

FISH BEHAVIOUR AND GUIDING OF FISH

Time of migration of salmonids in some Icelandic rivers

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Abstract

Fish counters can serve as an important tool for fish biology and management. For migratory fish stocks undergoing large fluctuations in stock size this is of even more importance.

An equipment for counting migrating fish in rivers and to measure their size was developed and tested in Icelandic rivers some years ago. Fish counters of this type are now in use in 16 places in Iceland and are revealing important data on the size distribution, the number of migrating fish migrating in the rivers and the timing of the run. In Iceland there are anadromous stocks of Atlantic salmon (*Salmo salar*) brown trout (*Salmo trutta*) and arctic char (*Salvelinus alpinus*).

Some examples of the use of the counters in Icelandic rivers are shown. There were considerable differences in the time that salmon enters the rivers depending on location. Salmon (2 years at sea) entered the rivers earlier than grilse (1 year at sea). Sea run char entered the river later in the summer than salmon.

When daily migration pattern is examined it can be seen that salmon was migrating at different time depending on the rivers in different location. It is proposed that environmental factors affect the timing. Char showed another diurnal migrating pattern than salmon in the same river. Furthermore sea run trout migrated, through the counter in River Grenlaekur, S-Iceland, in the night, where stationary trout migrated at all hours.

Introduction

Fish counters can serve as an important tool for fish biology and management. A fish counter to measure fish size and counting migrating fish in rivers was developed and tested in Icelandic rivers some years ago (Gudjonsson and Gudmundsson 1994). The counter is manufactured by Vaki Ltd. and 16 counters are now located in different rivers of Iceland. The counter is now working well but care should be taken when the counter is installed. Regular maintenance check is also important of the counter and its energy source that is usually a car battery and a solar cell.

It is of great importance for sound fishery management to know the size of fish stocks. For migratory fish stocks undergoing large fluctuations in stock size this is of even more importance. Sea run salmonids fall into this category. In Iceland there are anadromous stocks of three species; Atlantic salmon, brown trout and arctic char. The

salmon is of highest economical importance but the char and trout fishery are increasing in value. In Iceland stock size of salmonids can fluctuate largely, especially in the north (Scarnecchia 1984a, Antonsson *et al.* 1996). With data of the run from a counter and accurate catch statistic, the size of the spawning stock is known. Spawning - recruit analyses are therefore enabled. The counter can give information about the size distribution and the number of fish of each species based upon size. Information on the time of run of each species will be available as well as other information on the migratory behaviour.

In this paper we show some examples of the use of the counter i.e. the size of the run of salmonids into the rivers, as well as information on the time of migration both during the summer and diurnal migration pattern in different stocks.

Materials and methods

The counter consists of two sets of infra-red light emitters and facing light sensing elements. By constantly monitoring the outputs from each sensor, a picture of an object passing through the counter, is obtained. Two microprocessors process and store the data of each fish passing through the counter, such as, its direction of movement, its height and length, the time and the date. The size of the fish of each species and age cohort is known for these rivers from catch data and was used to separate different groups of fish.

Data from Vaki fish counters in 4 locations in Iceland were used in this study (Figure 1). All 4 rivers have Vaki counter installed in fish-ways or obstacles built in the river.

Study sites

River Ellidaar is located within Reykjavik city in SW-Iceland. In R. Ellidaar a fence was built across the river close to the estuary. A fish-counter was installed in the fence. River Ellidaar is spring-fed river with average flow of approximately 5 m³/sec. The river is regulated for power production. Average annual catch of salmon in the river is approximately 1350 salmon (Gudbergsson 1998).

River Blanda is partly glacier-fed river in N-Iceland. The average flow is approximately 40 m³/sec. The river was dammed in 1991 and is regulated for power production. In the years 1982 to 1998 the river has had a run of 730 to 5301 salmon and 385 to 2058 sea run arctic char (Gudjonsson and Jonsson 1998a). There are two counters located in a fishway 2 km from the estuary.

River Vesturdalsa, NE-Iceland, is direct runoff river with average flow of approximately 5 m³/sec. The river has both salmon and sea-run arctic char runs. The average annual catch is 241 salmon and 582 char (Gudbergsson 1998). At the lower part of the river a wall was built across the river in which a counter was placed.

River Grenlaekur, SE-Iceland is a small spring-fed river with flow of approximately 2,5 m³/sec. The river has a good run of sea trout. The average annual catch is 2147 trout (Gudbergsson 1998). The counter is placed in a wall built across the river at the lower end of river.

Results

Char and salmon in River Blanda (Figure 2) could be separated on the basis of fish size. This has also been possible for other rivers in Iceland as in River Vesturdalsa. Stationary trout and sea-run trout in River Grenlaekur were also separated on the basis of size.

In River Blanda salmon (2 sea-winter fish) arrived earlier in the summer than both grilse (1 sea-winter fish) and char (Figure 3).

The diurnal migration patterns for salmon and char were different and in the different rivers it was variable (Figures 4-5). It is suggested that the time of migration depended on environmental factors such as light and temperatures (Figure 6). These environmental factors were different for the 4 rivers, as well as the time of the season when the different stocks ascend the rivers.

Different migration behaviour can be observed in River Grenlaekur as sea run trout migrated up the river during the nights, when stationary trout migrated up and down the river at all hours (Figure 7).

Discussions

In this paper we emphasised to show different migration patterns in different stocks in various environments.

The primary role of fish counters for fishery management is to know how many fish are in a particular river and therefore gain important basic knowledge to be able to manage the fishery in that river, both the fishing effort and the time of the fishing season. Furthermore information on the timing of the run in the season is important. Some knowledge on the timing of the run was available from fishing experience. For example it is known that salmon enters the rivers in South- and West Iceland earlier than in North Iceland (Scarnecchia 1984a) and it is common knowledge that salmon (2 sea- winter fish) enters the river earlier in the summer than grilse (1 sea-winter fish) (Scarnecchia 1984b, Gudjonsson *et al.* 1995). Trout and char fishing in Iceland is less developed and the timing of the run is not as well known as the migration time of salmon, but salmon fishing has been developing for longer period of time. Therefore, information about the timing of the run of sea-trout or char is important to manage the time of the fishing.

It is known for earlier studies in River Blanda that both temperature and turbidity affect the run of fish up the river (Antonsson 198, Gudjonsson and Jonsson 1998b). In earlier years, before the river was dammed, it became more turbid due to glacier melting. Then fish migration up the river stopped completely. Now the river is less turbid since glacier silt fall to the bottom of the reservoir.

There is an interesting difference in the diurnal migration pattern of salmon and char. The intensity of light and temperature seem to be the environmental factors that affect the migration most. The fish run reached its maximum in the evening when the temperature has risen and before it becomes dark. In June it is not dark at all, but later in the summer it becomes dark earlier and earlier in the day and the effects on the diurnal timing of the run can be seen. In smaller rivers discharge become more important. Similar findings have been reported from rivers in Norway (Jensen *et al.*, 1998).

Sea trout showed very different migratory pattern than stationary trout in River Grenlaekur, where the sea trout migrated upstream during the nights whereas the stationary trout migrated both up and down the river at all hours. These findings are supported by a study using data storage tags in the sea trout in River Grenlaekur (Sturlaugsson and Johannsson 1998).

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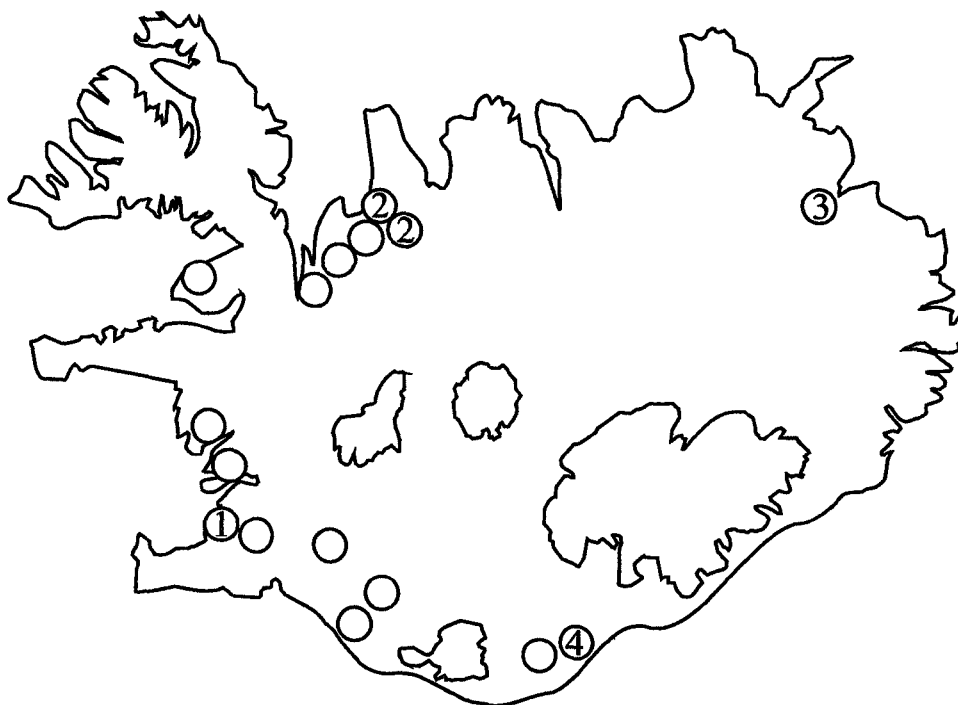


Figure 1. Location of Vaki fish counters in Iceland (O). Data from the following rivers are presented; 1. River Ellidaar, 2. River Blanda, 3. River Vesturdalsa and 4. River Grenlaekur.

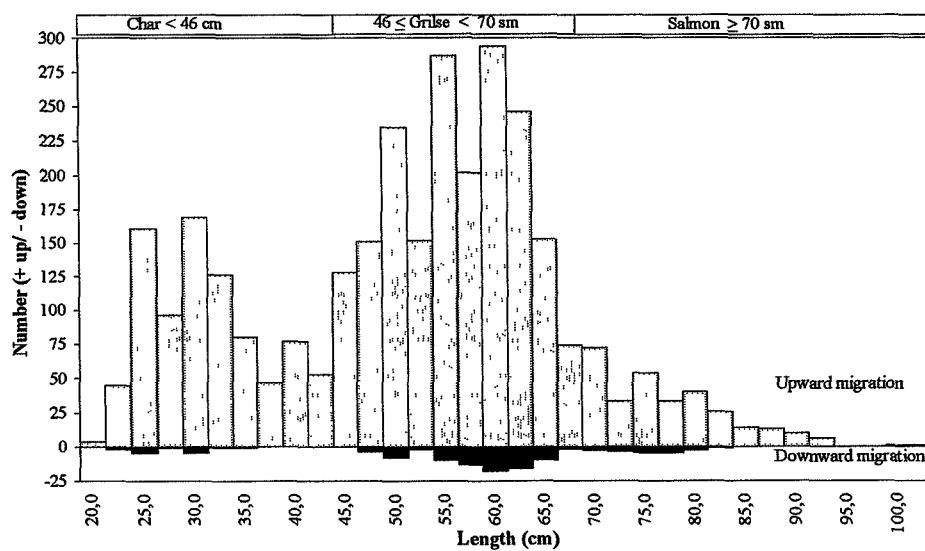


Figure 2. Length of up- and downward migrating fish in River Blanda in 1997.

