout eggs was studied in riffles of the Nuorittajoki, Siuruanjoki and Kiiminkijoki rivers, both upstream and downstream of peatland drainage areas (IV). Eggs were delivered to the incubation sites in late September and placed into perforated boxes together with gravel. The sets of boxes were buried into the riffle bed and covered with gravel and stones from the site. The incubation success was controlled in late February, for eyed-eggs, and prior to spring flood in late April, during hatching. The remaining sets were removed in late May - early June. The incubation period was thus divided into three successive phases. The survival at the end of each phase was expressed with the ratio of living eggs and/or alevins to the number of eggs implanted. Water quality was analysed from monthly samples taken from the stream.

To determine the effects of peatland drainage on the diet and growth of salmonid juveniles in the Nuorittajoki River, yearling salmon parr, stocked in May/June, were captured by electrofishing in late July - early August (V). Fish densities (Zippin 1958) and recapture rates were estimated for each riffle. The null hypothesis of no difference in the length, weight and condition of yearling salmon between the reference and affected riffles was tested with univariate analysis of variance. The strengths of the associations among fish lengths, weights and condition coefficients, fish densities and environmental variables were measured using Spearman correlation. The relative importance of various food items in the diet of the affected and the reference salmon was assessed by the IRI index (Prince 1975, Hyslop 1980), and Levins' index (Hurlbert 1978, Wootton 1990) was used to estimate the niche width at each riffle.

2.4 Loading estimates

The total annual particulate matter loadings (tn a^{-1}) were estimated for the peat mining areas in the catchment upstream of the study riffles using the material transport rates monitored for representative areas in the same region by the water authorities (III, IV, V). The loading from peat mining areas is relatively constant during the years of active mining, whereas that from forest drainage areas decreases significantly already within the first year after constructing drainage ditches (Heikurainen *et al*. 1978, Ahtiainen 1992), resulting in different loading values depending on the age of the drained area. The particulate matter loadings from the forest drainage areas were assessed using the transport values reported by Ahtiainen (1992) for respective areas in Finland (III, IV, V). In paper III, the loadings were calculated for areas drained within five years preceding sampling but, based on the actual measurements on the amount of fine-grained particulate matter on riffle beds, they seemed to be highly overestimated. Therefore, in papers IV and V only the areas with a maximum age of two years from the construction of ditches were included, the loading on the second year from ditching being approximately half of that of the first year (Ahtiainen 1992).

Relative loading values were calculated for each riffle studied by dividing the average annual loading by the mean flow of the respective riffle (IV, V) and also by dividing the value of relative loading by the mean upstream distance to the peat mining areas (V).

3 Results and discussion

3.1 Access to spawning grounds

Dams sometimes impede or delay upstream migrations of salmonids even after being fitted with fishways (Grande 1990, Arnekleiv & Kraabøl 1996, Chanseau & Larinier 1999). This is attributed to various factors including unsuitable entrance locations, improper hydraulic conditions and poor fishway maintenance. The sufficiency of water flow in the river stretch downstream of the fishway may also act as an impediment especially when fishways are located further away from the main flow, e.g. at regulating dams.

3.1.1 The attraction of fish entrance

In connection with a hydropower plant, the optimal location for the entrance is close to the turbine draught tubes because the fish are generally attracted to the relatively high discharge from the turbines (Jens *et al*. 1981, Gowans *et al*. 1999). The location is not always responsible for the poor efficiency of a fish entrance, since only a small proportion of fish actually monitored near the entrance may finally enter the fishway (Johlander 1999, Chanseau & Larinier 1999, I). Salmon have also been noticed to swim back and forth within the collection channels that lead into fishways, sometimes descending back into the tailrace (Williams 1998). Similar behaviour has been observed at fish entrances (Laine 1990, Gowans *et al*. 1999, I). The reluctance to enter may result from improper hydraulic conditions or, in certain cases, from a temperature difference between the turbine flow and the fishway flow (Banks 1969). Also the motivation of fish may sometimes be involved (Johnsen *et al*. 1998, I).

A number of 1SW salmon and sea trout passed through the Isohaara fishway during the first years of its operation. There was no difference in the extent to which the fish used the two alternative entrances (Laine *et al*. 1995). The number of MSW salmon was negligible, revealing the inefficiency of the fish entrances to attract these large-sized fish (I). A fairly high discharge is required for attracting large migratory fish such as salmon into a vertical slot fishway (Larinier 1998). At Isohaara, the maximum fishway discharge was only 0.2 % of the mean river flow. Most salmon passed through the fishway when the headwater level, and thus the fishway discharge, was high. Fish entrance attraction also seemed to increase with decreasing tailwater levels as a result of higher water velocities at the entrance (I). Entrance velocities of 1.0 - 2.4 m s^{-1} are recommended for anadromous fish (Clay 1995) and the maximum water velocities at the southern, vertical slot entrance of the Isohaara fishway, approximately 1.2 m s^{-1}, might have been too small to induce MSW salmon to enter. Denil fishways, on the other hand, characteristically have the highest velocities close to the surface (Katopodis *et al*. 1997) and backwater effects from high tailwater elevations decrease the velocities and may reduce entrance attraction (Rajaratnam *et al*. 1985, 1986).

After increasing the fishway discharge and replacing the Denil chute of the northern entrance by a pool forming a small waterfall at the entrance in September 1997, the number and size of salmon increased in the fishway. This observed increase coincided with a decrease in salmon catches at the Finnish coast and below the old powerhouse at the Isohaara dam. This suggests improved fish entrance attraction (II). Subsequently, salmon were not observed gathering close to the entrance without entering the fishway, as previously observed (I).

