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Atlantic salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L., passage in a regulated northern river – fishway efficiency, fish entrance and environmental factors

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Abstract The number and the size of Atlantic salmon, *Salmo salar* L., using the Isohaara fishway was elevated by increasing the fishway discharge and by changing the type of the pass entrance. The fishway is intended to help fish bypass a hydroelectric station located close to the mouth of the large, regulated River Kemijoki, in northern Finland. Multi-sea-winter (MSW) salmon returned to the river mouth during peak flows in early June but did not use the fishway until 1 month later. Their number in the fishway was positively correlated with the tailwater level. One-sea winter (1-SW) salmon, which arrived approximately one month later, started to enter the fishway without corresponding delays. In autumn, a high tailwater level and a small drop at the fish entrance seemed to be needed for the successful passage of these small-sized salmon and sea trout, *Salmo trutta* L.

KEYWORDS: fish entrance, fish passage, fishways, *Salmo salar*, *Salmo trutta*.

Introduction

Migratory fish stocks of large and mid-sized rivers are severely affected by hydroelectric developments, which block the migration routes. The resulting water level regulation diminishes suitable spawning and nursery areas and leads to deterioration of the quality of the remaining habitats. Tributaries and headwaters often maintain their potential for reproduction. By providing access to these areas, migratory fish stocks can be supported in regulated rivers. Fishways are water passages designed to dissipate the energy in the water to facilitate fish ascent at migratory obstructions (Clay 1995). When the fishway is in connection with a hydropower plant, its discharge is considerably smaller than that through turbines. It is therefore essential that the fish entrance is designed and located properly to enable and to stimulate fish ascent from the tailrace (Clay 1995; Larinier 1998). Flows and appropriate water velocities at the entrance are used for fish attraction (Katopodis 1990; Clay 1995). The nature of the flows in relation to fish attraction is, on the whole, poorly understood and considered to require much more research (Northcote 1998).

Atlantic salmon, *Salmo salar* L. and sea trout, *Salmo trutta* L., display spawning runs during different flow conditions (Beach 1984; Winstone, Gee & Varallo 1985) and display different migration and search patterns downstream of fishways (Johlander 1999). The Isohaara fishway, close to the mouth of the regulated River Kemijoki, in northern Finland, was suspected to favour the ascent of sea trout and be size selective for salmon (Laine, Kamula & Hooli 1998). Almost all the salmon that passed through had spent only one winter at sea (one-sea winter or 1-SW), although large multi-sea-winter salmon (MSW) were observed close to the two alternative fish entrances (width 0.75% of the river width) with no attempts to enter. An inadequate fishway discharge (~0.15% of the turbine discharge) together with poor attraction of the

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fish entrances was suspected to be the main reason for the lack of MSW salmon in the fishway.

The main emphasis of this paper lies in the responses of salmon and sea trout to the changes made in the flow conditions at the fish entrance to improve the passage of MSW salmon. The role of environmental factors, such as water temperature, river discharge and water level, is also assessed as they play an important role in both timing and success of fish ascent.

Study area

The River Kemijoki, which runs from northern Finland into the northern part of the Gulf of Bothnia of the Baltic Sea (Fig. 1), has a watershed area of 51 000 km^2 (MQ = 556 m^3 s^{-1}, MHQ = 3370 m^3 s^{-1}). The first dam was constructed at Isohaara, 3 km from the river mouth, in 1949. Thereafter, four dams were completed in the 100-km-long downstream reach of the main stream during the years 1957–1976. To compensate for the losses caused to the sea fishery, large scale stocking was started at the river mouth and the nearby sea area in the early 1980s. On average 580 000 salmon smolts and 93 000 sea trout smolts were stocked annually in the 1990s, prior to and during this study. Stocking brown trout, *S. trutta* L., in the river reservoirs to compensate the losses of river area was not successful (Vehanen 1997).

There are approximately 50 trap nets at the sea area in the vicinity of the river mouth and 100–150 nets in the river downstream of the dam each summer. Intensive fishing starts when the first salmon arrive in late May – early June and continue to October, when mainly anadromous whitefish, *Coregonus lavaretus* (L.), and sea trout are caught. There are no temporal fishing limits in the so-called ‘terminal fishing area’ downstream of the dam and at a limited area outside the river mouth.

The 200-m-wide Isohaara dam has two power houses, one on the northern shore and the other on the southern shore (Fig. 1). The discharge capacity of each powerhouse is approximately 500 m^3 s^{-1}. The fishway was completed in connection with the new powerhouse in 1993. Its total rise is 12.5 m and total length 230 m, including two entrance sections (see Fig. 1). The southern vertical slot entrance (slot width 0.35 m and height 2.3 m) continues as a vertical slot tunnel section (slope 4%) receiving light through openings in the roof and walls of the tunnel. The uncovered northern entrance was originally formed of