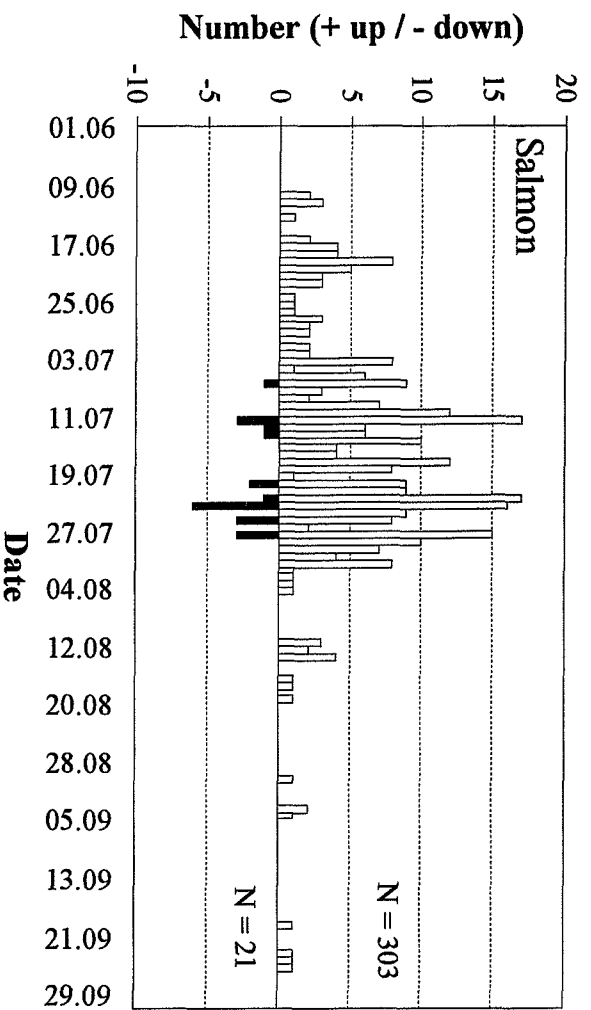
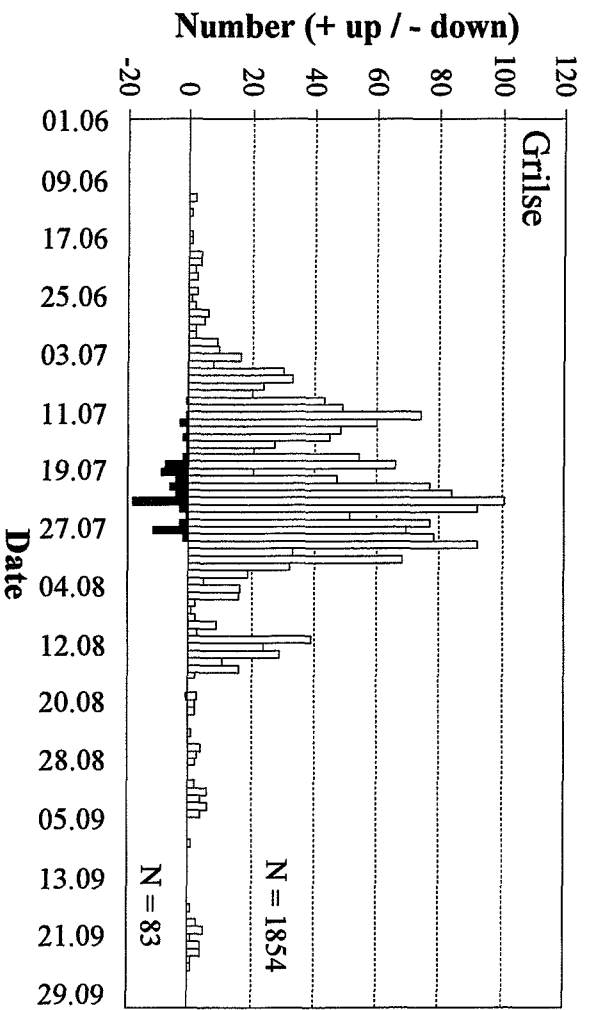
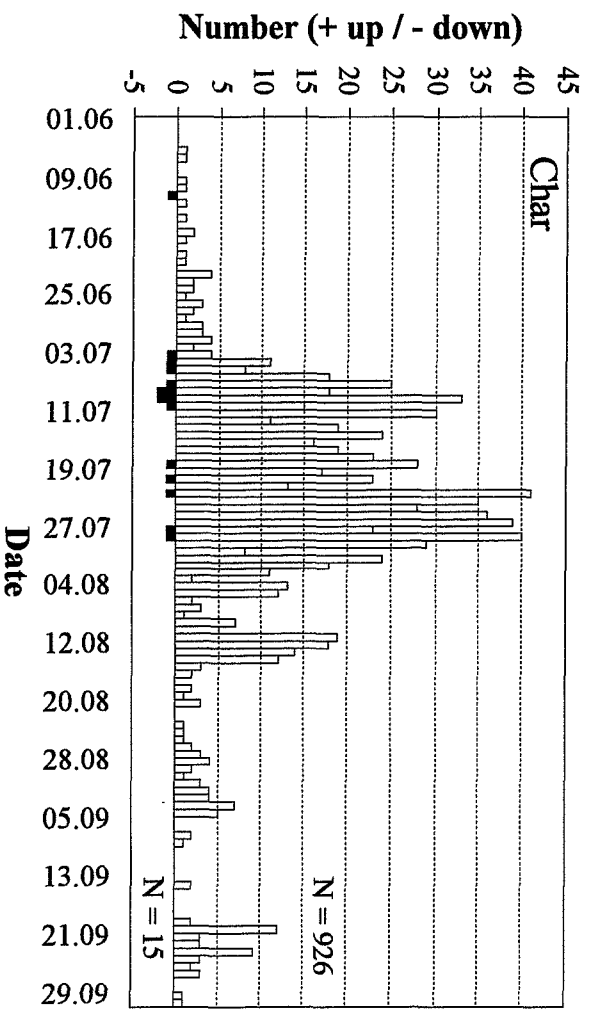


Figure 3. Number of char, grilse and salmon passing through the counter daily in River Blanda in 1997.

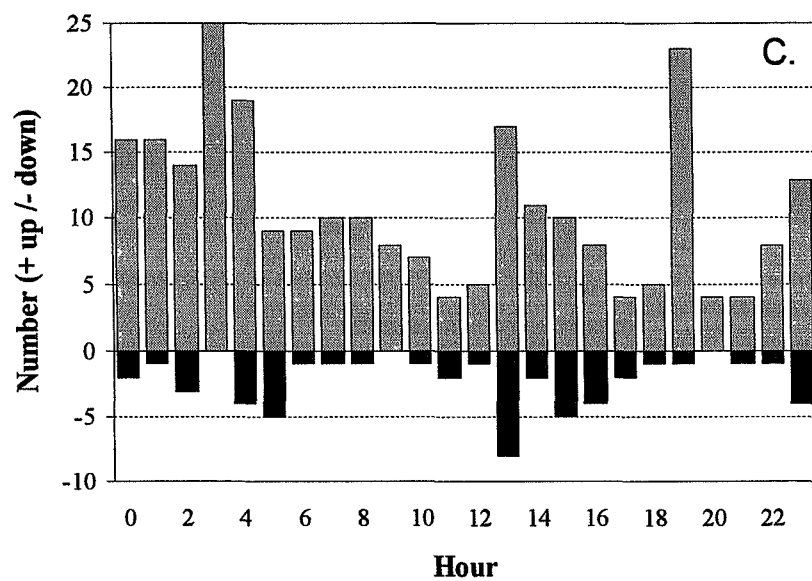
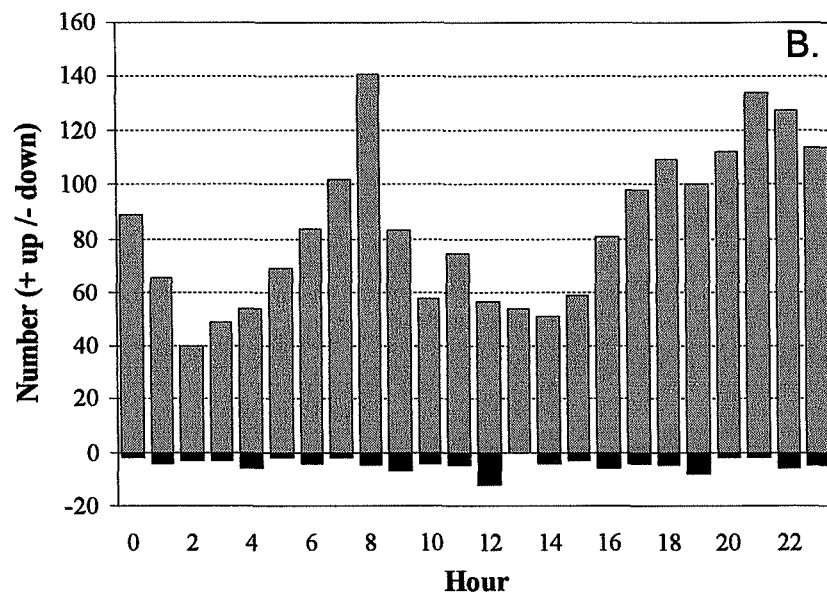
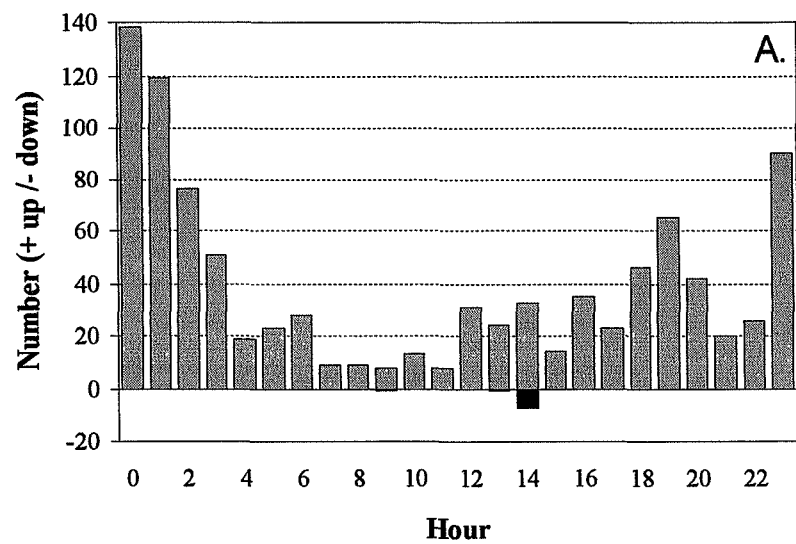


Figure 4. Time of salmon (1 and 2 SW) passing through the counter in River Ellidaar (A), River Blanda (B) and River Vesturdalsa (C) in 1997.

