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Adverse impact of forestry on fish and fisheries in stream environments of the Isojoki basin, western Finland

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The effects of forestry on fish and fisheries were studied in the Isojoki basin, western Finland. The most abundant fish species in the study area, brown trout (*Salmo trutta* L.), was found in 27 of 50 brooks studied. Enzyme electrophoresis revealed at least five genetically differentiated stocks of brown trout in the brooks. Regression analysis indicated that the population density of brown trout was positively dependent on the abundance of pools, stony bottom material (2 to < 10 cm in diameter), undercut banks in the streams, and water pH, while the abundance of ditches in the catchment area and shading by the tree canopy affected the density negatively. Incubation experiments showed that sedimentation with mineral and humus material impaired the survival of trout eggs in the rapids. The results suggest that dredging of brooks and increased soil erosion due to drainage may threaten the reproduction and genetic diversity of trout stocks in the brooks and main river.

Introduction

In the river basins of the Boreal zone, the largest forest areas are mainly located in the upper reaches and watershed divide areas of the catchments. The headwater streams are usually, but not always, the most pristine parts of the river systems. In Finland, for instance, the adoption of efficient practices in forest logging and draining together with the dredging of brooks has accelerated the anthropogenic impact and threats to stream environments since the 1950s.

The alteration of the terrestrial ecosystem is reflected in the productivity and structure of the aquatic ecosystem in many ways (Vannote *et al.* 1980). Forest management measures, e.g. logging and drainage, have caused substantial changes to the water quality and sediment loading of streams and to the spawning and nursery habitats of fish, those of salmonids in particular (Heikurainen *et al.* 1978, Bergquist *et al.* 1984, Everest *et al.* 1987, Simonsson 1987, Ahtiainen 1988). Such impacts affect the primary production and composition of benthic animals (Chutter 1969, Gregory *et al.* 1987, Holopainen and Huttunen 1992, Vuori and Joensuu 1996) but also the food supply, growth, survival and reproduction of anadromous salmonids and other fish in a stream (Condore and Kelley 1961, Cooper 1965, Holtby and Hartman 1982, Bergquist *et al*. 1984, Murphy *et al*. 1986, Wilzbach and Cummins 1986). The construction of forest roads on mountainous slopes has had similar effects (Beschta 1978, Fahey and Coker 1992, Clarke and Scruton 1997). Clear cuttings have led to changes in seasonal and diurnal patterns of water temperatures thus having impacts on the state of the stream-dwelling fish stocks (Brown 1970, Hartman *et al*. 1984, Beschta *et al*. 1987, Holtby 1988). Forest drainage in the catchment may also cause hydrological changes in the stream environment (Heikurainen *et al*. 1978, Seuna 1982, Ahtiainen 1988).

Despite the extent of forestry activities in northern Europe, there has been only a few studies about their effects on fish fauna and fisheries in streams (e.g., Bergquist *et al*. 1984, Simonsson 1987). Most studies have been conducted in North America (e.g., Gibbons and Salo 1973, Meehan *et al*. 1984, Verry 1986, Salo and Cundy 1987), and have limited application to Scandinavian streams owing to the differences in fish species, climate, geomorphology, soil characteristics, harvesting technology and watercourses.

In this study our aim was to identify the critical environmental changes caused by forest management measures affecting fish and fisheries in northern forestal stream environments. We started with the assumption that the main impacts of forestry on fish arise from changes in water quality and in stream habitats. To exclude the impacts of other land use practices, we focused our study mainly on brook environments within a river basin where the proportion of forests is high. Because brown trout (*Salmo trutta* L.) is a typical, and often the only, fish species in such headwater streams we further concentrated our study on the effects of forestry on the brown trout stocks, including the maintenance of their genetic diversity. Finally, we examined the importance of brown trout for local fishing in brooks and in the river system.

This paper reviews the findings of research into the consequences of forestry for fish stocks and fisheries in stream waters. The study was conducted at the Finnish Game and Fisheries Institute as part of the Joint Research Project on the Effects of Forest Management on the Aquatic Environmet and their Abatement (METVE).

Material and methods

Basic characteristics of the Isojoki catchment area

Isojoki flows from its spring-fed headwaters in Lauhanvuori National Park into the southern part of the Gulf of Bothnia, near the town of Kristiinankaupunki (Fig. 1). The catchment area of the Isojoki is 1 112 km^2 and the length of the main river is 75 km. In addition to the main river and its tributaries, there are over 50 brooks in the river basin. The Isojoki catchment area is largely covered by forests and wetlands (over 80%), only 0.4% comprising of lakes. In places there are areas with easily eroding sandy soils. Humic water and low pH values are typical of brooks flowing from bogs and wetlands, the lowest pH values being < 5 in summer. Water is most oligotrophic in the spring-fed brooks near Lauhanvuori National Park.