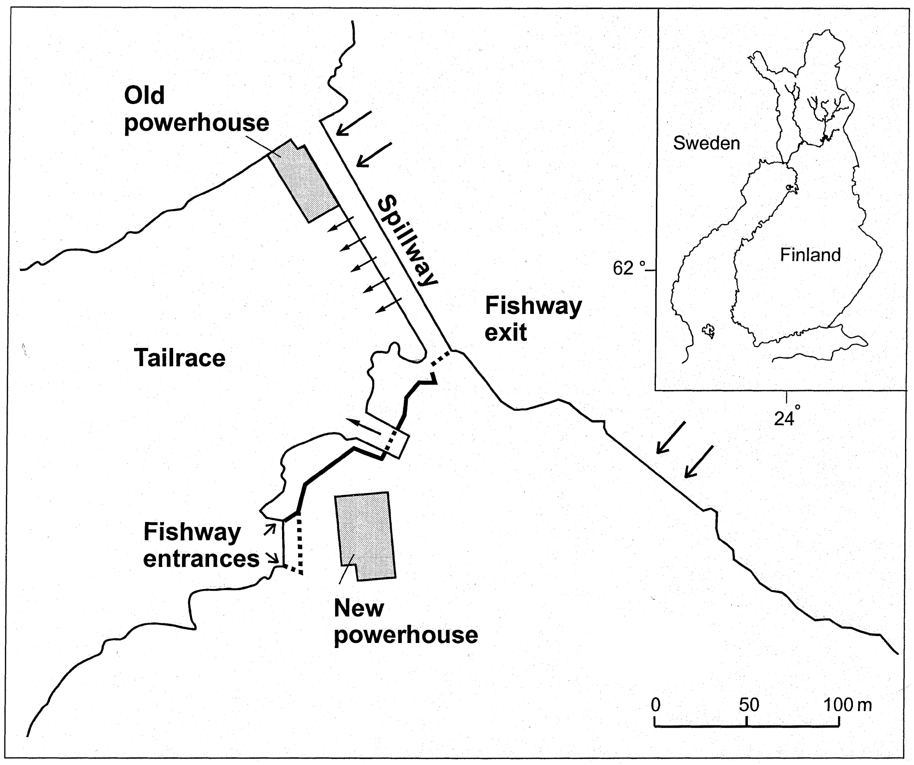

Figure 1. The Isohaara dam close to the mouth of the River Kemijoki and the location of the fishway.

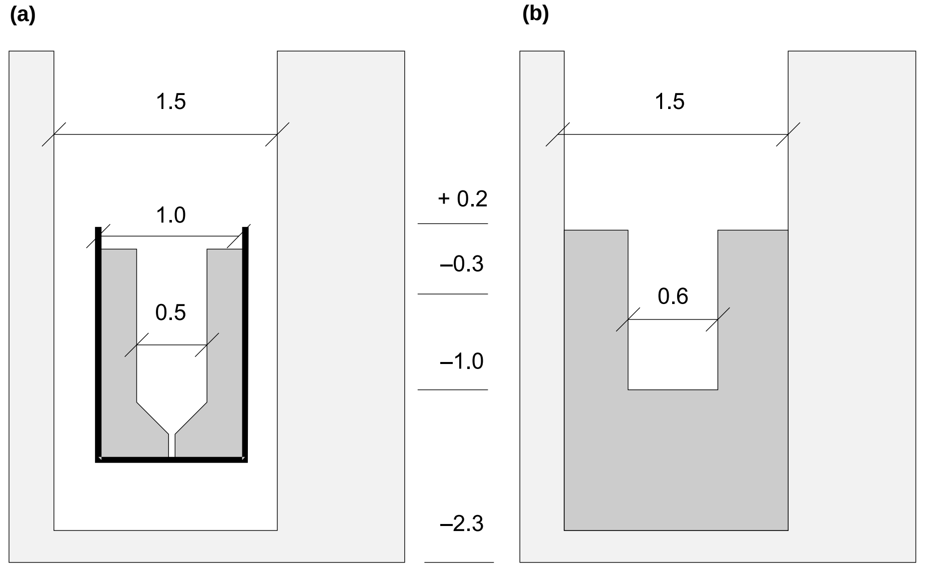

Figure 2. The entrance weirs of the Isohaara fishway: (a) the northern, Denil entrance, the vertical position of which was adjustable according to the tailwater level, (b) the new slot entrance that replaced the Denil entrance in September 1997. Dimensions in metres.

a 5-m-long Denil chute with an adjustable slope (11–16%; Fig. 2). The base of this entrance, being designed for high tailwater levels, was 1.6 m higher than that of the vertical slot entrance. The entrance continues as an uncovered vertical slot section (slope 7%) to the junction pool of the two entrance sections; see Laine *et al.* (1998) for further details.

The original discharge of the fishway was $0.5 \pm 0.1\ m^3\ s^{-1}$ depending on the headwater level. An auxiliary flow of $0.4\ m^3\ s^{-1}$ was produced by a pump. The discharge was increased by $0.2–0.3\ m^3\ s^{-1}$ and the vertical slots were widened from 0.30 to 0.35 m during the fourth year of the fishway operation, in 1996. In the late summer of 1997, the Denil-chute of the northern entrance was removed. A weir, with a 0.6-m-wide notch in the middle, was placed at the entrance (Fig. 2) and another 5 m upstream. Thus, a large pool was formed with a small waterfall at the fish entrance and another in the upper end of the pool.

Materials and methods

All fish that passed through the fishway were gathered into one of the most upstream pools. Salmonids were counted individually each day by transferring them with a dipnet into a large releasing pool upstream of the gathering pool. Altogether 1437 salmon and 660 sea trout passed through the fishway during 1996–1999. Salmon were initially reared in hatcheries receiving river water from upstream of the Isohaara dam but were stocked at the river mouth or the nearby sea area as smolts. The sea trout recorded include an unknown proportion of brown trout, as large numbers of stocked brown trout migrate from the river each year (Vehanen 1997). The returning salmon are mostly 1–2 kg in weight (length 0.5 m) after 1 year at sea, reaching 4–6 kg (0.7–0.8 m) usually during the second and 10–15 kg (0.9–1.1 m) during the third sea winter. The corresponding weights for sea trout are 0.5–1, 1.5–2.5, 3–4 and 5–8 kg (lengths 0.4–0.45, 0.5–0.6, 0.6–0.7 and 0.7–0.8 m, respectively) (e.g. T. Zitting-Huttula, M. Hiltunen & J. Autti, unpublished data).