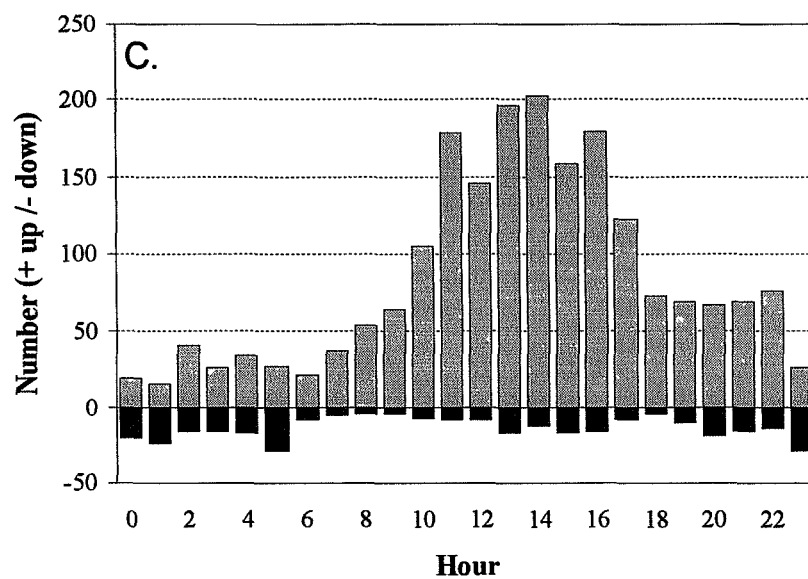
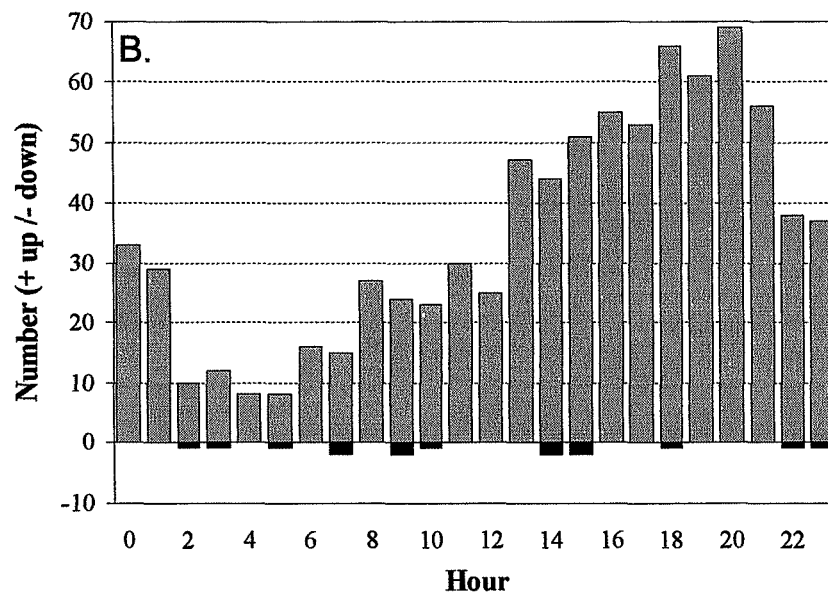
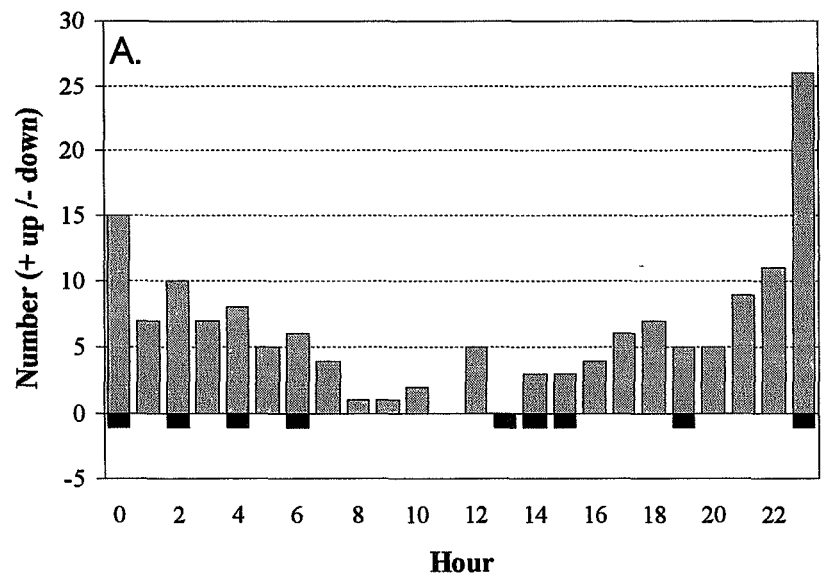


Figure 5. Time of char passing through the counter in River Ellidaar (A), River Blanda (B) and River Vesturdalsa (C) in 1997.

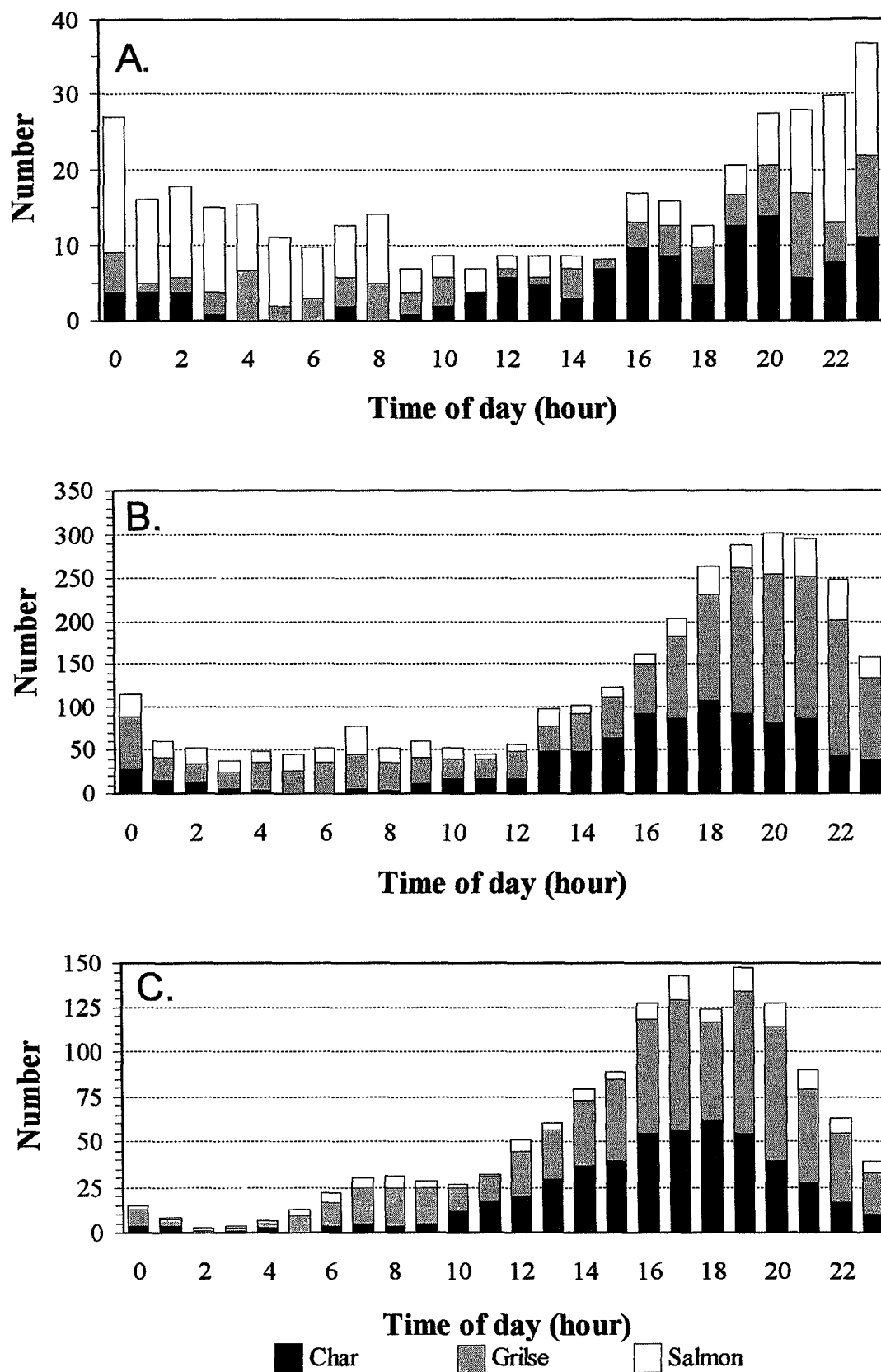


Figure 6. Time of char, grilse and salmon passing through the counter in River Blanda in June (A), July (B) and August (C) in 1998,

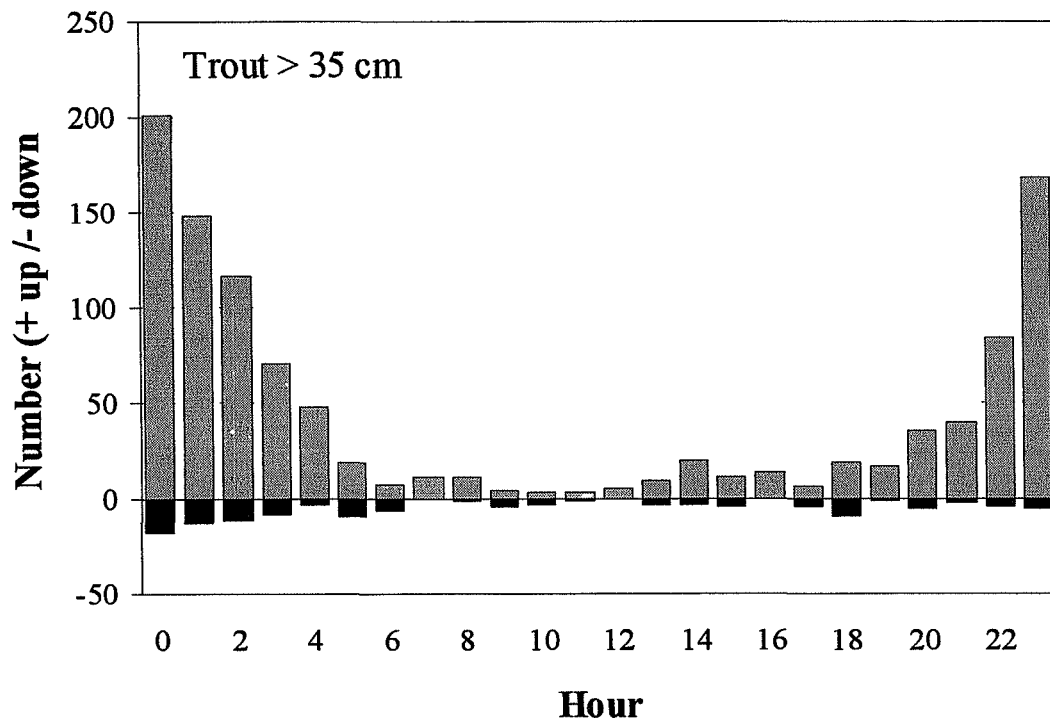
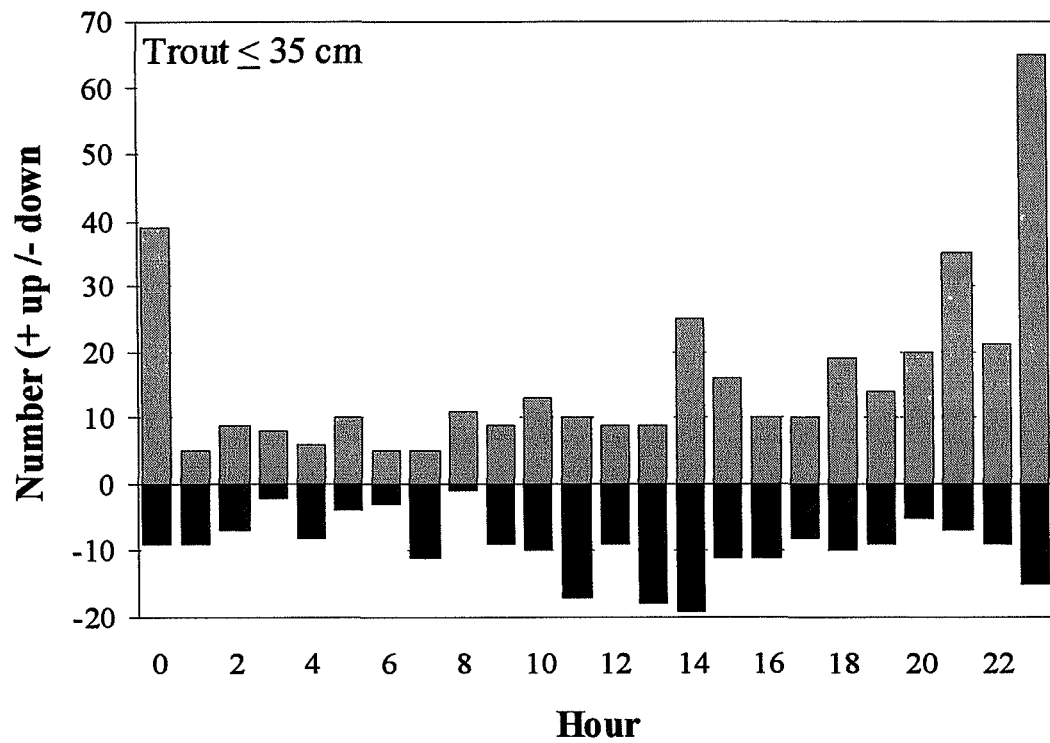


Figure 7. Time of trout passing through the counter in River Grenlaekur in 1998. Trout < 35 cm are stationary, but trout > 35 cm are sea run.