Forest drainage and dredging have been the most extensive practices of forestry in the Isojoki catchment area. In this study, the total length of forest ditches was measured upstream from the electrofishing sites by means of a map survey covering 40% of the total Isojoki catchment area. The total length of forest ditches was 4 600 km, or on average, 10 km of forest ditch per km^2 of catchment. Quantitative data on the extensive dredgings of brooks were not available. Other forest management practices include clear cutting and soil preparation but exact data on these activities could not be collected. The fertilization of forests in this area has almost stopped.

Construction of the study

Evaluation of forest management activities in the Isojoki river basin was divided into five items (I–V).

I. The fish catches in the Isojoki basin in 1992 and the importance of forest brooks for fisheries were studied by means of a mailed fisheries inquiry.

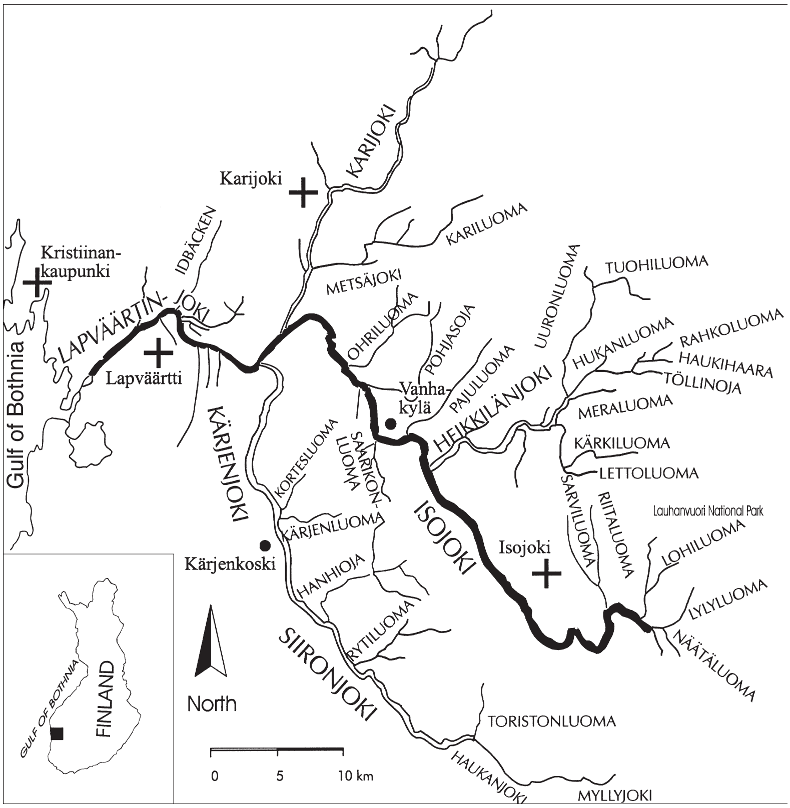

Fig. 1. Location of the Isojoki river basin and the study brooks.

A questionnaire was sent to every other household and owner of a summer cottage in the municipalities of Isojoki and Karijoki. Replies were received from 70.5% of the people contacted. Long-term observations and opinions of local people on changes in the watercourse and fish stocks were gathered at the same time. The results were estimated to the target population according to Cochran (1977).

II. Basic data on the fish fauna and the habitat in the forest brooks were collected by electric fishing and field observations in 1991. Three successive removals were used and the population densities were estimated according to Zippin (1958). This survey was conducted in a total of 50 forest brooks at 90 fishing sites, each of which was 50–100 m long. At each site the following variables were measured in cross-sections every 10 m along the brook channel: mean depth, mean velocity of surface water, distribution of bottom substrate (classified in five categories; 1: sand and finer < 0.2 cm, 2: coarse gravel 0.2–< 2 cm, 3: small stones 2–<10 cm, 4: stones 10–< 30 cm, 5: boulders ≥ 30 cm in diameter; in %), coverage of aquatic vegetation and shading by tree canopy (in %), and abundance of pools, undercut banks and thresholds. The further analysis of data was conducted only for brown trout aged 1 year and older as the catchability of 0+ parr was poor. The variations observed in the population density of brown trout were explained using multivariate regression analysis on the basis of habitat and catchment factors except in the Kärjenjoki tributary, where no trout were found. In order to obtain normally distributed, homoscedastic residuals, the variables were $\log(x)$- or $\arcsin\sqrt{x}$-transformed. The independence of the residuals was ensured with the Durbin-Watson test (Sokal and Rohlf 1981).