A stepwise multiple regression was used to test the effect of environmental variables on the number of salmon and sea trout passing through the fishway for each of the study years separately. River discharge, headwater level, tailwater level and total drop, i.e. the difference between the headwater level and the tailwater level at the dam, were used as independent variables. Also, the magnitude of daily changes in these variables and in water temperature were included. Entrance drop was used instead of total drop for the years 1998 and 1999, when the modified fish entrance was in use. The entrance drop was estimated from measurements, which were related to the simultaneously recorded difference between the headwater and tailwater levels, i.e. as a function of the hydraulic head at the dam (Spearman correlation coefficient $r_S = 0.995$, $n = 8$, $P < 0.001$). Statistical analysis was limited to the main period of upstream migration, which was determined by excluding the first and last 5% of ascending fish each year.

The delay between arriving at the river mouth from the feeding migration and entering the fishway was evaluated for salmon in 1998. This was based on a catch survey that was sent to fishermen having net traps suitable for catching salmon. The final data consisted of the daily number and the daily total weight of a total of 1416 salmon caught by eight net traps during June and July. Each of these was fishing constantly during this time period. Autocorrelation (ACR) analysis was used for studying the effect of consecutive days on the environmental variables and on the number of fish caught by net traps and passing through the fishway. The relationships between the environmental variables and the trap catch or the number of fish in the fishway were then identified using cross-correlation (CCR) analysis designed for time series (SYSTAT 1992). The parameters used in CCR were the daily numbers of fish, the daily means and the prior moving 3-day averages of the environmental variables and the difference between each variable and that of the previous day. For water temperature, which was either gradually increasing or decreasing during the season, only the difference was investigated. Lags for a maximum of 3 days were included because the weather phenomena at the Gulf of Bothnia are very short, depending on cyclonic action. The time periods examined were June and July for the trap catch, corresponding to MSW and 1-SW salmons, respectively. Summer (water temperature > 13 °C) and autumn (< 13 °C) were the two periods used for the fishway data. Only the effect of the daily means and the difference of the environmental variables were examined for these data because of the short-term discharge pattern of this river with a peaking power plant.

Results

Inter-year variation in fish passage rates and environmental conditions

Most salmon passed through the Isohaara fishway in late summer and in autumn, whereas the majority of sea trout ascended early in the summer (Fig. 3). Only a few individual fish used the fishway during the spillway flow releases in early June. Seine netting at the old powerhouse (see Fig. 1), conducted for disease and stocking control purposes, and netting in the river downstream of the dam yielded catches which were either decreasing or had no trends during the study (Table 1). The inter-year variation in the number of 1-SW and MSW salmon in the fishway did not follow the catch per unit effort in these two locations ($\chi^2 = 631.601$, d.f. = 3, $P < 0.001$; $\chi^2 = 247.806$, d.f. = 2, $P < 0.001$, respectively). Instead, there was an increasing ratio between the mean daily number of salmon in the fishway and the number of salmon caught per unit effort below the dam until the year 1998, and no change in 1999 when compared with 1998. No trends were observed in the sea trout frequencies (Table 1). The ratio between sea trout and salmon was significantly higher in the fishway (0.57 ± 0.33) as compared with the seine and the net catches below the dam (0.05 ± 0.02 and 0.11 ± 0.02, Mann–Whitney U-test, $U = 0.00$, $P = 0.02$ and $U = 0.00$, $P = 0.03$, respectively, see also Table 1).

The first salmon in the size category of 8–10 kg (0.8–0.9 m) passed through the fishway after its discharge was increased. However, salmon schools including MSW salmon of 15–20 kg in weight (length 1.1–1.2 m) were still observed to gather below the fish entrances with no attempts to enter. Soon after replacing the Denil chute from the northern entrance by a pool and a small waterfall, the first MSW salmon in the weight category of 10–12 kg (1.0 m) passed through the fishway. Only the altered entrance was used in 1998 and 1999. Subsequently, no more salmon schools were observed to gather close to the entrance and also the first salmon weighing over 15 kg (> 1.1 m) passed through the fishway. This, in addition to the increased number of MSW salmon, points to improved fish entrance attraction and thus improved fishway efficiency.

The daily variation in the salmon frequencies was best explained by the variation of the water level variables at the dam (Table 2). In 1999, when the salmon numbers were inversely related to the entrance drop, the drop was on average higher (0.70 ± 0.25 m) than in 1998 (0.50 ± 0.25 m, $t = 5.48$, $P < 0.001$), resulting from a lower tailwater level (see Table 3). The sea trout frequencies seemed to be weakly related to the tailwater level in 1999. Total discharge and change in the water temperature from the previous day were selected by the model with slightly higher coefficients of determination in 1997 and 1998 (Table 2).