UPSTREAM MIGRATION OF SALMONIDS IN RELATION TO WATER TEMPERATURE

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ABSTRACT

River discharge is the factor most frequently reported as controlling upstream migration of salmonids to their spawning areas. However, the effects of water flow are frequently modified by other factors, for instance water temperature. Fishes are poikilotherms, and hence swimming activity increases with temperature. Because of the low swimming ability at low water temperatures, this may be a restricting factor for ascending obstacles especially in spring and autumn. Experiences from several studies indicate that even small obstacles are difficult to ascend at temperatures below about 5-6 °C, and at least 8 °C seems to be necessary to ascend larger obstacles. Most studies conclude that when the water temperature has increased to the critical temperature necessary for ascending obstacles, it appears to have little effect on the initiation of runs. However, some exceptions exist.

INTRODUCTION

Several environmental factors may influence the upward migration of salmonids in rivers. The rate of flow is most frequently cited as controlling ascent. However, the effects are modified or strengthened by other factors, e.g. water temperature and quality and general meteorological conditions (reviewed by Banks 1969). In this paper, effects of water temperature on upstream migration is reviewed. Water temperature is particularly important in the spring in northern, temperate streams. Even small obstacles are difficult to ascend at low temperatures. High water temperatures may also decrease the intensity of upward migration. Therefore, in this review effects of low, optimum and high water temperatures will be discussed in separate sections. First however, as a basic for this discussion, the relation between maximum sustained swimming speed and temperature of fishes is presented.

CRITICAL SWIMMING SPEED AND TEMPERATURE

Fishes are poikilotherms, and therefore all activity, including swimming activity, increases with temperature until the optimum range specific for each species is reached. This is demonstrated in Fig. 1, which illustrates the critical swimming speed of fingerling sockeye salmon at different temperatures (Brett 1967). Above the optimum range, oxygen becomes a limiting factor for swimming effort, and hence, swimming speed decreases with increasing temperature.

MIGRATION AT LOW WATER TEMPERATURES

Because of the low swimming ability at low temperatures, low temperature may be a restricting factor for ascent. This is specially noticeable where fish have to pass obstacles.

Several reports describe the role of water temperature barriers in governing salmonid movements under natural conditions. Menzies (1939) reported that in the Rivers Tay and Spey in Scotland Atlantic salmon would enter from the estuary when temperature was 1 °C, but when temperature was below 4.5 °C they never proceeded beyond 15 or 20 miles from the head of the tide. They would not ascend obstacles at temperatures below 5-6 °C, but freely passed up-river at higher temperatures. Pyefinch (1955) made similar observations at Pitlochry Dam in Scotland, and Jackson & Howie (1967) at Cataleen's Fall in the Erne River (Republic of Ireland), respectively. Mills and Graesser (1981) refer to the upstream movement of salmon in the River Cassley in Scot-

land in the spring being governed by water temperature and point out that fish do not jump some formidable falls on the river until the water temperature exceeds 11 °C.

In the first obstacle in the River Vefsna in Norway (the Forsjordfossen waterfall), a temperature barrier of about 8 °C seems to exist. The first Atlantic salmon usually enter the pool beneath the Forsjordfossen waterfall in late May, but high water flows ($>300 \text{ m}^3 \text{ s}^{-1}$) and low water temperatures (3-5 °C) prevent them from ascending the waterfall at that time (Jensen et al. 1989). Experiences from many years have revealed that neither Atlantic salmon nor anadromous brown trout manage to ascend this 10 m high waterfall until the spring flood has decreased to below $300 \text{ m}^3 \text{ s}^{-1}$ and the water temperature has increased to above 8 °C. This temperature barrier is demonstrated in Fig. 2. In most years water flow decreases to below $300 \text{ m}^3 \text{ s}^{-1}$ and water temperature increases to above 8 °C at about the same time, and therefore the effects of these two parameters are difficult to separate. In 1981, however, water flow became less than $300 \text{ m}^3 \text{ s}^{-1}$ by 12 June. Still, ascent did not commence until the water temperature reached 7.3 °C five days later, and only 14 fish were recorded over the next two weeks until temperatures exceeded 8 °C. A large number of fish ascended when temperatures were between 8-9 °C (Fig. 2).

A temperature barrier of about 8 °C is observed in spring also at obstacles in some other Norwegian rivers, like Kobbforsen in the River Ranaelva (Berg 1979) and Sandsfossen in the River Suldalslågen (Johnsen et al. 1996).

In autumn, migration may again be restricted by low water temperatures. This was demonstrated among brown trout spawners in the fish ladder at the Hunder dam on the River Gudbrandsdalslågen, eastern Norway by Jensen and Aass (1995). When the Hunder trout starts migrating in late June, the water temperature usually exceeds 10 °C, and is commonly 11-18 °C during the most intensive migration period in August and the first half of September. However, in late September and October, when temperatures were below 10 °C, ascent decreased, and at temperatures below 6 °C no fish ascended.

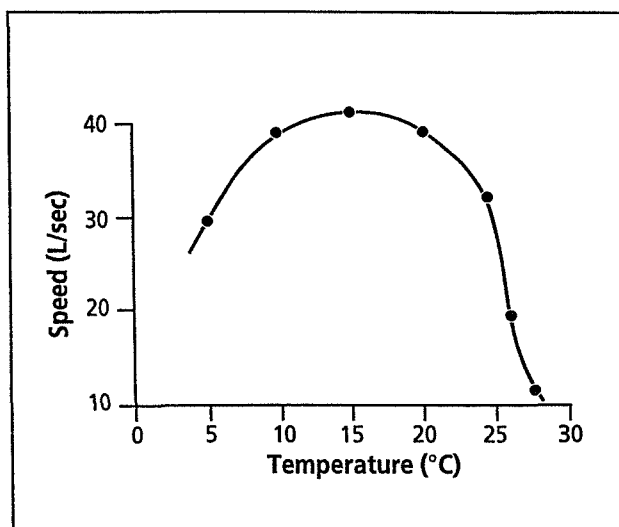


Fig. 1. The relation between temperature and the critical swimming speed of fingerling sockeye salmon acclimated to 15 °C (from Brett 1967).

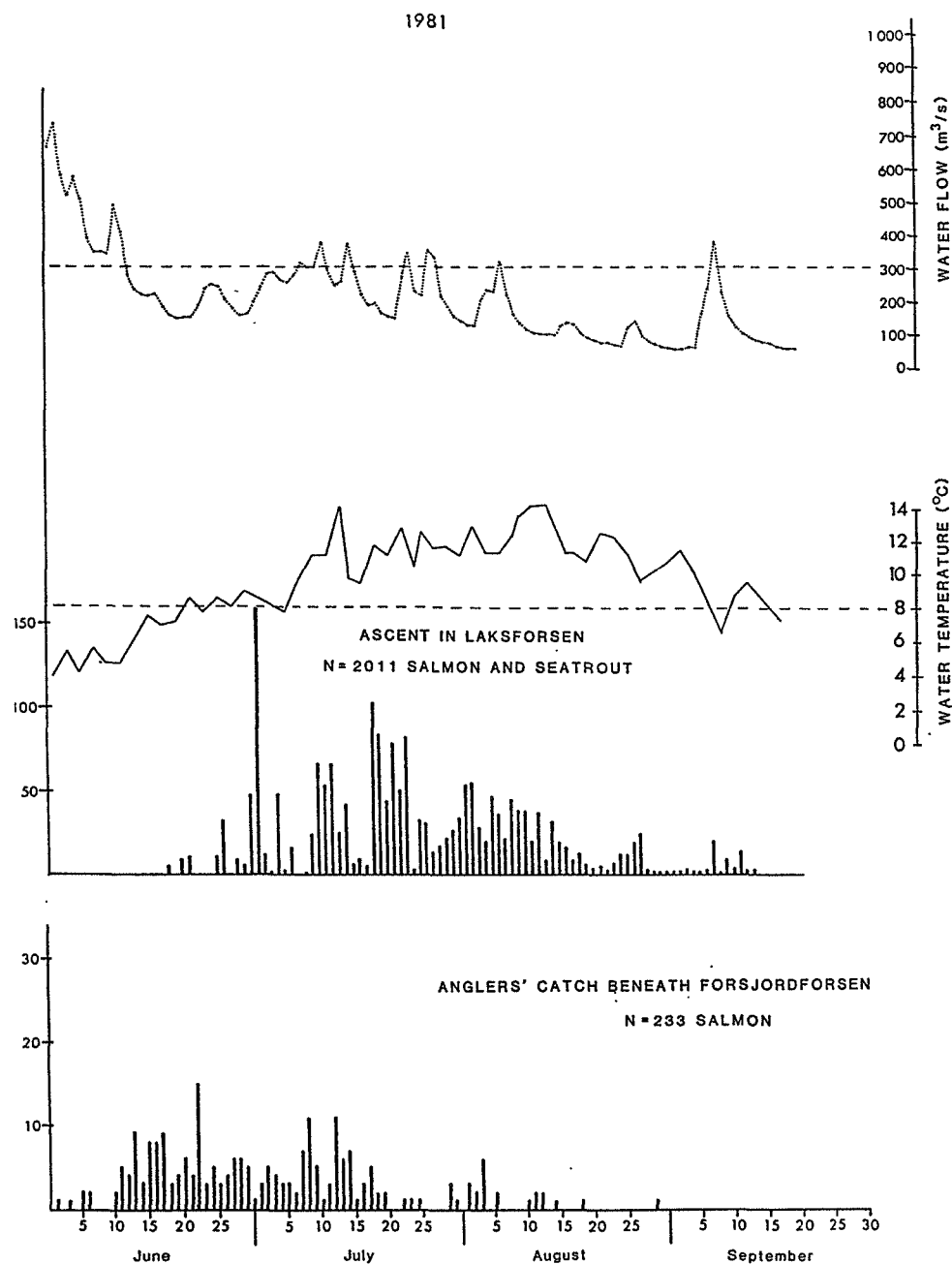


Fig. 2. Daily catch of Atlantic salmon in the pool beneath the Forsjordfossen waterfall in the River Vefsna in 1981, daily ascent of anadromous fish in the fishway in the Laksfossen waterfall 13 km farther upstream, as well as water temperature (°C) and flow (m³ s⁻¹) in the river.

MIGRATION AT OPTIMUM WATER TEMPERATURES

Most studies conclude that when the water temperature has increased to above the critical temperature necessary for ascending obstacles, it appears to have little effect on the initiation of runs (Banks 1969). However, some exceptions exist. In the Laksfossen waterfall in the River Vefsna in Norway, Jensen et al. (1986) analysed daily ascent of Atlantic salmon over 3 years. Ascent was correlated to 12 physical and meteorological parameters by multiple regression analysis. Increase in water temperature was included in the regression model in all 3 years. Increase in river flow was also included in 2 of the 3

years, while no other variable was included in the regression model at the 0.05 significance level. Similarly, Swanberg (1997) demonstrated that migration of bull trout *Salvelinus confluentis* in the Blackfoot River, Montana was cued by an increase in maximum daily water temperature and a decrease in discharge from peak runoff.