III. Because water quality data were available from only a few brooks and the results of the basic fish survey were not suitable for closer evaluation of the effects of environmental factors on 0+ trout parr, 11 brooks were selected for further experimental research. In these brooks, overdense stockings with 6–8 cm-long hatchery reared 0+ trout (2 parr m^{-2}) were made in rapids both in a natural state and affected by dredging and forest drainage. The parr were released in early June (12 rapids in 1992 and 20 rapids in 1993) and the population density of parr was assessed at the end of the growing season, in late August –early September, using electric fishing. Morphometric characteristics similar to those in item (II) were measured. The water quality of the brooks was surveyed from May to October by analysing or measuring water samples taken twice a month for colour, pH, GRAN alkalinity, turbidity, suspended solids, COD, total P, total N and total Fe. The minimum observed values of pH and alkalinity and the maximum values of the other parameters were used in further analyses. The variations in parr population density were analysed on the basis of environmental characters in the stocked brook reaches as in item (II).

IV. Trout egg survival was evaluated through incubation experiments. In autumns 1992 and 1993, newly fertilized eggs of migratory brown trout were scattered together with gravel into plastic perfoliated Vibert boxes, 50 eggs in each. These egg incubation boxes were placed in a total of 11 rapids in the same study brooks as mentioned in item (III), 20 boxes in each rapids. In addition, incubation boxes were placed in the Vanhakylä rapids in the main river. The boxes were placed in rapids on the potential spawning grounds and covered with cobbles to prevent them from being flooded out during autumn and winter flows. As a control in the main river, brown trout eggs were incubated in Vibert boxes in a hatchery located in the same rapids. The hatching success of the eggs was assessed in April–May when the boxes were removed from the rapids.

V. During electric fishing, material was also collected for study of the genetic characteristics of the local populations of brown trout. Samples were taken and analysed from a total of 273 trout from 8 brooks (Idbäcken, Östermyran, Karijoki, Pajuluoma, Hukanluoma, Meraluoma, Riitaluoma and Lohiluoma), and from 180 trout originating from two hatchery stocks (Vanhakylä and Laukaa). Samples were also collected from brooks where only few trout were caught at the electric fishing sites. The brooks in which less than ten trout were collected are not included in this study.The enzyme genetic variation of brown trout populations was examined by electrophoresis (Allendorf *et al*. 1977, Nei 1978, 1987).

Results

Fish catch in stream environment

Fish catch in Isojoki watercourse in the municipalities of Isojoki and Karijoki was estimated to be 5 300 kg in 1992 (Table 1). Brown trout was the most important species in the study area and in brooks almost the only species. The distributions of local brown trout and migratory sea trout overlap, with catches of local brown trout being concentrated in the brooks and those of sea trout in the main river. The grayling (*Thymallus thymallus* (L.)) and the pike (*Esox lucius* L.) were also important species but fishing for them is restricted to the main river and its tributaries.

The most common fishing location was the main river. Brooks were also important for angling with 25% of households fishing in the brooks.

About 40% of the people that responded to the

Table 1. Fish catches (kg) in the Isojoki basin in the municipalities of Isojoki and Karijoki in 1992. Brown trout catch includes both local brown trout and migratory sea trout.

Fish species	Main river	Tributaries	Brooks	Total
Brown trout (*Salmo trutta* L.)	942	414	212	1 570
Grayling (*Thymallus thymallus* (L.))	1 146	353	41	1 540
Pike (*Esox lucius* L.)	1 082	303	82	1 468
Other fish	528	155	1	685
Total (kg)	3 698	1 227	337	5 263
Total (%)	70	23	7	100

fisheries questionnaire had observed changes in the natural state of the river, most noticeably due to sanding of brook channels and increases in flow fluctuations in tributaries and brooks (Fig. 2). Fourty per cent of the people had noticed changes, most of them negative, in the abundance of fish in the watercourse. The changes were attributed, first, to forest and wetland ditching and, second, to brook dredging.