Timing of salmon and sea trout runs

The salmon catch close to the river mouth had two peaks in 1998 (Fig. 4). Most MSW salmon arrived in June when the water temperature was below 7 °C (mean weight of all salmon caught 8.4 kg). Significant ACR between the number of salmon caught on

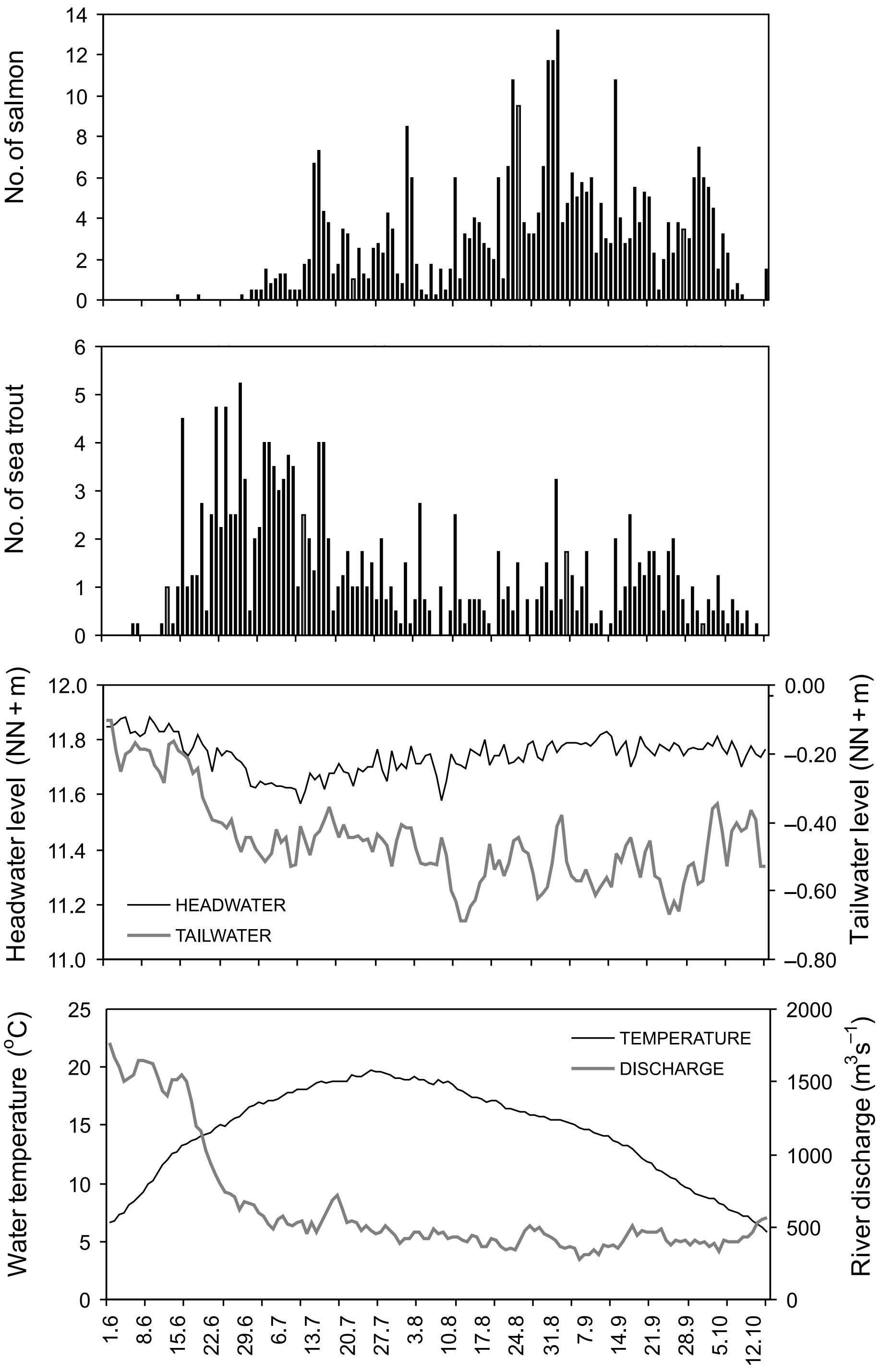

Figure 3. The average daily number of salmon and sea trout passing through the Isohaara fishway in 1996–1999 with means for headwater and tailwater level, river discharge and water temperature at the dam (NN = fixed level at the dam).

consecutive days indicated a temporal migration pattern (Table 4). The largest daily salmon catches coincided with SW, S and SE winds in that order. Also the highest wind velocities were measured during S and SW winds. The salmon catch in June was positively correlated with the seawater level for no lag and with the river discharge for a lag of 3 days. In July, mostly 1-SW salmon were arriving (mean weight of all salmon

Table 1. The number of salmon and sea trout passing through the Isohaara fishway in 1996–1999, the annual salmon and sea trout catch at the River Kemijoki downstream of the Isohaara dam by seine (unit effort = 1 draw) and by nets (unit effort = 1 net fishing day), and the ratio between the daily number of fish in the fishway and catch per effort (seine or nets)

	Salmon				Sea trout			
	1996	1997	1998	1999	1996	1997	1998	1999
Fishway								
Total number passing (MSW)	143 (20)	355 (65)	551 (98)	388 (23)	148	181	145	186
n per day*	1.2	2.9	4.5	3.4	1.2	1.5	1.2	1.6
Seine catch†								
n of efforts	83	64	62	82	83	64	62	82
Total number caught	605	342	243	270	10	25	16	17
n per unit effort	7.3	5.3	3.9	3.3	0.1	0.4	0.5	0.2
Net catch‡								
n of efforts	3765	4736	3118	–	3765	4736	3118	–
Total number caught	1150	1200	930	–	150	110	100	–
n per unit effort	0.31	0.25	0.30	–	0.04	0.02	0.03	–
Ratio								
Fishway seine	0.16	0.55	1.15	1.03	12.00	3.75	2.40	8.00
Fishway nets	3.87	11.60	15.00	–	30.00	75.00	40.00	–

*Between 15 June and 15 October.
†Catch data at the old powerhouse (Jyrki Autti, unpublished data, 1996–1999).
‡Based on catch surveys of the years 1996–1998 (Jyrki Autti, unpublished data, 1996–1999).

caught 2.4 kg). The July catch was positively correlated with the seawater level (Table 4).