MIGRATION AT HIGH WATER TEMPERATURES

High water temperatures may decrease the intensity of upward migration. Elson (1969) concluded that the intensity of Atlantic salmon ascent in the Northwest Miramichi River increased with increasing water temperature to a temperature of within 5 or 6 °C of the upper lethal temperature limit, and then decreased. In the River Dee, Wales, Alabaster (1990) estimated the rate of migration of Atlantic salmon to be reduced to about 0.5 of the average at a mean weekly maximum water temperature of 19.5 °C, and reduced to about 0.25 of the average at 25.5 °C.

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SIK OCH ÖRING I EN FISKTRAPPA; OLIKA VATTENFÖRINGAR FÖR RESPEKTIVE ART

WHITEFISH AND TROUT IN THE SAME FISHWAY; DIFFERENT FLOW FOR DIFFERENT SPECIES

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ABSTRACT

Lake Hornavan and Lake Storavan in the upper part of the Skellefte river are regulated for water power production (Fig. 1). In connection with the regulating dams some fishways have been built. The upper part of these fishways is a pool and orifice fishway and the lower part is a Denil fishway (Fig. 2). Two of the most important species of fishes in the region are trout and whitefish. Both these species migrate between the lakes and the outlet streams. Studies have shown that an increased flow in the fishways gives an increasing number of ascending trouts but a decreasing number of ascending whitefish (Table 1-4). A decreased flow in the fishways gives quite the opposite effect. The ascending time of trout and whitefish are almost similar (Fig. 3). This means that the fishways can not be effectively used for both species at the same time. Because of the low number of ascending trouts the fishways are at present mainly used for trout.

BAKGRUND

Sjöarna Storavan och Hornavan i övre delen av Skellefteälven är reglerade för vattenkraftändamål (Fig. 1). Regleringsamplituden i Storavan resp Hornavan är 2,0 resp 2,9 m.

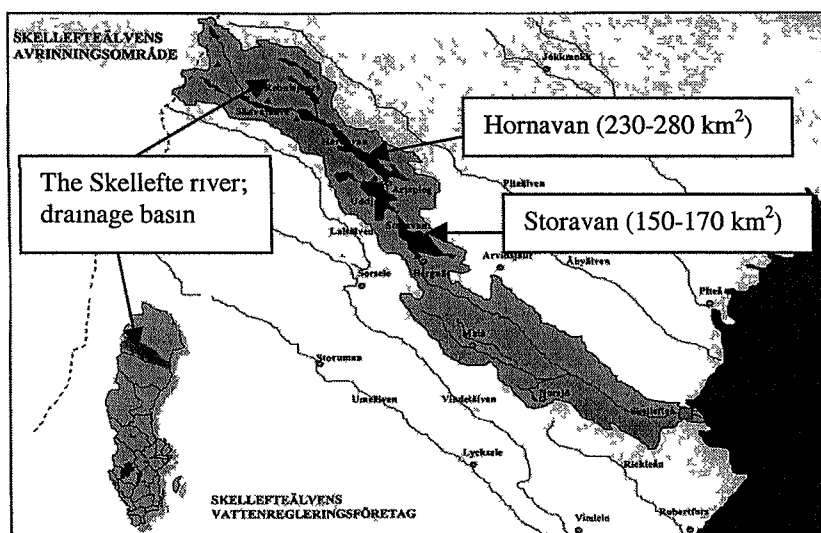


Fig. 1. Skellefteälven; avrinningsområde och regleringssjöarna Hornavan och Storavan (Karta från Skellefteälvens vattenregleringsföretag).

Fig. 1. The Skellefte river; drainage basin and the regulated lakes Hornavan and Storavan (Map from Skellefteälvens vattenregleringsföretag).

Det råder alltså ett nödvändigt samspel mellan strömmarna och sjöarna i öringens livscykel och det är viktigt att öringens vandring mellan strömmarna och sjöarna fungerar bra.

FISKTRAPPOR VID REGLERINGSDAMMARN

I anslutning till regleringsdammarna har anlagts totalt fyra fisktrappor, av vilka en ligger vid utloppet av Storavan (Bergnäsdammen), medan resterande tre fisktrappor ligger vid två utlopp från Hornavan (Tjärnas och Hemströmmen). Fisktrappan vid Bergnäsdammen anlades omkring 1955, medan fisktrapporna vid dammarna i Tjärnas och Hemströmmen anlades omkring 1960. Samtliga fisktrappor är byggda enligt samma princip. Den övre delen av fisktrapporna består av en bassängtrappa, medan den nedre delen består av en Denilränna (Fig. 2). Fisktrappan vid Bergnäsdammen är i sin helhet byggd i trä, medan fisktrapporna i Tjärnas och Hemströmmen är byggda i betong, med undantag av Denilrännan.

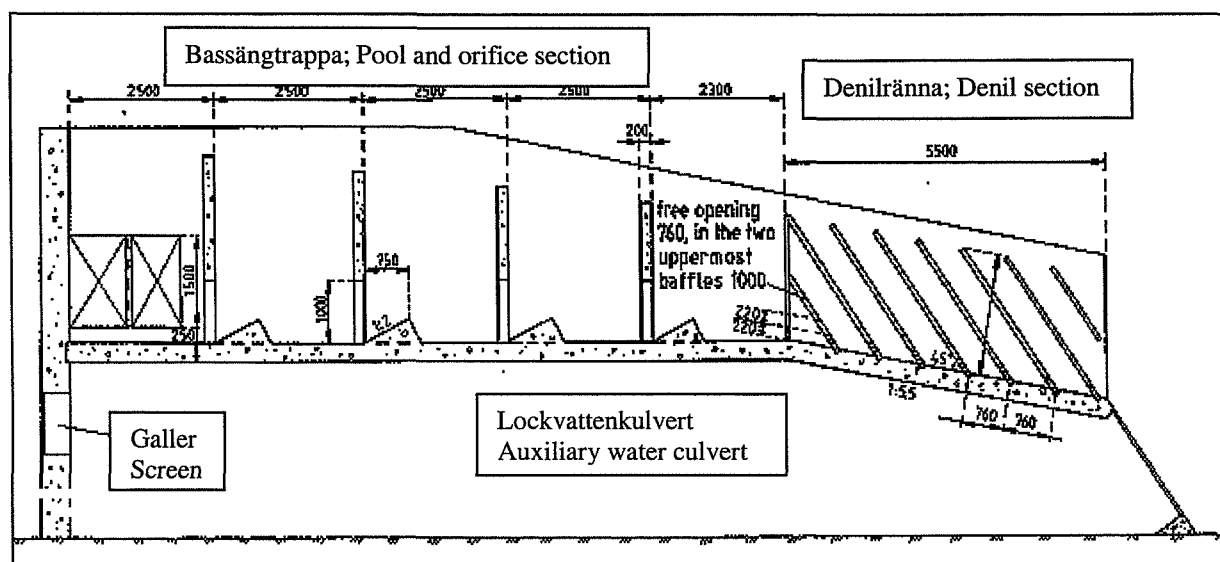


Fig. 2. Principskiss över fisktrappan i Tjärnas vid utloppet av Hornavan.
Fig. 2. Structures of the Tjärnas fishway at the outlet of lake Hornavan.

Fisktrappan vid Storavans utlopp är ca 30 m lång, medan fisktrapporna vid Hornavans utlopp är 15-20 m långa. Den maximala tappningen i fisktrapporna uppgår till ca 1 m³/s, men storleken på denna tappning kan regleras stegvis med spetluckor i utgången av fisktrapporna. Därutöver sker en tappning av vatten (s k lockvatten) till området vid ingången till fisktrapporna för att locka upp fisk i trapporna. Denna tappning sker i speciella rännor eller kulvertar under fisktrapporna (Fig. 2). Mängden lockvatten uppgår till ca 2 m³/s.

Fallhöjden i fisktrappan vid Storavans utlopp varierar mellan ca 1,0 m och ca 3,0 m, beroende på vattenstånd i sjön. Motsvarande fallhöjd i fisktrapporna vid Hornavans utlopp varierar mellan 0 och ca 2,3 m, beroende på vattenstånd i sjön. Fallhöjden i fisktrapporna är således relativt liten.

Sikens och öringens vandringsperioder sammanfaller i stort och omfattar i huvudsak perioden juni-augusti (Sörensen 1959, Fig. 3). Detta innebär att fisktrapporna måste fungera samtidigt för bägge arterna för att vandrigen ska kunna anses fungera tillfredsställande.

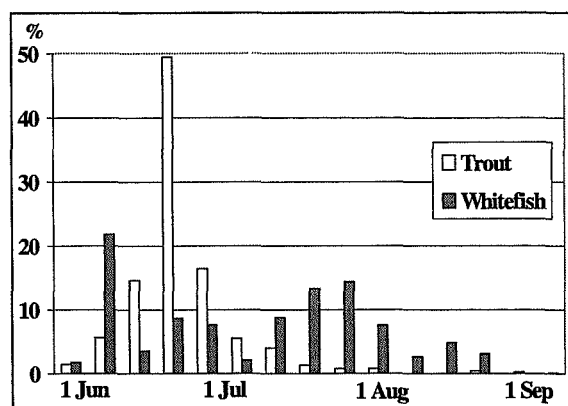


Fig. 3. Uppvandringstider för öring och sik.
Fig. 3. Ascending time of trout and whitefish.

RESULTAT FRÅN FUNKTIONSSTUDIER AV FISKTRAPPORNA

Speciella studier, vilka främst bedrevs omkring 1960, har visat att fisktrapporna vid utloppen av Storavan och Hornavan ej fungerar bra för öring och sik samtidigt. Öring har visat sig vandra bättre vid höga tappningar i fisktrapporna, medan sik visat sig vandra betydligt bättre vid låga tappningar. I fisktrappan vid Storavans utlopp påverkas uppvandringen av öring och sik dessutom av tappningsfördelningen genom de två utskoven i Bergnäsdammen.

Studier av fisktrappan vid Bergnäsdammen visade att tappningsändringar genom de bägge dammutskoven medförde stora skillnader i uppvandring av öring resp sik (Sörensen 1961). En högre tappning genom det vänstra dammutskovet (utskovet närmast fisktrappan) medförde en ökad uppvandring av öring, men en minskad uppvandring av sik. Uppvandringen av öring per dygn var ca 1,7 ggr högre vid en tappning av 5 m³/s genom det vänstra utskovet, jämfört med vid nolltappning genom utskovet (Tabell 1).

Tabell 1. Uppvandring av öring vid olika tappningar genom Bergnäsdammen.
Table 1. Ascending of trout at different discharges through the Bergnäs dam.

Tappning i fisktrappan Flow in the fishway	Tappning (m ³ /s); Discharge (m ³ /s)		Antal öringar; Number of trouts	
	Höger dammutskov Right flood gate	Vänster dammutskov Left flood gate	per dygn per 24 h's	Totalt (n) Total (n)
1/1;1/2	125	0	14,2	142
1/1;1/2	120	5	23,6	189

Uppvandringen av sik per dygn var ca 3 ggr lägre vid en tappning av 15 m³/s genom det vänstra dammutskovet, jämfört med vid nolltappning genom utskovet (Tabell 2).

Tabell 2. Uppvandring av sik vid olika tappningar genom Bergnäsdammen.

Table 2. Ascending of whitefish at different discharges through the Bergnäs dam.

Tappning i fisktrappan Flow in the fishway	Tappning (m ³ /s); Discharge (m ³ /s)		Antal sikar; Number of whitefish	
	Höger dammutskov Right flood gate	Vänster dammutskov Left flood gate	per dygn per 24 h's	Totalt (n) Total (n)
1/12	125	0	1 010	2 019
1/12	100-125	5	619	3 711
1/12	110	15	336	2 683

Resultaten från studierna visade tydligt att öring hade lättare att hitta ingången till fisktrappan vid en högre tappning genom det vänstra dammutskovet, medan förhållandet var det rakt motsatta för siken. Det kan noteras att vid studierna av öringuppvandringen nyttjades en högre tappning i fisktrappan än vid studierna av sikuppvandringen (jfr Tabell 1-2).