The height of the small waterfall, i.e. the drop, at the northern, modified entrance ranged from 0.05 to 1.0 m in 1998 depending on the hydraulic head, i.e. the difference between the headwater level and the tailwater level at the dam. Maximum water velocities were estimated to be less than 4.4 m s^{-1} for drops lower than 1.0 m, and less than 4.0 m s^{-1} for the more frequent drops of less than 0.8 m (II). No relationship was found between the numbers of 1SW salmon passing through the fishway and the entrance drop in summer, while MSW salmon seemed to prefer smaller drops. In autumn, there was an inverse relationship for 1SW salmon indicating that high velocities could form an obstacle for them during low temperatures (see also Gowans *et al*. 1999). A corresponding inverse relationship was observed also in 1999, when the tailwater level was on average lower than in 1998, a year with high river discharges.

The total number of sea trout was relatively steady in the fishway each year as was its catch in the river downstream of the dam and on the coast. This indicated successful passage through the modified fish entrance under most environmental circumstances encountered, with the possible exception of the highest drops, especially when connected with low water temperatures in autumn (II).

3.1.2 Environmental conditions and the passage of salmon

The first MSW salmon arrived at the mouth of the Kemijoki River in early June and 1SW salmon approximately one month later. One month after the first salmon were caught at the river mouth, the first MSW salmon entered the Isohaara fishway. At that time, water temperature exceeded 16 °C, which was considerably higher than in the much smaller Norwegian rivers Vefsna and Suldalslågen for the first Atlantic salmon ascending the fishways (8 °C and 10 °C, respectively, Johnsen *et al.* 1998). Later in the summer, the daily number of salmon passing through the fishway was correlated with the catch outside the river mouth for a maximum lag of only one day.

Water temperature and river discharge are essential for river migration in anadromous salmonids (Clarke *et al*. 1991, Jonsson 1991, Smith *et al*. 1994, Northcote 1998). Salmon arriving in early summer are likely to experience much higher flow rates combined with much lower water temperatures than those arriving in late summer (Laughton 1991). During high flows, excessive turbulence may disorientate the fish or prevent their approach to fishways (Beach 1984). Furthermore, high water levels during the spill may weaken the efficiency of fishway entrances (Williams 1998). Together these conditions may affect the ability of salmon to progress upstream.

Variations in water temperature, river discharge and headwater level explained the greatest amount of variation in salmon frequencies during the first three years of fishway operation (I). In the remaining years, water level variation at the dam seemed to be important in explaining salmon frequencies whereas river discharge and change in water temperature determined sea trout frequencies (II). After closing the spillway gates, the tailwater level approximates that of seawater, which is affected by the direction and velocity of winds. Onshore winds raise the water level thereby decreasing water velocities downstream of the dam. A high tailwater level may have induced upstream movement of MSW salmon in the river and seemed to be more important for ascent in the Kemijoki River than discharge during the main migration period following the closing of the spillway gates (II).

3.1.3 The passage of fish with a weak swimming ability

The simultaneous passage of a wide variety of fish species and sizes can perhaps best be attained by providing fishways that offer various velocity zones and swimming depths. Natural fishways or nature mimicking channels (see Katopodis 1999) may be best in fulfilling these criteria, but they are not feasible at high dams or at densely constructed areas due to size constraints. In such conditions, pool-type fishways, vertical slot fishways, Denil-fishways, fish locks or fish lifts, recently classified as 'technical fishways' (DVWK 1996), are favoured.

Whitefish were not observed passing through the Isohaara fishway, which was constructed primarily for passing salmon and sea trout (I). Most whitefish enter the Kemijoki River in late autumn, when the water temperature is around 5-6 °C. It is possible that the fishway was hydraulically unsuitable for passing whitefish ascending in low temperatures and close to the time for spawning, when their swimming ability is considerably weaker than in the summer (Beach 1984, Bernatchez & Dodson 1985). During the summer months whitefish were observed in the vicinity of the powerhouses. However, they were not observed passing through the fishway. This may be due to a reluctance to enter or unsuitability of the fishway for them.

European river lampreys, which enter the rivers in late summer and autumn, do not generally use fishways built for anadromous fish. Slot velocities of approximately 1.4 m s^{-1} were critical for their ascent in the Isohaara fishway (I). Bunches of plastic bristles attached to the bottom of the slots to reduce velocities ensured the passage of lamprey through the vertical slot section of the fishway (I). Lamprey were not observed passing through the Denil section in the upper part of the fishway, despite bottom velocities lower than 0.5 m s^{-1}. The reluctance or inability to use the Denils may have been due to the different hydraulic characteristics in comparison to the vertical slot section downstream.

In vertical slot fishways, baffles direct the water jet from the slots towards the centre of the pool where the energy of the jet is dissipated (Rajaratnam *et al*. 1986, Wu *et al*. 1999), whilst the closely spaced baffles of Denil fishways reduce the water velocities by causing part of the flow to turn back on itself (Rajaratnam & Katopodis 1984). A wide variety and size range of freshwater species successfully use Denil fishways, the passage efficiency being affected by the slope, the length and the water velocities of the chutes (Slatick & Basham 1985, Katopodis *et al*. 1991, 1997, Bunt *et al*. 1999). However, at least small fish have been observed to be attracted to the secondary flows around the baffles, which may result in failed ascents in Denil fishways (Larinier & Miralles 1981). Visual reference seems to be an important factor in ascending Denil fishways (Larinier 1990), which might explain the unsuitability of this fishway type for passing lamprey.