No salmon entered the fishway in June, when the river discharge exceeded 1000 $m^3 s^{-1}$, the turbines were used in full capacity and the spillway gates were open continuously (Fig. 4). After closing the spillway gates in late June, the tailwater level was considerably lower than during the spillway flow releases. It was also highly correlated with the seawater level (CCR = 0.94 for no lag and CCR = 0.50 for a lag of 1 day), had no regular daily variation and showed only a minor correlation with the river discharge (CCR = 0.27 for the same hour). Sea trout started to enter the fishway in June and MSW salmon in early July. Most 1-SW salmon used the fishway in late summer and in autumn (Fig. 4). The first MSW salmon passed through the fishway approximately 1 month after the first salmon had arrived at the river mouth (Fig. 4). No corresponding delay could be observed for 1-SW salmon. The daily number of salmon passing through the fishway in July was positively correlated with the number of salmon caught with net traps outside the river mouth with a maximum lag of only 1 day (CCR = 0.40 for no lag and CCR = 0.44 for a lag of 1 day).

The numbers of fish passing through the fishway were autocorrelated in summer (Table 5). Both the correlation coefficient and the lag were, however, smaller than those for salmon in the trap catches (see Table 4). The daily number of MSW salmon was positively related to the tailwater level and inversely related to the entrance drop, which ranged from 0.05 to 1.0 m in 1998. Also the number of 1-SW salmon was positively related with the tailwater level (Table 5). In addition, an inverse relationship was found with the entrance drop in autumn, when the drop was on average higher (0.65 ± 0.25 m) than in summer (0.50 ± 0.15 m, $t = 3.694$, d.f. = 105, $P < 0.001$). Corresponding relationships were found for sea trout in autumn (Table 5). As a whole, MSW salmon, 1-SW salmon and sea trout ascended in a wide range of fish entrance drops (Fig. 5).

Discussion

Improving fish entrance efficiency

The salmon catches at the Finnish coast of the Gulf of Bothnia and in rivers running into it decreased during this study and were only half of the 1996–1997 level in 1998 (ICES 1999). According to the regional fisheries authority, the salmon catch in the terminal sea area of the River Kemijoki also decreased from the estimated

Table 2. Results of multiple regression analysis testing the significance of environmental factors in explaining the number of ascending salmon and sea trout ($\log_{10}$-transformed) in the Isohaara fishway. Only the parameters significant at the 0.05 level are shown (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$)

	B	t	F	r^2
Salmon				
1996				
Tailwater level	−0.399	−2.388*		
Constant	0.020	0.166	5.702*	0.08
1997				
Tailwater level	0.593	3.679***		
Headwater level†	39.139	3.330**		
Constant	−40.997	−3.253**	16.941***	0.36
1998				
Headwater level†	62.597	3.366**		
Δ entrance drop	−0.054	−1.998*		
Constant	−66.197	−3.328**	5.810**	0.15
1999				
Entrance drop	−0.009	−4.197***		
Constant	1.249	6.998***	17.616***	0.20
Sea trout				
1997				
Total discharge†	0.593	4.534***		
Constant	−1.117	−3.562**	20.560***	0.17
1998				
Δ water temperature	0.328	3.749***		
Constant	0.314	9.604***	14.058***	0.15
1999				
Tailwater level	0.371	2.036*		
Constant	0.454	4.425***	4.143*	0.06

†$\log_{10}$-transformed.

Table 3. Means for the environmental variables measured at the Isohaara dam between 15 June and 15 October for the separate study years. NN = fixed level at the dam

	1996	1997	1998	1999
Water temperature (°C)	14.8 ± 3.7	16.3 ± 4.4	14.2 ± 4.1	14.7 ± 3.8
River discharge ($m^3 s^{-1}$)	522.0 ± 385	296.0 ± 177	794.0 ± 420	466.0 ± 130
Headwater level (NN+ m)	11.74 ± 0.10	11.74 ± 0.10	11.74 ± 0.08	11.70 ± 0.15
Tailwater level (NN+ m)	−0.52 ± 0.30	−0.60 ± 0.24	−0.31 ± 0.21	−0.50 ± 0.16

50–70 t in 1996–1997 to only half of that in 1998, decreasing further in 1999. This decrease was reflected in the seine catches at the old powerhouse, but did not appear in the Isohaara fishway, where the number of salmon and especially that of MSW salmon increased until 1998.