Vid likvärdiga tappningar genom de bägge dammutskoven erhöles en betydligt bättre uppvandring av öring ifall tappningen i fisktrappan var hög (Fig. 4 och Tabell 3). Vid halv tappning (1/2) i fisktrappan var uppvandringen av öring per dygn ca 4 ggr större än vid 1/12-tappning. Vid full tappning (1/1) var uppvandringen av öring ca 3 ggr större än vid 1/12-tappning. Ännu större skillnader erhöles i uppvandring av sik vid de olika tappningarna i fisktrappan. Vid 1/12-tappning var uppvandringen av sik per dygn nästan 100 ggr större än vid 1/1-tappning. Vid 1/2-tappning i fisktrappan var uppvandringen av sik däremot endast ca 2 ggr större än vid 1/1-tappning.

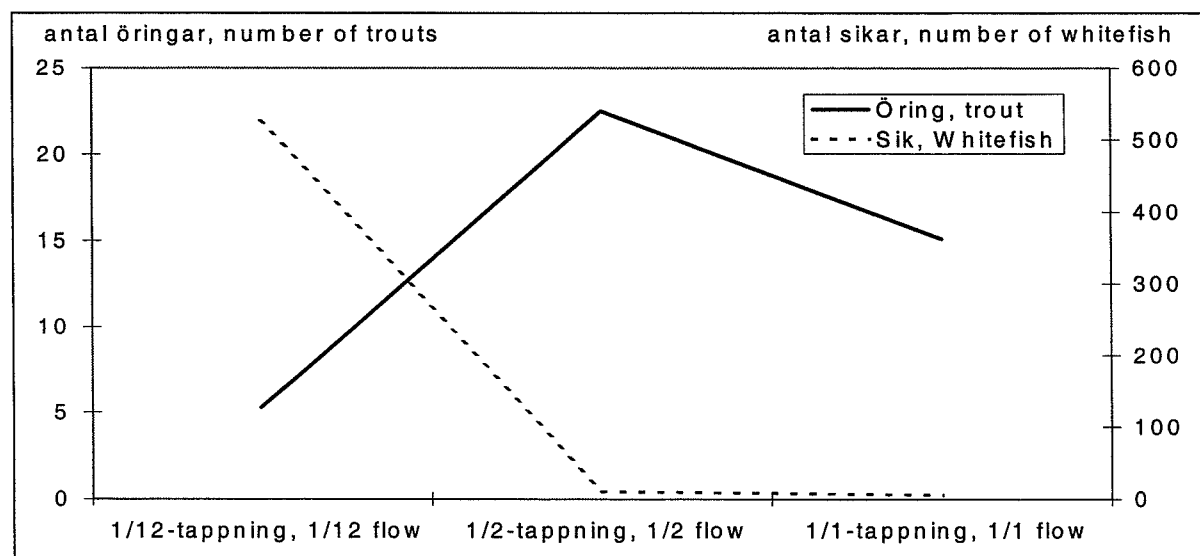


Fig. 4. Uppvandring av öring och sik vid olika tappningar i Bergnäs fisktrappa.

Fig. 4. Ascending of trout and whitefish at different flows in the Bergnäs fishway.

Tabell 3. Uppvandring av öring och sik vid olika tappningar i Bergnäs fisktrappa.
Table 3. Ascending of trout and whitefish at different flows in the Bergnäs fishway

Tappning i fisktrappan Flow in the fishway	Tappning (m ³ /s) Discharge (m ³ /s)		Antal fiskar per dygn Number of fishes per 24 h's		Totalt (n) Total (n)	
	Höger dammutskov Right flood gate	Vänster dammutskov Left flood gate	Öring Trout	Sik Whitefish	Öring Trout	Sik Whitefish
1/1	110-125	0; 5; 15	15,1	5,6	151	111
1/2	110-125	0; 5; 15	22,5	10,3	180	165
1/12	100-125	0; 5; 15	5,3	526	42	8 413

Studier av sikuppvandringen i fisktrapporna vid Hornavans utlopp (Tjärnas resp Hemströmmen) gav i stort samma resultat som studierna av uppvandringen i fisktrappan vid Bergnäsdammen. Vid 1/4-tappning i fisktrapporna var uppvandringen av sik betydligt större än vid 1/1-tappning. I Tjärnas var uppvandringen av sik per dygn ca 10 ggr större vid den lägre tappningen i trappan (Tabell 4). I Hemströmmen var skillnaden i uppvandring av sik något mindre mellan de två tappningarna, eller ca 5 ggr högre vid den lägre tappningen.

Öringen har ej medtagits i redovisningen av studierna av fisktrapporna i Tjärnas resp Hemströmmen, eftersom endast några enstaka öringar vandrade upp i fisktrapporna.

Vid studierna i Tjärnas och Hemströmmen vittjades fisktrapporna 3 ggr per dygn. Sikuppvandringen i Tjärnas varierade under dygnet och var störst under förmiddagen (kl 07.00-13.00). I Hemströmmen var uppvandringen av sik mer jämnt fördelad över dygnet, möjligen med en viss koncentration till eftermiddagen (13.00-19.00). Sammantaget erhöles således inget tydligt mönster i sikens uppvandring under dygnet.

Tabell 4. Uppvandring av sik vid olika tappningar i fisktrappan i Tjärnas.
Table 4. Ascending of whitefish at different flows in the Tjärnas fishway.

Tappning i fisktrappan Flow in the fishway	Period Period	Antal sikar Number of whitefish				Totalt (n) Total (n)
		07.00	13.00	19.00	Per 24 h's	
1/1	1/7-4/8	7	12	9	28	436
1/4	1/7-4/8	103	103	55	261	2601
1/1	13/8-30/8	1,2	3,7	1,9	7	49
1/4	13/8-30/8	12	28	26	66	535

En del sik som vandrade upp i fisktrapporna i Tjärnas och Hemströmmen längdmättes. Resultaten visade att andelen större sik (> 30 cm) var något högre vid 1/1-tappning i fisktrapporna än vid 1/4-tappning. I fisktrappan i Tjärnas ökade denna andel från 27 % till 40 % (Tabell 5). Skillnaden i sikens storleksfördelning mellan de två tappningarna var dock ej

markant. I Hemströmmen var resultatet jämförbart med Tjärnas. Eftersom antalet längdmätta sikar var relativt litet (n = 162 i Tjärnas) är det vanskligt att dra alltför långtgående slutsatser av dessa studier.

Tabell 5. Längdfördelning på uppvandrande sik vid olika tappningar i fisktrappan i Tjärnas.
Table 5. Length distribution of ascending whitefish at different flows in the Tjärnas fishway.

Tappning i fisktrappan Flow in the fishway	% sik % whitefish			Totalt (n) Total (n)
	< 25 cm	25,1-30,0 cm	> 30 cm	
1/1	11,1	48,8	40,1	45
1/4	12,8	59,8	27,4	117

Den öring som vandrar upp i fisktrapporna utgörs av både smolt och återvändande lekfisk. Detta innebär att storleken på den uppvandrande öringen kan variera kraftigt. Den minsta öringen som vandrar i fisktrapporna är ca 20 cm och den största öringen är ca 75 cm. I vikt motsvarar dessa längder ca 0,1 kg respektive ca 6-7 kg. De mest frekventa längderna på öringen är 40-60 cm (ca 1-3 kg).

I Fig. 5 redovisas längdfördelningen på den öring som vandrade upp i fisktrappan vid Bergnäsdammen 1990. Detta år har valts som exempel med tanke på att antalet uppvandrade öringar detta år var relativt stort (n=122). Resultatet från 1990 års kontroll bedöms ej avvika nämnvärt från övriga år. I fisktrappan vandrar både vild och odlad öring. Den odlade öringen härrör från utsättningar som Skellefteälvens vattenregleringsföretag utför årligen enligt ålägganden i vattendomar. Den öring som sätts ut är 25-30 cm lång och har en medelvikt på ca 200 g. Vid 1990 års kontroll var den odlade öringen som vandrade upp i trappan av större storlekar än den vilda (Fig. 5). Detta resultat kan möjligen tolkas som att vild öring har större drift och bättre förmåga än odlad öring att vandra upp i fisktrappan vid mindre storlekar.

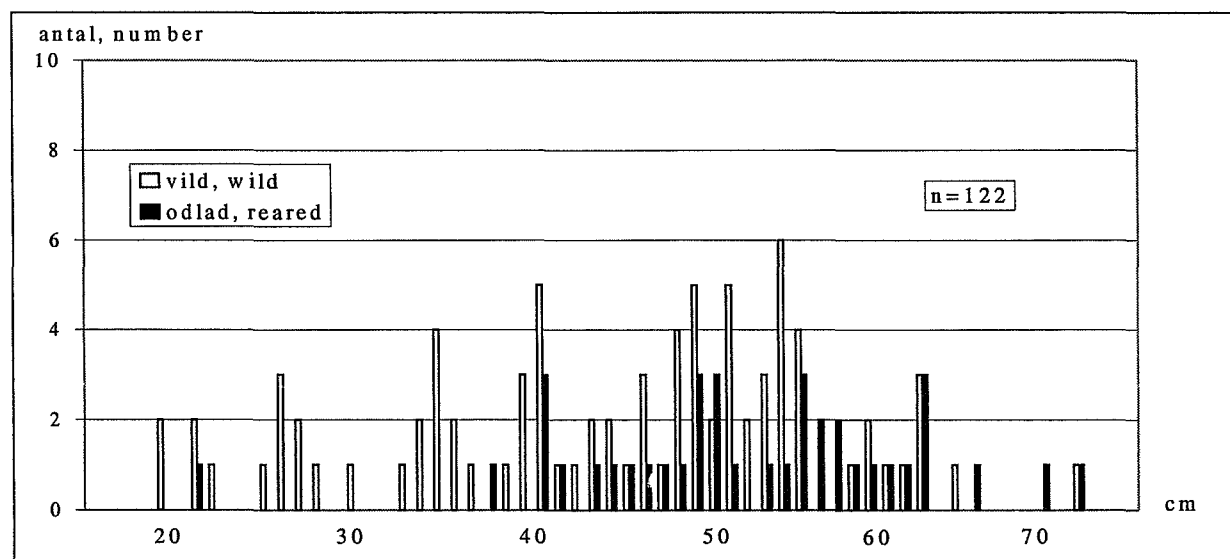


Fig. 5. Längdfördelning hos öring i fisktrappan vid Bergnäsdammen (från studier 1990).
Fig. 5. Length distribution of ascending trout at the Bergnäs fishway (from studies 1990).

Sammanfattningsvis visar studierna att fisktrapporna i Skellefteälven vid utloppen av Storavan och Hornavan ej fungerar bra samtidigt för öring och sik. Däremot fungerar fisktrapporna bra eller relativt bra för en art i taget. I dagsläget prioriteras uppvandringen av öring, eftersom detta bestånd är svagt. Dessutom har sikens betydelse för fisket i området minskat under senare år.

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TELEMETRISTUDIER VID FISKVÄGAR

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ABSTRACT

Telemetry studies in connection with fishways: Many fishways, ladders and others constructions do not functioning or have ineffectual function. In many cases it is of great importance to know how the fish is moving towards the fishway and finding the entrance. Since 1993 experiments were carried out to find useful method for positioning of small-scale movement of fish. High-speed transmitters (50 -250 msec pulsgap) working on the same frequency in combination with a high-speed antenna-switch were used. The method made it possible to measure the small-scale movement in a square of 5 * 5 meter with a maximal deviation of ± 2 m within 1 second. In field study of salmon during spawning movement at the Lilla Edet Hydropower plant in Götaälven 92 cases were registered then the salmon tried to find the entrance of fishladder without success.