As with lampreys, most cyprinids seemed to congregate in the resting pool downstream of the Denil section during the years studied (Laine unpublished). They were observed to pass through the Denil chutes in great numbers only when the fishway discharge was at its minimum during the removal of fish from the gathering pool in the upstream part of the fishway. Under these circumstances, the Denil section seemed to operate as a very small, pool-type fish pass temporarily suitable for passing small-sized, freshwater fish (see also Larinier 1998). Correspondingly, whitefish have been observed to ascend successfully in a combined Denil and pool-type fishway in Sweden after diminishing the discharge from that necessary for passing sea trout (Nilsson & Karlström 1999), which potentially indicates their different requirements for flow.

3.1.4 The site of release - an underlying factor

Wild and stocked fish can have different patterns and success in river migration (Jonsson *et al*. 1990, McKinnell *et al.* 1994, Økland *et al.* 1995), which may be reflected in their motivation and chances of entering the fishway. In the Kemijoki River, all salmon are raised in the river water but stocked as smolts at the river mouth and at sea. This should be taken into consideration when assessing the fishway efficiency, i.e. the number of salmon ascending and the delay in entering the fishway (II). There is evidence that hatchery-reared Atlantic salmon return to the area of release at sea when mature (Sutterlin *et al.* 1982, Gunnerød *et al.* 1988) and spend a significantly longer time at sea before entering the river than wild salmon during the same migration period (Jonsson *et al.* 1990, Heggberget *et al.* 1993). Their motivation for migrating up river may also be weak as speculated by Johnsen *et al*. (1998) based on observations at the Sandsfossen waterfall in the Suldalslågen River, Norway.

Sea trout seemed to have no particular difficulty in locating and ascending the fishway. Unlike salmon, they started to ascend in the fishway soon after the spillway flow releases. Also, the ratio between sea trout and salmon was significantly higher in the fishway as compared to the catches in the river downstream of the dam and to catches at the coast.

This can at least partly be explained by the proportion of brown trout which originate from river stockings and have the urge to migrate upstream (II).

3.2 Effects of peatland drainage on salmonid production

3.2.1 Changes in the riffle bed quality

Particulate matter deposition was found to occur in riffles affected by peat mining in the tributaries of the Siuruanjoki River (III). The amount of fine-grained organic matter increased significantly with increasing loading from peat mining areas upstream during the frost-free period following the spring flood. Fe was shown to be attached to the finest particles on the riffle beds (diameter < 0.075 mm), and its amount increased with the organic dry weight of this fraction (III). This indicates that the fraction may at least partly originate from precipitation of the Fe-rich high apparent molecular weight fraction of dissolved organic matter in the humic rivers studied (see Heikkinen 1990b).

The effect of particulate matter from peat mining areas on riffle substrate quality seemed to be much more intense than that of respective loading from forest ditching areas, which are generally concentrated on much drier and thinner mires (III). The particulate matter originating from drained peatlands is mainly organic (Ihme *et al*. 1991), whereas the proportion of inorganic material increases on drier soil types. Fine sediment potentially has the same biological effect in streams no matter of its origin (Lloyd *et al*. 1987) but the severity of its effect depends on its concentration, particle size and shape, which in turn are related to sediment source (Hicks *et al*. 1991, Lake & Hinch 1999).

3.2.2 Incubation success

In the boreal humic rivers studied, only 0.2 - 9.1 % of brown trout eggs produced alevins that were still alive at the end of the incubation period, depending on location. The overall incubation success was extremely low. Yet, significant differences were observed between the riffles, the percentage of living alevins being lower in the riffles affected by peatland drainage (IV) and thus susceptible to increased deposition and retention of land-derived fine-grained particulate matter (Sallantaus 1988, Heikkinen 1990a,b,c, Ahtiainen 1992, III).

The existing concentration of interstitial oxygen is regarded as one of the main factors influencing the survival of salmonid eggs to hatching (Chapman 1988, Rubin & Glimsäter 1996). A concentration of 10 mg l^{-1} has been reported in Sweden to be the limit below which hypoxia causes the death of sea trout alevins prior to emergence (Rubin & Glimsäter 1996). In the Nuorittajoki River, where the percentages of living alevins were the lowest of the rivers studied, the respective concentrations were below 10 mg l^{-1} in the river water (mean monthly saturation 62-76 %) during several winter and spring months (IV). An increased deposition of particulate matter on river beds decreases the permeability of the gravel and reduces the water exchange and thus the oxygen concentrations inside the gravel as shown by Bjornn and Reiser (1991) and Pauwels and Haines (1994). Also, decomposition of organic particulate matter probably consumes oxygen and therefore decreases the oxygen concentrations in the gravel (Bjornn & Reiser 1991, Hicks *et al*. 1991). Its proportion is particularly high in particulate matter originating from drained peatlands, especially peat mining areas (Ihme *et al*. 1991).

Sufficient oxygen concentration inside the gravel is only one of several factors that can determine whether successful embryonic and larval development takes place in gravel spawners (Zeh & Dönni 1994). The pH values, for example, reached a minimum of 5.3 at several sites during the spring flood. This is above the treshold for direct mortalities of salmon and trout alevins, which lie between pH levels of 5.0 and 4.5 (Alabaster & Lloyd 1980, Peterson & Martin-Robichaud 1986). Yet, the effects of acidity depend on the other chemical characteristics of the water (Vuorinen *et al*. 1998). In the rivers studied, the survival of brown trout at the eyed-egg stage decreased with increasing Fe loading from peat mining areas and at the pre-emergence stage with increasing Fe loading from forest drainage areas (IV). The survival of alevins also decreased with increasing Fe concentration in the river water. The most intensive decrease in survival, from an average of 70 % to 3 %, was observed between late February and late May – early June, a time period showing the highest Fe concentrations in the river water. Thus, the role of Fe seems to be essential in the humic rivers studied. Fe-organic compounds may be especially harmful on the incubation success of salmonid embryos because they are susceptible to precipitation and sedimentation (Kuntze 1982) and may be particularly effective in decreasing the permeability of the gravel (see also III).