From 1996 onwards, when the water intake slots at the fish exit were widened, higher fishway discharges were obtained under the same headwater levels when compared with the years 1993–1995. During these first years of fishway operation the proportion of MSW salmon of all salmon passed was negligible and the largest salmon weighed only 3–4 kg (Laine *et al*. 1998). After the Denil entrance was replaced by a pool and a small waterfall, no more observations were made of salmon gathering close to the entrance with no attempts to enter. Also the number and the maximum size of salmon increased in the fishway. The small waterfall at

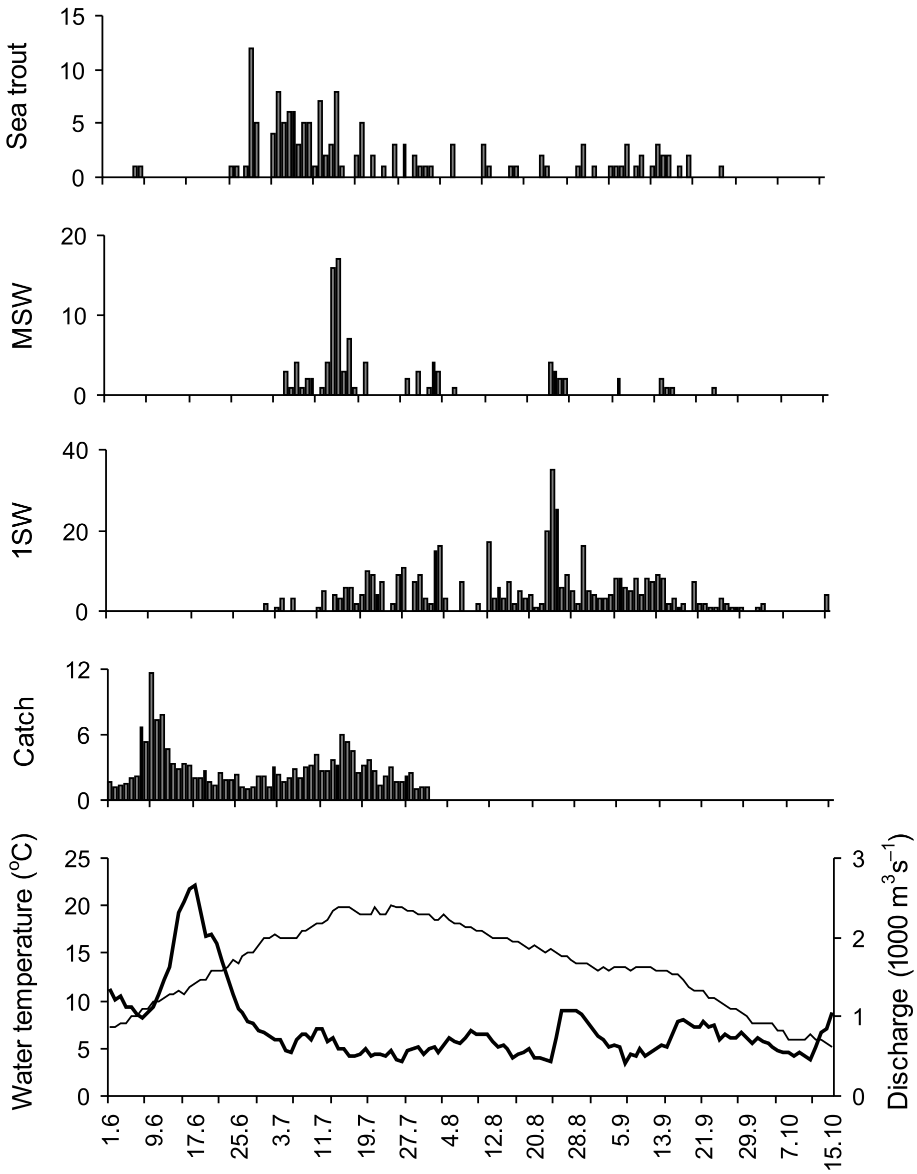

Figure 4. The daily number of sea trout, multi-sea-winter salmon (MSW) and one-sea-winter salmon (1-SW) in the gathering pool of the Isohaara fishway, and the mean daily number of salmon per trap in the sea area at the river mouth (catch) in 1998. The mean daily water temperature (delicate line) and the mean daily discharge (strong line) are shown below.

the fish entrance was more effective in stimulating the ascent of salmon from the tailrace than the preceding Denil entrance or the alternative vertical slot entrance, close to which schools of salmon had also been regularly observed (Laine *et al.* 1998).

Denil fishways characteristically have the highest velocities close to the surface (Katopodis, Rajaratnam, Wu & Tovell 1997) and immediately downstream of the entrance the velocities decrease rapidly, especially below the water surface (Rajaratnam, Katopodis & Van der Vinne 1985). A fairly high discharge is required for attracting large migratory fish such as salmon into a vertical slot fishway (Larinier 1998). The maximum discharge of the Isohaara fishway was increased from 1.0 to 1.4 $m^3 s^{-1}$. Water velocities were usually between 1.0 and 1.2 $m s^{-1}$ at the vertical slot entrance. The vertical slot tunnel section has, however, a low slope resulting in low velocities as tailwater increases (see also Rajaratnam *et al.* 1985; Rajaratnam, Van der Vinne & Katopodis 1986), which may weaken the attraction of the entrance considerably. The drop at the modified fish

Table 4. Autocorrelation (ACR) between the daily numbers of salmon per trap outside the river mouth for lags of 1–3 days and cross-correlations (CCR) between the numbers of salmon caught and environmental variables (daily = daily mean, 3-day = prior moving 3-day average, diff = difference between the present and the previous day) in June 1998 (MSW salmon) and July 1998 (1-SW salmon). A cross-correlation for a lag of 0–3 indicates a relationship of the catch to parameters monitored 0–3 days earlier (0 = the present day). Only significant correlations ($P < 0.05$) are presented