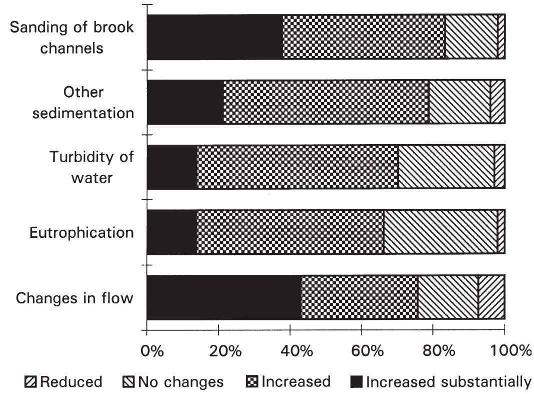

Fig. 2. Results from the fisheries questionnaire about observed changes in the brooks of the Isojoki river basin.

Effect of habitat characteristics on the population densities of ≥ 1-year-old brown trout

A significant regression model ($p < 0.01$) was obtained on the basis of the basic fish survey. The independent variables explained 43% of the variation in the population densities of one year and older brown trout. The most significant single variables were the abundance of pools, the pH value of water, the abundance of undercut banks and (with a negative influence) the abundance of forest ditches upstream of the catchment area (Table 2).

The population densities of brown trout in dredged brooks were compared with those in natural brooks. The mean population density at dredged sites was 4.7 trout 100 m^{-2} (range 0–35), and at natural sites 11.0 m^{-2} (range 0–56). The log-transformed means differed significantly from each other ($p = 0.03$).

Effect of habitat characteristics on the population densities of 0+ brown trout parr

The regression model for the population density of 0+ trout parr was also significant ($p < 0.001$) and the independent variables explained 69% of the variations in the population density. The most significant single variables were the mean water depth (negative influence) and the abundance of pools in the stocked stream reaches. Other independent variables accepted into the model were the abundance of stones with a diameter 2 to <10 cm, the abundance of undercut banks in the brook channel (positive influence) and the percentual shading of the tree canopy above the brook (negative influence) (Table 3).

Survival of brown trout eggs

In the Isojoki basin, the survival rate of brown trout eggs was highest ($\bar{x} = 82\%$) in the Lohiluoma brook, in the groundwater areas of Lauhanvuori National Park and lowest ($\bar{x} = 0\%$) in the extremely sandy brook of Hukanluoma, which flows through readily eroded sandy soils. The mean survival rate of eggs was > 50% in two brooks, 10%–50% in four brooks and <10% in three of the brooks studied.

In the Lylyluoma brook, there were two incubation sites in the same rapids. The mean survival

Table 2. Multivariate regression for the population density (indiv. × 100 m^{-2}) of ≥ 1-year-old brown trout in the Isojoki basin ($N = 58$, $R^2 = 0,425$, $F = 9.795$, $p < 0.01$, $D = 1.946$, $r = 0.001$). Symbols: R^2= regression coefficient, F = F-value, D = Durbin-Watson test value of independence of residual variation, r = autocorrelation, S.E. = standard error, T = test value of single regression factor and p = significance level.

Independent variables	R^2	S.E.	T	p
Constant	–1.371	1.076	–1.274	0.208
Abundance of pools	1.022	0.261	3.919	< 0.001
Water pH	0.444	0.157	2.834	0.006
Abundance of undercut banks	0.594	0.254	2.343	0.023
Abundance of forest ditches	–0.494	0.250	–1.979	0.053

rate of eggs was 77% at the upper site and 57% at the lower site. Immediately upstream of these rapids was a new clear-cut and ditched area with the soil prepared for forest planting. The lower incubation site was characterized by deeper and slower flow and the incubation boxes were filled with humus and mineral material similar to the soil upstream. The incubating boxes in the Vanhakylä rapids in the main river were covered and filled with dark sand and mineral material, and the mean survival rate of eggs was 2%. The survival rate of the eggs in the Vanhakylä hatchery was about 75%.

Population genetics of brown trout in the Isojoki basin

Brown trout were caught in 27 of 50 brooks studied and they are distributed throughout the catchment area excluding the Kärjenjoki tributary. Brown trout was frequently the only species in the brooks, particularly in the upper reaches.

The studied eight brook populations genetically differed significantly ($p < 0.001$) from the cultivated stocks of the Isojoki sea trout. The brown trout from the brooks could be divided into at least five genetically differentiated stocks (Fig. 3). Those in the lowermost reaches, the Pajuluoma brook in the middle reaches and the brooks in the uppermost reaches of the river system form three genetically clearly differentiated stocks. The tributaries Karijoki and Heikkilänjoki, too, each have their own differentiated stocks.