3.2.3 Foraging and growth

The increased levels of fine-grained particulate matter were suspected to be the main reason for the smaller size, the lower condition coefficient and the emptier stomachs of the salmon caught from the affected riffles in the Nuorittajoki River (V). Fine sediment that settles in streams or moves in suspension can reduce salmonid viability (Hicks *et al*. 1991) but determination of the effects that deposited fine sediments have on salmonids is complicated by the variability in responses among salmonid species and by the adaptability of salmonids to ambient sediment levels (Everest *et al*. 1987). Fish may also avoid high concentrations of suspended sediments (Bisson & Bilby 1982, Sigler *et al*. 1984), which might be connected to the smaller recapture rates of stocked yearling salmon in the affected riffles of this study (V).

The basic prey composition of yearling salmon was similar at both the reference riffles and the affected riffles (V). Trichopteran larvae were ranked as the most important food items in both types of riffle. No difference was found in the sequence and relative importance of the next important food categories. Niche width was also similar in both riffle types indicating no change in the extent to which yearling salmon utilise the niche dimension between these riffles. The proportion of large-sized trichopteran larvae, *Rhyacophila* and *Hydropsyche*, of the total stomach volume of yearling salmon was, however, lower in the affected riffles when compared to the reference riffles. This was contradictory to the observed densities of these larvae with respect to peat mining in the same region (Karvonen 1995).

The results of this study together with observations on the occurrence and abundance of benthic macroinvertebrates (Karvonen 1995) do not suggest major changes in the composition or reductions in the abundance of benthic invertebrates downstream of peatland drainage areas in the originally humic River Nuorittajoki. The smaller size, the lower condition coefficient and the emptier stomachs of affected salmon are thus more probably connected to a reduced ability to feed (see Sigler *et al*. 1984, Rowe & Dean 1998) or to increased stress along with habitat degradation, which is finally seen in decreased growth (see Alabaster & Lloyd 1980, McCormick *et al*. 1998).

4 Restoring the reproductive cycle - problems and solutions

Access to spawning grounds is most critical in the reproductive cycle of anadromous salmonids in regulated streams. A migration corridor can be opened by constructing fishways at obstructions provided that a sufficient amount of potential production areas exist upstream. The efficiency of a fishway for passing migrating fish depends on several factors including the location and attraction of the entrance and the hydraulic conditions inside the fishway. At a basic level, it has been stated that fishway dimensioning should cater to the demands of the weakest species or the developmental stages that might use the fishway (DVWK 1996). However, it looks unlikely that a fishway which enables the passage of such species or developmental stages would effectively attract large anadromous salmonids to enter (I, II). Even now, economic considerations often set the limits in terms of structure and dimension of the passage facility, resulting in as small dimensions and discharges as possible, which may result in poor efficiency of the facility at least for the largest individuals (I).

The location of entrances need to be optimally set so that fish can readily find them. It is desirable that the entrance is placed at the farthest upstream point which the fish can reach, and its perceptibility should be secured by providing a high velocity barrier immediately upstream (Andrew & Geen 1960). In connection to a hydropower plant, the most optimal site is close to the turbine draught tubes (Jens *et al*. 1981). In addition to the location, special attention has to be paid to the attractiveness of the entrance (II). This requires knowing which species and developmental stages will be involved and what is their swimming ability. A fairly high discharge is required for attracting large anadromous salmonids (Larinier 1998). Additionally, reactions to water velocity appear dominant in the behaviour of upstream migrating fish because attempts to use light, sound, air bubbles or other means to influence fish movement or improve fish passage have been mostly unsuccessful (Williams 1998). The size of opening at the entrance has to be selected so that it is as large as economically and practically feasible to supply with water to meet the desired velocity condition (Clay 1995). A water velocity of 1.2 m s^{-1} is considered minimal for the entrance (Andrew & Geen 1960). Vertical slot and Denil entrances may be problematic in this respect because backwater effects from high tailwater elevations decrease velocities and therefore reduce entrance attraction considerably (Rajaratnam *et al*. 1985, 1986, I, II).

The efficiency of a combined Denil and vertical slot fishway for passing MSW salmon was improved at the Isohaara dam, northern Finland, by replacing one of the entrances by a pool forming a small waterfall at the entrance (II). In low temperatures and low tailwater levels, however, high water velocities at the entrance formed an obstacle for at least some of 1SW salmon and sea trout (see also Gowans *et al*. 1999), the maximum swimming speed being inversely proportional to temperature, fish length and the maturity stage (Wardle 1980, Beach 1984, Bernatchez & Dodson 1985, Katopodis 1994, 1999). The Denil section of the fishway proved to be unsuitable for most small freshwater fish, river lamprey and most likely for whitefish.

In fishway design, the migratory behaviour and the demands of the specific species of interest need to be considered. In 'technical' fishways (see DVWK 1996), reconciling the needs of fish species with a differing swimming ability may in some cases succeed by modifying the hydraulic conditions of the swimming routes (Nilsson & Karlström 1999, II). This requires, however, that the periods of active migration do not overlap. In rivers with multi-species migrants, more than one type of fishway structure may be required for the most efficient passage of a wide variety of species (Banks 1969, Schwalme *et al*. 1985, Williams 1998, I, II). For anadromous species, priority should be given to the attractiveness of the fish entrance while for species with a weaker swimming ability, hydraulic comfort within the fishway may be of greater importance (Larinier 1998, I, II). Unsuitable fishway entrance locations, poor attraction at the entrance or unsuitable hydraulic conditions within the pass may result in delays at obstructions. The cumulative delay of fish associated with passage by a number of dams may then result in a decrease in energy stores which might ultimately lead towards decreased spawning success as speculated by Williams (1998).