			Lag			
			0	1	2	3
June						
Number of salmon	ACR			0.68	0.64	–
River discharge	CCR	Daily	–	–	–	0.40
Seawater level	CCR	Daily	0.38	–	–	–
		3-day	0.38	–	–	–
July						
Number of salmon	ACR			0.56	0.33	–
Seawater level	CCR	Daily	0.60	0.56	0.38	–
		3-day	0.45	0.58	0.57	0.46
		Diff	0.37	–	–	–

entrance ranged from 0.05 to 1.0 m in 1998, and depended on the difference between the headwater level and the tailwater level. Maximum water velocities, estimated from $(2gh)^{0.5}$, where $g = 9.81$ m s^{-2}; and h = entrance drop (m), would 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. It is expected that such water velocities would be within the burst range of most salmon and trout at Isohaara, except possibly for the smaller individuals. High water velocities, although they may prove difficult or even impossible for fish to overcome, are considered to be a major factor instigating the upstream movement of salmonids (Winstone *et al.* 1985). The noise and the turbulence of high velocity water below an obstruction can stimulate fish to move forward (Beach 1984), which might explain the superiority of the new entrance to both the Denil and the vertical slot entrance in the Isohaara fishway.

The number of sea trout passing through the fishway was relatively steady each year as was total catch at the Finnish coast (ICES 1999) and in the River Kemijoki. The ratio between sea trout and salmon was, however, much higher in the fishway than in the catches at the old powerhouse, in the river downstream of the dam and at the coast (ICES 1999). The fishway still seems to favour the ascent of sea trout (see Laine *et al.* 1998) although its efficiency in attracting salmon has improved.

The timing of the spawning runs

The first MSW salmon arrived to the mouth of the River Kemijoki in early June and 1-SW salmon approximately a month later. This is in accordance with other observations made at the river mouth (T. Zitting-Huttula, M. Hiltunen & J. Autti, unpublished data). Also elsewhere the oldest salmon were observed to enter the rivers first (Hansen & Jonsson 1991; Laughton 1991). The number of salmon caught outside the river mouth was positively correlated with the seawater level in June 1998, when the prevailing winds blew from the southern directions. These onshore winds, which raise the water level in the northern part of the Gulf of Bothnia and the lowest reaches of the rivers running into it, are reported to be the best for catching salmon (Ikonen 1986) and may induce salmon to congregate in the estuaries and initiate runs (Huntsman 1948; Banks 1969).

It was 1 month after the first salmon were caught at the river mouth that the first MSW salmon entered the Isohaara fishway. This delayed entry was typical for other study years. No observations were made of salmon at the dam during flood level discharges but the first salmon was caught at the old powerhouse soon after the spillway gates were closed (Jyrki Autti, unpublished data, 1996–1999). The first salmon was observed in the fishway usually 1–2 weeks later. Later in the summer, when mainly 1SW salmon were migrating, the daily number of salmon in the fishway was correlated with the catch at the river mouth for a

Table 5. Autocorrelation (ACR) between the daily numbers of fish in the fishway and cross-correlations (CCR) between the number of fish passed and the environmental variables in summer (water temperature ≥13°C) and autumn (< 13 °C) 1998. Entrance drop = difference in water level just upstream of the fishway entrance and tailwater level. For other explanations, see Table 4

		Lag			
		0	1	2	3
Summer: MSW salmon					
Number of salmon	ACR		0.57	–	–
Entrance drop	CCR	−0.23	−0.35	−0.35	−0.28
Tailwater level	CCR	0.27	0.36	0.38	0.38
Summer; 1-SW salmon					
Number of salmon	ACR		0.48	–	–
Tailwater level	CCR	0.28	0.26	–	–
River discharge	CCR	−0.24	–	–	–
Summer; sea trout					
Number of sea trout	ACR		0.34	–	–
Autumn; 1-SW salmon					
Entrance drop	CCR	−0.60	−0.48	–	–
Tailwater level	CCR	0.65	0.50	–	–
River discharge	CCR	0.58	0.45	–	–
Autumn, sea trout					
Entrance drop	CCR	−0.38	−0.45	−0.56	–
Tailwater level	CCR	0.36	0.49	0.44	0.42
River discharge	CCR	–	0.48	0.47	0.42

maximum lag of 1 day. This refers to only a minor delay between these sites. However, the peak numbers of 1-SW salmon were recorded in the fishway during late summer and autumn, when the salmon catch outside the river mouth is marginal (T. Zitting-Huttula, M. Hiltunen & J. Autti, unpublished data). Salmon arriving early in the summer are likely to experience much higher flow rates combined with much lower river temperatures than those arriving later (Laughton 1991). During high flows excessive turbulence may disorientate the fish or prevent their approach to fishways. Also high water levels during high flows weaken the efficiency of fishway entrances (see Beach 1984; Williams 1998). Together these conditions affect the ability of salmon to progress upstream. Sea trout, however, started to ascend soon after closing the spillway gates and most had passed through the fishway by August.

Fish release site locations may be important in determining the fishway efficiency. All salmon, although raised in the river water, are stocked at the river mouth and the nearby sea area as smolts, whereas a great proportion of the sea trout recorded in the fishway may originate from the river upstream and thus have the urge to home to waters upstream of the dam. There is evidence that hatchery-reared Atlantic salmon return to the area of release at sea when mature (Sutterlin, Saunders, Henderson & Harmon 1982; Gunnerød, Hvidsten & Heggberget 1988). Farmed salmon also spend a longer time at sea before entering the river than wild salmon (Jonsson, Jonsson & Hansen 1990; Heggberget, Økland & Ugedal 1993). This, together with the environmental factors discussed above, could explain the observed delay for salmon.