Discussion

Large-scale forest drainage is one of the most extensive forest management practices carried out in this study area as it is in the other coastal river basins of the Gulf of Bothnia. The elevation of the river basin is low, and the brooks have been dredged at the same time as the land has been drained. Both operations have been commonly used to improve forest growth in lowland areas. Even though the dredging of brooks is rarely practised any more, long-term effects on the stream environment are evident. Moreover, as shown by the observations and opinions of local people, the measures have had a very harmful impact on brown trout stocks in the brooks. The bulk of the total fish catch from river systems is normally taken from the main river, but brooks and tributaries are also valuable for fishing activities in a river basin with very few lakes. Due to the lack of earlier catch data from our study area it is not possible to assess the changes caused by forestry. In the opinion of local people, however, the catch level has fallen during the last decades and the effects of forest management measures are thought to be the main reason for the decline, especially in brook waters.

Regression models for 0+ and older trout showed that the population density was best explained by the abundance of pools and undercut banks in the brooks. The abundance of stony benthic material in rapids also had a positive influence on the population density of 0+ parr. Such factors represent the physical diversity of the

Table 3. Multivariate regression analyse for the population density of 0+ brown trout parr (indiv. × 100 m^{-2}) of the stocking experiments (N = 28, R^2 = 0.691, F = 10.269, p < 0.001, D = 2.044, r = –0.104). Symbols: R^2 = regression coefficient, F = F-value, D = Durbin-Watson test value of independence of residual variation, r = autocorrelation, S.E. = standard error, T = test value of single regression factor and p = significance level.

Independent variables	R^2	S.E.	T	p
Constant	2.718	0.365	7.450	< 0.001
Average water depth	–1.354	0.301	–4.491	< 0.001
Abundance of pools	0.673	0.196	3.424	0.002
Stones 2 to < 10 cm in diameter	0.157	0.052	3.036	0.006
Shading percentage of tree canopy	–0.588	0.223	–2.641	0.015
Abundance of undercut banks	0.234	0.117	2.003	0.057

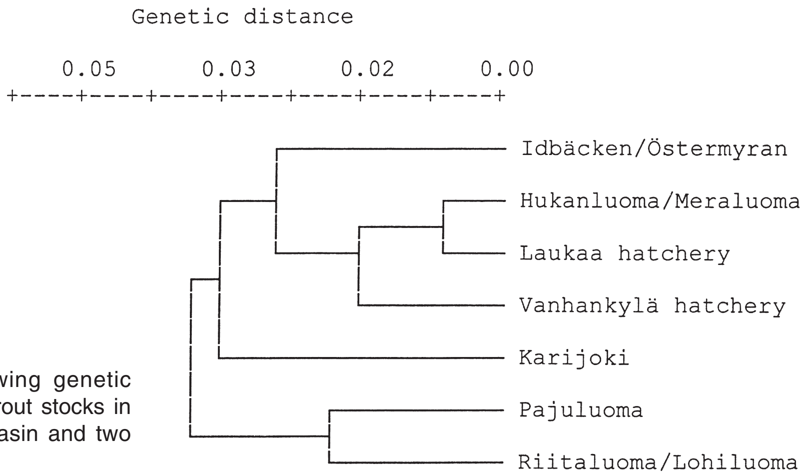

Fig. 3. Dendrogram showing genetic distances between brown trout stocks in the brooks of the Isojoki basin and two hatchery stocks.

brook channel, as suggested by many authors (e.g., Bohlin 1977, Egglishaw and Shackley 1982, Heggenes 1988, Heggenes and Saltveit 1990, Mäki-Petäys *et al*. 1997), and increase the availability of potential habitats for brown trout in streams. The dredging of brooks, however, reduces the abundance of these features in the brook environment. The importance of these factors was demonstrated by the significantly lower population density of trout in dredged brooks than in natural streams. The dredging of brooks appears to be the most important, single forestry practice impairing the physical diversity and production of brown trout in a stream environment. Moreover, the changes are long lasting or permanent; in the Isojoki basin, most of the dredging was carried out 20 to 30 years ago.

Contrary to the common findings that brown trout prefer deep water in the rapids (e.g., Kennedy and Strange 1982, Nielsen 1986, Heggenes 1988), the population density of 0+ parr was correlated negatively with the mean water depth in the rapids studied. This is probably a result of dredging, which has cleared and deepened the middle part of the stream and forced parr to concentrate in shallow shore areas with a coarse bottom substrate. Brown trout parr also tend to avoid the deeper parts of the rapids in bigger rivers, whereas the highest densities of parr have been found in shallow, slowly flowing shore areas covered by stones and boulders (Lindroth 1955, Karlström 1977).