Even when there is a migration corridor that can be effectively utilised, the availability and the quality of spawning and rearing habitats still has a major effect on the number and quality of smolts produced. Large annual spawning populations probably help maintain high-quality spawning habitats because fine sediments and organic materials that have been deposited into the gravel tend to be washed downstream during redd construction and spawning (Chapman 1988, Bjornn & Reiser 1991, Weaver & Fraley 1993). When spawning populations decrease, the overall quality of spawning habitats most likely declines (Everest *et al*. 1987). This needs to be taken into account when re-establishing spawning runs into rivers or river stretches that have been unused for a considerable period of time. The situation is more challenging if the catchment has human impacts resulting for example in increased levels of fine-grained particulate matter (III).

In this study, the salmon affected by fine-grained particulate matter from peatland drainage areas were smaller and thinner by the end of the summer following stocking and had a significantly smaller proportion of full stomachs than did the salmon caught from the reference riffles (V). Also the incubation success was lower in the affected riffles (IV). Thus it seems probable that the increased transport and deposition of fine-grained particulate matter at the riffle bed would eventually affect the number and quality of smolts produced, naturally depending on the amount of loading. The mechanisms involved include changes both in the water quality and in the riffle bed quality, which affect the incubation success of salmonid embryos and the survival, foraging and growth of juveniles in the recipient riffles. In addition to increased levels of fine-grained particulate matter, the increase in the Fe content of high molecular weight dissolved organic matter transported to rivers, followed by its precipitation and sedimentation on the river bed, was proposed to be involved (III, IV). Therefore, it is most important to direct attention at the retention of Fe from peatland drainage waters and implement measures that would enhance the success of natural spawning for salmonids and help ensure environmental quality.

There are also other aspects in the reproductive cycle of salmonids that need to be considered in rehabilitation projects of regulated rivers. Although upstream passage can be more or less solved and the demands of salmonids for water and riffle bed quality satisfied, the safe passage of smolts through impoundments and dams can still be problematic. Combined with the effective fishing on the feeding grounds and on the spawning runs, this may result in few if any fish returning to the spawning sites. The timing of the smolt run can be used in giving directions for operating the flow of water to the power plant so that turbine-induced mortality can be minimized (Hesthagen & Garnås 1986, Montén 1985) but there may be a great need also for fisheries regulation and supportive stocking upstream of the obstructions to actually sustain the spawning run at a reasonable level. Special attention should be paid to the safe passage of the largest salmon which, by entering the rivers early in the summer, are most vulnerable to fishing due to the delays caused by high water levels and excessive turbulence combined with low water temperatures (II).

References

Ahtiainen M (1992) The effects of forest clear-cutting and scarification on the water quality of small brooks. Hydrobiol 243/244: 465-473.

Alabaster JS & Lloyd RL (1980) Water quality criteria for freshwater fish. Butterworths, University Press, Cambridge.

Andrew FJ & Geen GH (1960) Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Int Pac Salmon Fish Comm, Bull 11: 1-259.

Arnekleiv JV & Kraabøl M (1996) Migratory behaviour of adult fast-growing brown trout (*Salmo trutta* L.) in relation to water flow in a regulated Norwegian river. Regul Rivers Res Man 12: 39-49.

Argent DG & Flebbe PA (1999) Fine sediment effects on brook trout eggs in laboratory streams. Fish Res 39: 253-262.

Avery EL (1996) Evaluations of sediment traps and artificial gravel riffles constructed to improve reproduction of trout in three Wisconsin streams. N-Am J Fish Man 16: 282-293.

Banks JW (1969) A review of the literature on the upstream migration of adult salmonids. J Fish Biol 1: 85-136

Beach MH (1984) Fish pass design - criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers. Fish Res Techn Rep 78, 46 p.

Bernatchez L & Dodson JJ (1985) Influence of temperature and current speed on the swimming capacity of lake whitefish (*Coregonus clupeaformis*) and cisco (*C. artedii*). Can J Fish Aquat Sci 42: 1522-1529.

Bisson PA & Bilby RE (1982) Avoidance of suspended sediment by juvenile Coho salmon. N-Am J Fish Man 4: 371-374.

Bjornn, TC & Reiser DW (1991) Habitat requirements of salmonids in streams. Am Fish Soc Spec Publ 19: 83-138.

Bond CE (1979) Biology of fishes. Saunders College Publishing, Philadelphia.

Bunt CM, Katopodis C & McKinley RS (1999) Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. N-Am J Fish Man 19: 793-803.

Chanseau M & Larinier M (1999) The behaviour of returning adult Atlantic salmon (*Salmo salar* L.) in the vicinity of Baigts hydroelectric power plant on the Pau River as determined by radiotelemetry. Bull Franc Peche Piscicult 353/354: 239-262.

Chapman DW (1988) Critical review of variables used to define effects of fines in redds of large salmonids. Trans Am Fish Soc 117: 1-21.

Clarke D, Purvis WK & Mee D (1991) Use of telemetric tracking to examine environmental influences on catch effort indices. A case study of Atlantic salmon in the River Tywi, South Wales. In: Cowx IG (ed.) Catch effort sampling strategies, their application in freshwater fisheries management, Oxford; Fishing News Books, Blackwell Science, p 33-48.

Clay CH (1995) Design of fishways and other fish facilities. 2nd ed. Lewis Publishers, CRC Press, Inc, Boca Raton, Florida.