The role of environmental factors for a successful ascent

The 4 years studied were different with respect to environmental conditions and fish abundance. The variation in the salmon frequencies in the fishway was not explained by the river discharge, an important factor in modifying both run timing and migratory success (Clarke, Purvis & Mee 1991; Jonsson 1991; Jensen, Hvidsten & Johnsen 1998). Instead, water level variation at the dam seemed to explain some of the daily variation in salmon frequencies. After the structural changes in the northern fish entrance, the number of MSW salmon passing through the fishway was positively correlated with the mean tailwater level on the exact day of ascent and 1–3 days earlier. The tailwater level follows that of the sea water, which is

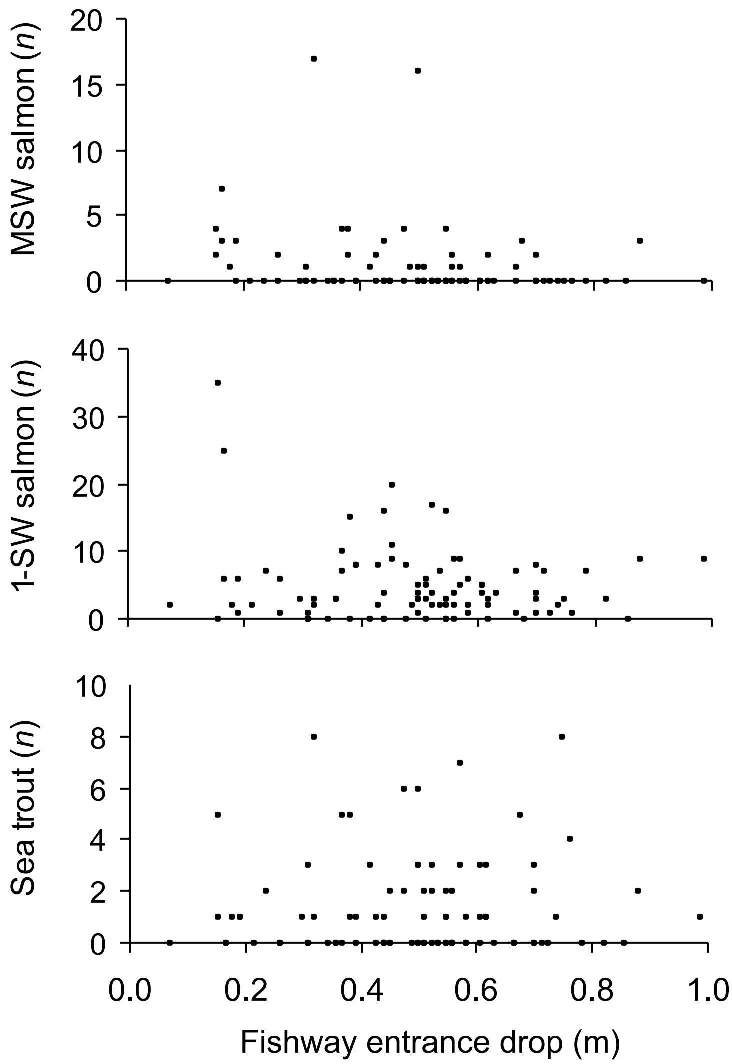

Figure 5. The daily numbers of multi-sea-winter salmon (MSW), 1-sea-winter salmon (1-SW) and sea trout in the Isohaara fishway plotted against the entrance drop in 1998.

affected by the direction and velocity of winds. Onshore winds, by raising the water level, decrease velocities downstream of the dam. For sea trout, total discharge and change in water temperature seemed to be more important than the water level variables.

There was no sign of high enough entrance drops that might have totally hindered salmon or sea trout from entering the fishway in 1998. No relationship was found between the numbers of 1-SW salmon or sea trout passing through the fishway and the entrance drop in summer. In autumn, when the drop was on average higher, there was an inverse relationship for both 1-SW salmon and sea trout. A high entrance drop in low water temperatures could be regarded as an obstacle for at least some of the salmon and sea trout, the maximum swimming speed being inversely proportional to the temperature (Wardle 1980; Beach 1984) and fish length (Katopodis 1999). An inverse relationship was observed between the number of salmon in the fishway and the entrance drop also in 1999, when the entrance drop was on average 0.20 m higher than in 1998.

The daily number of salmon passing through the fishway in this large, northern, regulated river with a peaking power plant, was not related with the difference between the present and the previous day for the environmental variables monitored in 1998. It seems that the effect of rapid changes from the river regulation cannot be measured sufficiently accurate by investigating the daily means, as can be more easily carried out in an unregulated river, where the changes are more gradual. Without counters recording the exact time of entry, it is difficult to trace the effect of these diel changes on the number of fish passing through the fishway. Furthermore, net fishing downstream of the dam has a great effect on the number of salmon that reach the fishway. If there are only a few fish available downstream of the fishway, changes in environmental factors may result in little effect on the fish numbers and the effect of the environmental stimuli will easily be underestimated. Such is the case also if the motivation of fish to migrate upstream is weak. The decrease in ACR when comparing the daily salmon catch close to the river mouth and the daily number of salmon in the fishway, for example, may partly point to this.

Sea trout seemed to have no particular difficulty in locating and ascending the fishway. In spite of increased fishway efficiency, the number of salmon was still small. If needed, the motivation of salmon to ascend can be improved by changing the stocking practice of the river. The intensive fishing downstream of the dam and at the river mouth may, however, be problematic for the development of additional fish passage facilities to enable fish to reach the potential spawning areas upstream of the Isohaara reservoir.

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