Changes in water quality also influence fish populations in the brooks. The population density of brown trout depended significantly on the pH value of the water. Low pH values are typical of brooks flowing from bogs and swampy areas. According to Lipkin and Setälä (1989), very low pH values have been recorded in ditches draining acidic Littorina soils near the river mouth; moreover, due to nutrient-poor sandy soils the headwaters are also potentially threatened by acidic deposition. Vuori *et al*. (1995) found that 66% of the variations in the mean pH and 58% of the variations in the minimum pH of the brook waters of the Isojoki basin were explained by the percentage of wetlands in the catchment. Acidity acts as a limiting factor, especially in the reproduction phase of fish. It is not possible to determine exact tolerance limits for fish in general or for brown trout in particular, because the effects of acidity depend on the other chemical characteristics of the water (*see* Vuorinen *et al*. 1998), and local fish stocks can, to some extent, adapt to acidic circumstances (e.g., Tuunainen *et al*. 1988).

The negative effects of forest drainage on the population density of brown trout may be caused by temporary or permanent changes in water quality. Other properties of brook water besides pH may also contribute. Vuorinen *et al*. (1998) found that the aluminium and iron concentrations in the brook waters of the Isojoki basin may be toxic to brown trout and grayling, toxicity increasing with decreasing pH and temperature. The increase in toxicity with the drainage is in agreement with the studies of Vuori *et al.* (1995) who demonstrated that 73% of the variations in the mean concentration of aluminium in these brook waters was explained by the drainage intensity in the catchment. Forest ditching was also one of the factors explaining the variations in the mean concentration of iron, the minimum values of GRAN alkalinity and the maximum concentrations of suspended solids in the brook waters. Vuori and Joensuu (1996) suggested that drainage has increased the sediment load, impaired the habitat structure and reduced the species number of the benthic macroinvertebrates in these brooks. Drainage-induced sanding of brooks and changes in the prey community also affect the brown trout stocks, and possibly hydrological changes, too.

The population density of 0+ parr was negatively dependent on shading on the brook channel by the tree canopy. Brookside clear cuttings reduce the shading effect of trees and may raise the temperature of the brook water substantially (e.g. Hartman *et al.* 1984, Beschta *et al.* 1987, Ahtiainen 1990). Many of the brooks in the study area are cool, spring-fed headwater streams, with summer temperatures at around + 10 °C. Increasing water temperatures were measured in one of the study brooks, where on sunny summer days the water temperature rose from +9 °C to +11 °C within a 1-km section of brook flowing through a clearcut area. As the brown trout grow within a range of 4–19 °C, with the fastest growth at ca. 13 °C (Elliot 1994), a rising water temperature appears to increase the biological productivity in the coolest trout brooks by bringing it closer to the optimum temperature for trout growth.

The results from the egg incubation experiments indicate that the effects of increased soil erosion and sedimentation are first observed in a suboptimal spawning environment where egg survival may be naturally lower. Differences in egg survival were clearest between the most pristine brook, Lohiluoma and the very sandy brook Hukanluoma; the survival rate in most of the other brooks was midway between these extremes. Differences were also found between various incubation sites within a single set of rapids in the Lylylouma brook, where the accumulation of mineral soil in the boxes indicates increased erosion due to forest management measures. In Sweden, Olsson and Persson (1988) have reported reduced survival of brown trout eggs related to deposition of sand on the incubation substrate. High concentrations of peat material had a similar effect (Olsson and Persson 1986). The effects of soil erosion are clearly cumulative in the main river. Thus reduced egg survival appears to be one of the main threats to the survival and production of local brown trout stocks and to the natural sea trout stock in the river system.

The genetic variability of local brown trout stocks revealed five genetically differentiated stocks, all of which also differed significantly from the cultivated Isojoki sea trout stocks. The number of differentiated stocks in the river system migth be still higher as we did not study all the brown trout brooks. Maintaining genetic variability presets an important challenge to the management and conservation of brown trout stocks in the river system. Differentiated stocks, though having the same origins, may always contain some genetic material lacking in other stocks; moreover no single stock can contain all the genetic material of the entire fish stock. The different brown trout stocks and their conservation should always be taken into account in activities affecting brook waters. Forest management measures, such as drainage and brook dredging, may pose a threat to the genetic diversity of fish stocks.

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