Coble DW (1961) Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans Am Fish Soc 90: 469-474.

DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau) (1996) Fischaufstiegsanlagen – Bemessung, Gestaltung, Funktionskontrolle. Merkblätter zur Wasserwirtschaft 232.

Eaglin GS & Hubert WA (1993) Effects of logging and roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. N-Am J Fish Man 13: 844-846.

Eklöv AG, Greenberg LA, Brönmark C, Larsson P & Berglund O (1999) Influence of water quality, habitat and species richness on brown trout populations. J Fish Biol 54: 33-43.

Elliott SR, Coe TA, Helfield JM & Naiman RJ (1998) Spatial variation in environmental characteristics of Atlantic salmon (*Salmo salar*) rivers. Can J Fish Aquat Sci 55 Suppl 1: 267-280.

Everest FH, Beschta RL, Scrivener JC, Koski KV, Sedell JR & Cederholm CJ (1987) Fine sediment and salmonid production - a paradox. In: Salo E & Cundy T (eds) Streamside management and forestry and fishery interactions. University of Washington, College of Forest Resources, Contribution 57, Seattle, p 89-142.

Gowans ARD, Armstrong JD & Priede IG (1999) Movements of adult Atlantic salmon in relation to hydroelectric dam and fish ladder. J Fish Biol 54: 713-726.

Grande R (1990) Fish ladders in Norway. Proceedings of the International Symposium on Fishways '90 in Gifu Japan, October 8-10, 1990, p 517-522.

Gunnerød TB, Hvidsten NA & Heggberget TG (1988) Open sea releases of Atlantic salmon smolts, *Salmo salar*, in Central Norway, 1973-83. Can J Fish Aquat Sci 45: 1340-1345.

Heggberget TG, Økland F & Ugedal O (1993) Distribution and migratory behaviour of adult wild and farmed Atlantic salmon (*Salmo salar*) during return migration. Aquaculture 118: 73-83

Heikkinen K (1990a) Nature of dissolved organic matter in the drainage basin of a boreal humic river in Northern Finland. J Env Qual 19: 649-657.

Heikkinen K (1990b) Seasonal changes in iron transport and nature of dissolved organic matter in a humic river in northern Finland. Earth Surface Processes and Landforms 15: 583-596.

Heikkinen K (1990c) Transport of organic and inorganic matter in river, brook and peat mining water in the drainage basin of the River Kiiminkijoki. Aqua Fennica 20: 143-155.

Heikurainen L, Kenttämies K & Laine J (1978) The environmental effects of forest drainage. Suo 29: 49-58.

Hesthagen T & Garnås E (1986) Migration of Atlantic salmon smolts in River Orkla of central Norway in relation to management of a hydroelectric station. N-Am J Fish Man 6: 376-382.

Hicks BJ, Hall JD, Bisson PA & Sedell JR (1991) Responses of salmonids to habitat changes. Am Fish Soc Spec Publ 19: 483-518.

Hurlbert SH (1978) The measurement of niche overlap and some relatives. Ecology 59: 67-77.

Hyslop EJ (1980) Stomach content analysis - a review of methods and their application. J Fish Biol 17: 411-429.

Ihme R (1994) Use of overland flow wetland treatment system for the purification of runoff water from peat mining areas (in Finnish with English summary). VTT Publications 798, Espoo, 140 p.

Ihme R, Heikkinen K & Lakso E (1991) Peat filtration, field ditches and sedimentation basins for the purification of runoff water from peat mining areas. Publications of the Water and Environment Research Institute 9, National Board of Waters and the Environment, Finland, p 25-48.

Jens G, Butscheck V, Köthke H, Kriegsmann F & Schiemenz F (1981) Funktion, Bau und Betrieb von Fischpässen. Richtlinien für die Anlegung von Fischtreppen an Stauanlagen. Arbeiten des Deutschen Fischerei-Verbandes, Heft 32, 27 p.

Jensen AJ & Aass P (1995) Migration of a fast-growing population of brown trout (*Salmo trutta* L.) through a fish ladder in relation to water flow and water temperature. Regulated Rivers: Research & Management 10: 217-228.

Johlander A (1999) Counting Atlantic salmon and sea trout in fishways in Southern Sweden – results and observations. In: Kamula R & Laine A (eds) Proceedings of the Nordic Conference on Fish Passage, 9-11 Sept. 1998, Oslo, Norway. DN-notat 1999-1. Trondheim, p 98-104.

Johnsen BO, Jensen AJ, Økland F, Lamberg A & Thorstad EB (1998) The use of radiotelemetry for identifying migratory behaviour in wild and farmed Atlantic salmon ascending the Suldalslågen River in Southern Norway. In: Jungwirth M, Schmutz S & Weiss S (eds) Fish Migration and Fish Bypasses. Fishing News Book, University Press, Cambridge, p 55-68.

Jonsson B, Jonsson N & Hansen LP (1990) Does juvenile experience affect migration and spawning of adult Atlantic salmon? Behav Ecol Sociobiol 26: 225-230.

Jonsson N (1991) Influence of water flow, water temperature and light on fish migration in rivers. Nordic Journal of Freshwater Research 66: 20-35

Jungwirth M (1998) River continuum and fish migration – going beyond the longitudinal river corridor in understanding ecological integrity. In: Jungwirth M, Schmutz S & Weiss S (eds) Fish Migration and Fish Bypasses. Fishing News Book, University Press, Cambridge, p 19-32.

Karvonen K (1995) The effects of peat mining on fluvial benthic fauna. Licentiate's thesis, University of Oulu, Department of Zoology. In Finnish.