INLEDNING

Många fiskvägar har bristande funktion eller fungerar inte alls. Bristerna bero oftast på trappans tekniska utformning och dess oförmåga att anlocka fisk genom felplaceringen av trappans nedersta steg. Om man skall rätta till dessa brister bör man med god precision kunna bestämma fiskens position i förhållande till trappan och/eller i trappan. Ett tänkbart hjälpmedel i detta sammanhang är radiotelemetry. Försök att mer exakt, inom ett begränsat utrymme (10*10 meter)kens förflyttningar följa fiskar provats i Indalsälven och i Ljungan 1991-92 (Gönczi 1992a-b). Den tillämpade metoden, kallad dipolmetoden, visade sig vara för långsam om fiskens ansimning mot ingången var mer än 0,5 m/s. Sedan 1993 påbörjades därför en serie försök att finna metoder för positionsbestämning av fisk vid småskalig förflyttning - närtelemetry.

METODIK

Telemetry som normalt används för övervakning och vandringskontroll är alldeles för långsam för närtelemetry. Endast få försök med positionsbestämning på kort avstånd med hjälp av telemetry (även ultraljud) finns beskrivna i litteraturen (Lagardere et.al 1990 och Juel and Westerberg 1993). Valet vid metodutvecklingen föll på en kombination av mycket snabba radiosändare och en mottagare med s k snabb antennswitch (ANTSCA). Det finns några vägar att förkorta scanningstiden vid telemetry. Normalt tilldelas varje individ en egen frekvens för säkerställande av identiteten vilket i sin tur kräver en viss lyssningstid per sändare. Lyssningstidens längd beror på sändarens sändhastighet (PG), antal antenner som används och antalet signaler som krävs per antenn för säkerställd identifikation. För att

eliminera behovet att scanna på många frekvenser tillverkas samtliga radiosändare på samma (upp till 15 st/frekv.) eller fåtal frekvenser. Därigenom förkortas scanningstiden avsevärt. För att ytterligare minska tidsåtgången tillverkas sändare på 50 - 250 msec PG med 25 msec stegring. Det senare medger individuell identifiering under förutsättning av att inte fler än två fiskar vistas inom antennernas räckvidd. Genom att både PG och pulsens varaktighet varierar något mellan varje sändare underlättas sändarnas identifiering genom dataanalys.

Det tekniska försöket genomfördes med mottagare med modellbeteckning RX-900 C tillverkad av Televilt International AB. Mottagaren har en intern logger med minneskapacitet på 1 Mb. Den lägsta detekterbara signalen är -136 dBm. Mottagaren anslutits till en antennswitch (Fig. 1.) för upp till 10 antenner, varav i tekniska försöket användes fyra och i Lilla Edet tre antenner. Antennswitchens scanningstid är steglöst inställbar på mellan 40 och 4000 msec.

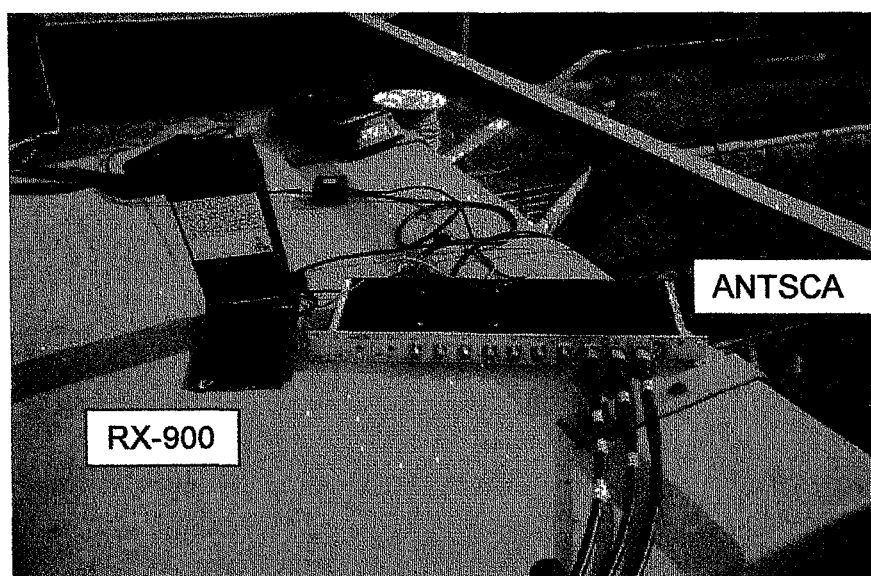


Fig. 1. Radiorecivier RX-900 with antennscanner (ANTSCA) for 10 antennas

Eftersom spaningsarealen är ytterst begränsad bör antennernas mottagningskapacitet mycket starkt begränsas. Viktigt är dessutom att eliminera antennernas rikt känslighet. Därför användes en vertikalt monterad spröstantenn (halverad dipol) (Fig. 2.). Genom att förse även sändarna med vertikalt monterade antenner minskas variationen av den mottagna signalstyrkan, så som falsk förflyttning, eftersom styrkan varierar även hos en helt stillastående sändare beroende bl a av turbulens i vatten, vågrörelser, temperaturskiktningar men även av sändarnas något varierande uteffekt. Ju fler data per tidsenhet som kan samlas in desto större är möjligheten att göra rättvisande beräkningar av fiskens "äkta" förflyttning.

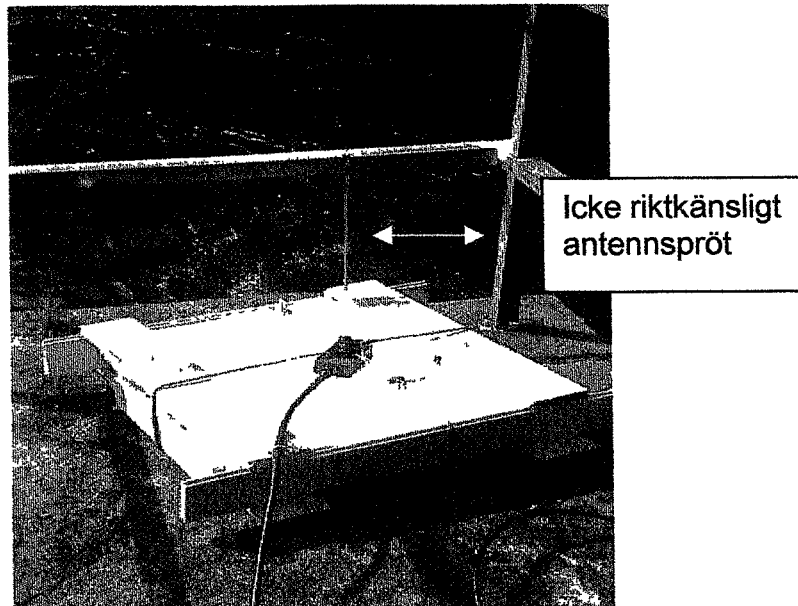


Fig. 2. Antenna used for small-scale telemetry, half-dipol non-direktional antenna

UNDERSÖKNING VID LILLA EDET, GÖTAÄLVEN

Vid kraftverket i Lilla Edet har en ny fiskväg byggts i samband med tillbyggnaden med en ny generator i avsikt att ersätta den gamla trappan. Försök bl a med Carlin-märkta fiskar visade att de flesta laxarna valde att vandra upp i den gamla trappan. Risken var uppenbart att om gamla trappan skulle stängas skulle merparten av laxuppvandringen utebli. Frågeställningen för den telemetriundersökning som genomfördes med ovan beskrivna metodik var att belysa om laxar försöker hitta ingången av den nya trappan och i så fall lyckas de ta sig in i densamma. Följande uppställning användes (Fig. 3.)

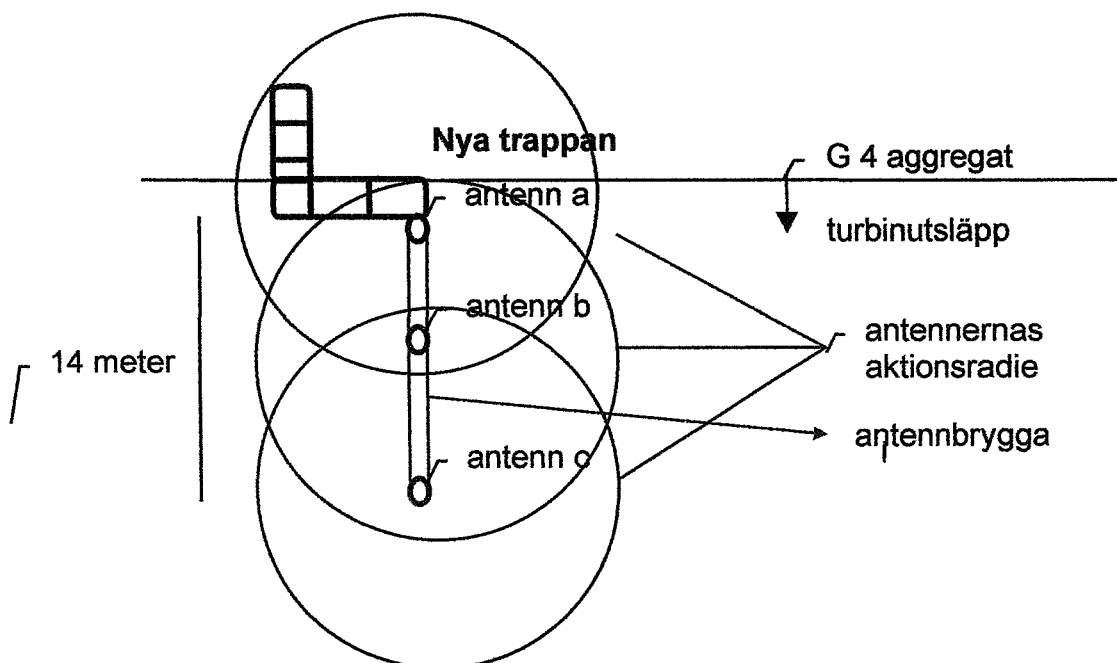


Fig. 3. Investigation area until the new fishladder at Lilla Edet Power Station. Telemetry with nondirektional, half-dipol antennas

Totalt har 11 laxar av 17 radiomärkta registrerats av mottagaren. Vid 92 tillfällen var någon lax maximalt 7 meter från trappans ingång. Ingen av dessa laxar har gått in i trappan. däremot har 6 av dessa hittat och vandrat upp i den gamla trappan. Undersökningen bekräftade således att laxar har svårt att finna nya trappans ingång. Det saknas topografiska strukturer för att leda fisken i området där vatten strömmen genom kraftverkets 4.e aggregat uppenbarligen är för dominerande i förhållande till trappans lockvatten.