Katopodis C (1990) Advancing the art of engineering fishways for upstream migrants. Proceedings of the International Symposium on Fishways '90, in Gifu, Japan, October 8-10, 1990, p 19-28.

Katopodis C (1994) Analysis of Ichthyomechanical data for fish passage or exclusion system design. Proc Int Fish Physiol Symp Vancouver, Canada, July 16-21 1994, Am Fish Soc & Fish Physiol Assoc, p 318-323.

Katopodis C (1999) Sustaining fish migrations: swimming performance and fish passage/exclusion methods. In: Kamula R & Laine A (eds) Proceedings of the Nordic Conference on Fish Passage, 9-11 Sept. 1998, Oslo, Norway. DN-notat 1999-1. Trondheim, p 23-30.

Katopodis C, Derksen AJ & Christensen BL (1991) Assessment of two Denil fisways for passage of freshwater species. American Fisheries Society Symposium 10: 306-324.

Katopodis C, Rajaratnam N, Wu S & Tovell D (1997) Denil fishways of varying geometry. J Hydr Eng, ASCE 123: 624-631.

Kuntze H (1982) Iron clogging in soils and pipes, analysis and treatment. German Association of Water Resources and Land Improvement, Boston.

L'Abée-Lund JH, Saegrov H & Lura H (1992) Resource partitioning and spatial segregation in native and stocked brown trout, *Salmo trutta* L., and Arctic charr, *Salvelinus alpinus* (L.), in a hydroelectric reservoir. Aquacult Fish Man 23: 623-632.

Laine A (1990) The effects of a fishway model hydraulics on the ascend of vendace, whitefish and brown trout in Inari, Northern Finland. Aqua Fennica 20: 191-198.

Laine A, Kamula R, Viitala J, Pohjamo T & Hooli J (1995) Salmon on the way up. Summary report of the research at the Isohaara fishway in the River Kemijoki, Finland. University of Oulu, Hydraulic and Water Resources Engineering Laboratory, Ser A 63: 1-42. In Finnish with an English abstract.

Lake RG & Hinch SG (1999) Acute effects of suspended sediment angularity on juvenile coho salmon (*Oncorhynchus kisutch*). Can J Fish Aquat Sci 56: 862-867.

Larinier M (1990) Experience in fish passage in France: fish pass design criteria and downstream migration problems. Proc Int Symp Fishways '90 Gifu, Japan, Oct 8-10, 1990: 65-74.

Larinier M (1998) Upstream and downstream fish passage experience in France. In: Jungwirth M, Schmutz S and Weiss S (eds) Fish Migration and Fish Bypasses. Fishing News Book, University Press, Cambridge, p. 127-145.

Larinier M & Miralles A (1981) Caractétistiques hydrauliques des passes á ralentisseurs. CEMAGREF rapport non publié. 52 p.

Laughton R (1991) The movements of adult Atlantic salmon (*Salmo salar* L.) in the River Spey as determined by radio telemetry during 1988 and 1989. Scottish Fisheries Research Report 50, 34 p.

Lloyd DS (1987) Turbidity as a water quality standard for salmonid habitats in Alaska. N-Am J Fish Man 7: 34-45.

Lloyd DS, Koenings JP & LaPerriere JD (1987) Effects of turbidity in fresh waters of Alaska. N-Am J Fish Man 7: 18-33.

McCormick SD, Shrimpton JM, Carey JB, O'Dea MF, Sloan KE, Moriyama S & Björnsson BT (1998) Repeated acute stress reduces growth rate of Atlantic salmon parr and alters plasma levels of growth hormone, insulin-like growth factor I and cortisol. Aquaculture 168: 221-235.

McKinnell S, Lundqvist H & Johansson H (1994) Biological characteristics of the upstream migration of naturally and hatchery-reared Baltic salmon, *Salmo salar* L. Aquacult Fish Man 25: 45-63.

Mills D (1989) Ecology and management of Atlantic salmon. Chapman and Hall, University Press, Cambridge.

Montén E (1985) Fish and turbines. Fish injuries during passage through power station turbines. Vattenfall, Sweden. 111 p.

National Board of Waters (1981) The analytical methods used by National Board of Waters. Rep 213. National Board of Waters, Helsinki, Finland.

Nilsson K-E & Karlström Ö (1999) Whitefish and trout in the same fishway; different flow for different species. In: Kamula R & Laine A (eds) Proceedings of the Nordic Conference on Fish Passage, 9-11 Sept. 1998, Oslo, Norway. DN-notat 1999-1. Trondheim, p 87-93.

Northcote TG (1998) Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In: Jungwirth M, Schmutz S & Weiss S (eds) Fish Migration and Fish Bypasses. Fishing News Book, University Press, Cambridge, p 3-18.

Økland F, Heggberget TG & Jonsson B (1995) Migratory behaviour of wild and farmed Atlantic salmon (*Salmo salar*) during spawning. J Fish Biol 46:1-7.

Olsson T & Näslund I (1985) Effects of mire drainage and peat extraction on benthic invertebrates and fish. Proceedings of the peat and environment 1985. International peat society symposium, 17.-20.9.1985, Jönköping, Sweden. The Swedish National Peat Committee and the International Peat Society, p 147-152.

Olsson TI & Persson B-G (1986) Effects of gravel size and peat material concentrations on embryo survival and alevin emergence of brown trout, *Salmo trutta* L. Hydrobiol 135: 9-14.

Parrish DL, Behnke RJ, Gephard SR, McCormick SD & Reeves GH (1998) Why aren't there more Atlantic salmon (*Salmo salar*)? Can J Fish Aquat Sci 55: 281-287.

Pauwels SJ & Haines TA (1994) Survival, hatching, and emergence success of Atlantic salmon eggs planted in three Maine streams. N-Am J Fish Man 14: 125-130.

Peterson RH & Martin-Robichaud DJ (1986) Growth and major inorganic cation budgets of Atlantic salmon alevins at three ambient acidities. Trans Am Fish Soc 115: 220-226.

Prince ED (1975) Pinnixid crabs in the diet of young-of-the-year copper rockfish (*Sebastes caurinus*). Trans Am Fish Soc 1034: 539-540.

Rabeni CF & Minshall GW (1977) Factors affecting microdistribution of stream benthic insects. Oikos 29: 33-43.

Rajaratnam N & Katopodis C (1984) Hydraulics of Denil fishways. J Hydr Eng, ASCE 110: 1219-1233.

Rajaratnam N, Katopodis C & Van der Vinne G (1985) M1-type backwater curves in Denil fishways. Proc. 7th Canadian Hydrotechnical Conference, Saskatoon, SK. Vol. IB: 141-156

Rajaratnam N, Van der Vinne G & Katopodis C (1986) Hydraulics of vertical slot fishways. J Hydr Eng, ASCE 112: 909-927.

Redding JM, Schreck CB & Everest FH (1987) Physiological effects on coho salmon and steelhead of exposure to suspended solids. Trans Am Fish Soc 116: 737-744.

Rowe DK & Dean TL (1998) Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. New Zealand J Mar Freshw Res 32: 21-29.

Rubin J-F (1998) Survival and emergence pattern of sea trout fry in substrata of different compositions. J Fish Biol 53: 84-92.

Rubin J-F & Glimsäter C (1996) Egg-to-fry survival of the sea trout in some streams of Gotland. J Fish Biol 48: 585-606.

Sallantaus T (1988) Water quality of peatlands and man's influence on it. Keynote speech - Symposium on the Hydrology of Wetlands in Temperate and Cold Regions Vol 2. Joensuu, Finland, 6-8 June 1988. Publications of the Academy of Finland 5: 80-98.

Saltveit SJ (1993) Abundance of juvenile Atlantic salmon and brown trout in relation to stocking and natural reproduction in the River Laerdalselva, western Norway. N-Am J Fish Man 13: 277-283.

Schwalme K, Mackay WC & Lindner D (1985) Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fish. Can J Fish Aquat Sci 42: 1815-1822.

Sigler JW, Bjornn TC & Everest FH (1984) Effects of chronic turbidity of density and growth of steelheads and coho salmon. Trans Am Fish Soc 113: 142-150.

Slatick E & Basham LR (1985) The effect of Denil fishway length on passage of some nonsalmonid fishes. Mar Fish Rev 47: 83-85.

Smith GW, Smith IP and Armstrong SM (1994) The relationship between river flow and entry to the Aberdeenshire Dee by returning adult Atlantic salmon. J Fish Biol 45: 953-960.

Smith RJF (1995) The control of fish migration. Springer Verlag, Berlin.

Solbé J (1988) Water quality. In: Laird L & Needham T (eds) Salmon and trout farming Aquaculture and Fisheries Support. John Wiley & Sons, Chichester, p 69-86.

Statzner B, Gore J & Vincent H (1988) Hydraulic stream ecology: observed patterns and potential applications. J N-Am Benthol Soc 7: 307-360.

Sutterlin AM, Saunders RL, Henderson EB & Harmon PR (1982) The homing of Atlantic salmon (*Salmo salar*) to a marine site. Can Tech Rep Fish Aquat Sci 1058, 6 p.

Swanston DN (1991) Natural processes. Am Fish Soc Spec Publ 19: 139-179.

Systat (1992) Systat for Windows: Statistics. 5th edition. Systat, Evanston, IL.

Tappel PD & Bjornn TC (1983) A new method of relating size of spawning gravel to salmonid embryo survival. N-Am J Fish Man 3: 123-135.

Trépanier S, Rodríguez MA & Magnan P (1996) Spawning migrations in landlocked Atlantic salmon: time series modelling of river discharge and water temperature effects. J Fish Biol 48: 925-936.

Wardle CS (1980) Effects of temperature on the maximum swimming speed of fishes. In: Ali MA (ed.) Environmental physiology of fishes. Plenum Press, New York.

Weaver TM & Fraley JF (1993) A method to measure emergence success of Westslope cutthroat trout fry from varying substrate compositions in a natural stream channel. N-Am J Fish Man 13: 817-822.

Vehanen T (1997) Fish and fisheries in large regulated peaking-power river reservoirs in northern Finland, with special reference to the efficiency of brown trout and rainbow trout stocking. Regulated Rivers Research and Management 13: 1-11.

Williams J (1998) Fish passage in the Columbia River, USA and its tributaries: problems and solutions. In: Jungwirth M, Schmutz S & Weiss S (eds) Fish Migration and Fish Bypasses. Fishing News Book, University Press, Cambridge, p 180-191.

Wootton RJ (1990) Ecology of teleost fishes. Fish and Fisheries Series 1. Chapman & Hall, London.

Wu S, Rajaratnam N & Katopodis C (1999) Structure of flow in vertical slot fishway. J Hydr Eng 125: 351-360.

Vuorinen PJ, Keinänen M, Peuranen S & Tigerstedt C (1998) Effects of iron, aluminium, dissolved humic material and acidity on grayling (*Thymallus thymallus*) in laboratory exposures, and a comparison of sensitivity with brown trout (*Salmo trutta*). Bor Env Res 3: 405-419.

Zeh M & Dönni W (1994) Restoration of spawning grounds for trout and grayling in the River High-Rhine. Aquat Sci 56: 59-69.

Zippin C (1958) The removal method of population estimation. J Wildl Man 22: 83-90.