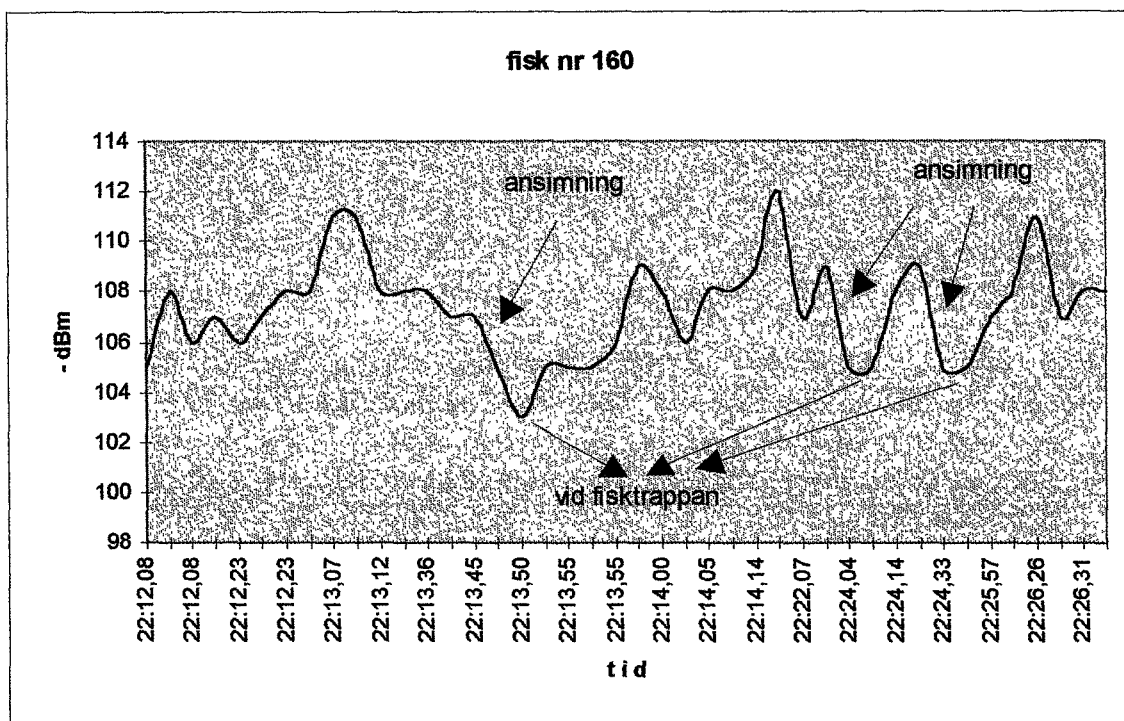


Fig. 4. The salmon tried to find (ansimning) the fishladder (vid fisktrappan) three times within 11 minutes

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Counting Atlantic Salmon and Sea Trout in Fishways in Southern Sweden

- Results and Observations

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ABSTRACT

Migrating Atlantic salmon and Sea trout were counted in fishways situated at two hydropower plants in the southern part of Sweden. The purpose of the investigations was to collect data about the number of fish that passed the fishways, the time of fish migration during the year and fish behavior at the fishways. The results showed variation in passage and migration between salmon and sea trout as well as between the two river systems. Analysis of results from several years revealed patterns and problems that would be difficult to obtain from one year's data. As well as providing data on fish passage, the research also resulted in experience that may be useful in investigations at other rivers. For instance, the trapping and manual counting of salmon and sea trout of different size in the same trap caused some problems. It was also experienced that while migrating activity was observed in the river both during day and night, very few salmonides passed the fishway at dark.

INTRODUCTION

Fish counting in fishways and other observations of fish passage are often used in order to collect information about both fish migration and the efficiency of different fish pass facilities (Travade, 1990). The results can also be used in monitoring programs for certain fish populations and in the management of fishery in a river system.

Research about fish passage has been done in some fishways in the southern part of Sweden. The results and experiences that are presented here, from fishways located at two hydropower dams, provide knowledge that may be useful in investigations and fishway management in other rivers.

SITES OF THE INVESTIGATIONS

At two hydropower stations in southern Sweden; Lilla Edet in River Göta älv and Marieberg in River Mörrumsån, migrating Atlantic salmon (*Salmo salar* L.) and Sea trout (*Salmo trutta* L.) have been counted through a period of more than fifteen years. The purpose of the investigations was primarily to collect data about the number of fish that pass the fishways, time of fish migration during the year and fish behavior at the fishways. The results have been used to improve functioning at present fishways, but also in population monitoring etc.

The River Göta älv runs from Lake Vänern to the Swedish west coast. (Fig. 1.) The annual mean discharge is about 550 m³/s. The hydropower station of Lilla Edet is located in the main

stream, about 55 km from the mouth of the river. At present two fishways are situated at the dam of the powerstation; an older one (built in wood) on the west side of the river, and a newer one (built in concrete) in the middle part of the dam, close to a turbine outlet. Both are of the same construction type; pool-and-weir. Through the counting period, since 1983, an average of about 1500 adult salmonides has passed the fishways yearly. (Varying between about 700-3600 individuals per year. Cultivated salmon dominate in number.)

The River Mörrumsån runs into the Baltic Sea (Fig. 1.), and has an average flow of about 27 m³/s. Minimum flow is 7 m³/s. A fishway is built at the dam of the hydropower station Marieberg, about 10 km from the mouth of the river. This fishway, which is of vertical-slot type, is situated close to the west riverbank, at the opposite side of the river from the turbine tailrace. A small passage from a pool below the fishway ends close to the turbine outlet. Through the counting period (1974-1991) about 400 to 3300 adult salmonides yearly have passed the fishway. (Average number about 1000 individuals per year.) Due to problems when large amounts of salmon and sea trout gathered in and close below the fishway, the counting ended in the autumn of 1991. Since then the fishway stays open to passage and the control of passage and upstream recruitment is made by electrofishing.

The fish counting in both R. Göta älv and R. Mörrumsån was done by trapping in the fishways, followed by manual counting. At Lilla Edet also automatic counting has been used. (Trap and automatic counter, fig. 4.) The activity and search pattern of salmon at Lilla Edet was also followed in an area close to the fishways by using radio telemetry (Gönczi, 1998).

The counting period in the two river systems mainly was started in late May and ended at the beginning of November. Though in R Göta älv the counting period has varied and in some years has started in the beginning of May and not ended until late November.



Figure 1. Location of the rivermouth of R. Göta älv (R.Gö.) with Lilla Edet and R. Mörrumsån (R.Mö.) with Marieberg.

RESULTS AND OBSERVATIONS

The investigations during a period of more than fifteen years, both at Lilla Edet and Marieberg, have provided a large amount of data. Some of these data as well as experiences may be of general interest and are presented in the following.

Fish migration during summer and autumn seasons

In Sweden the period of spawning migration of salmon and sea trout in the rivers could start at spring and continue until late autumn. The spawning periods differ between rivers and populations, but in this south region of Sweden the spawning by sea trout often begins in the middle of October while salmon spawning period often starts about 2 weeks later. The migration and fish passage at Lilla Edet and Marieberg that has been noted shows some differentiation in patterns (Figure 2.a-d.)

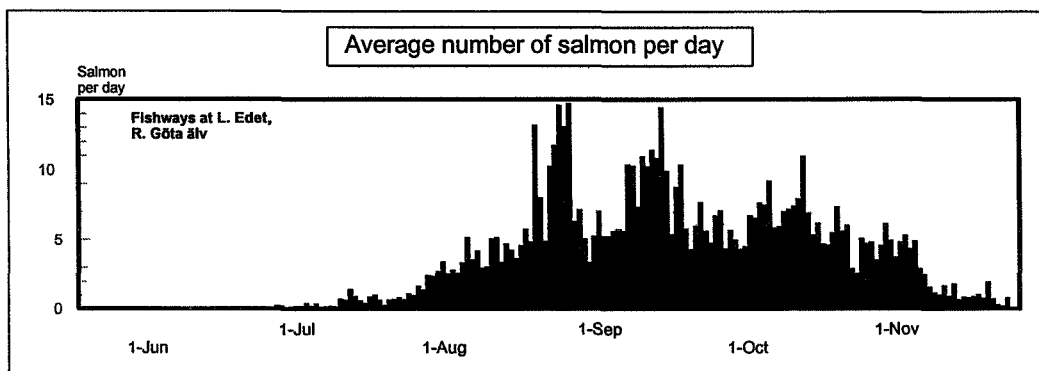


Figure 2.a. Salmon passage at Lilla Edet.

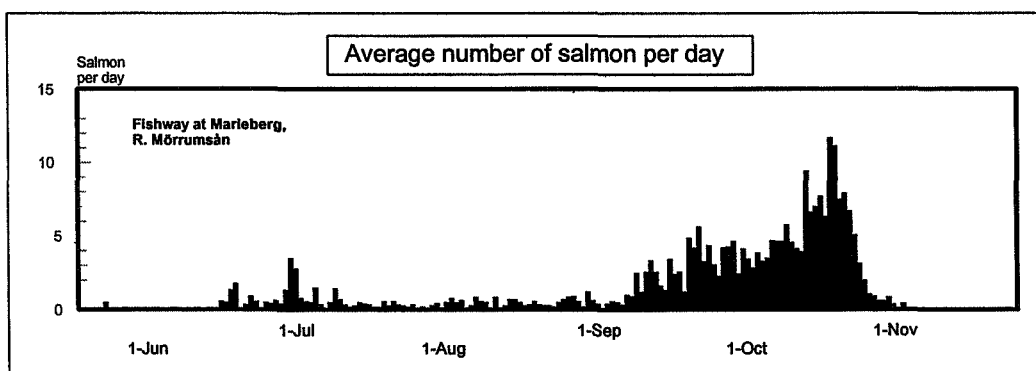


Figure 2.b. Salmon passage at Marieberg.

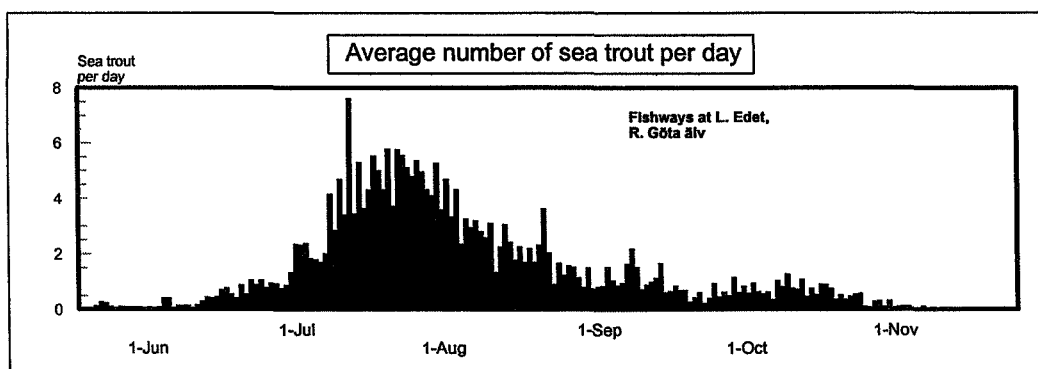


Figure 2.c. Sea trout passage at Lilla Edet

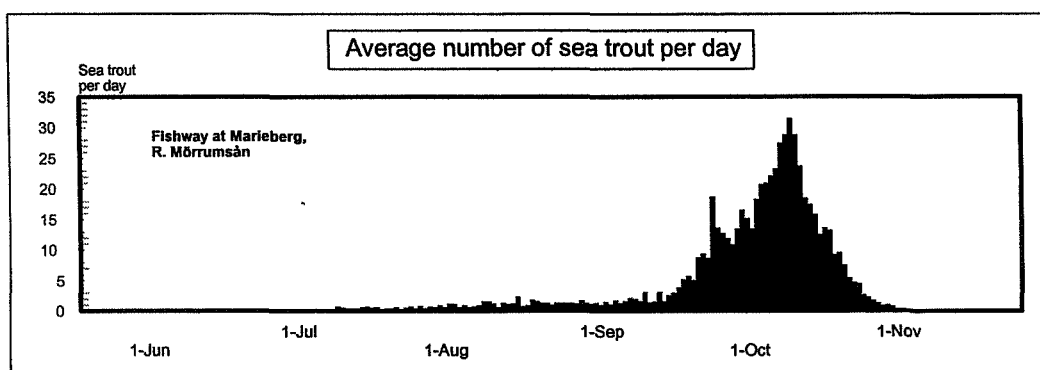


Figure 2.d. Sea trout passage at Marieberg .

Figure 2.a-d. Distribution of A. salmon and Sea trout passage during the migration season in the fishways at Lilla Edet, R. Göta älv and at Marieberg, R. Mörrumsån. (Counting period in both rivers includes ~15 years.)

One conclusion of the results is that the migration pattern of adult salmon and sea trout varies, even within a geographic region. Knowledge of the actual situation in a water system, including knowledge of the different species and their migration, is important when suitable fishways should be built or adjusted. For instance, adaptation of fishway entrance to seasonal water flows during the main migration period, could be of special value.

Fish passage during day and night

From the data that were collected in the automatic fishcounter at Lilla Edet, a diurnal migration pattern was observed. In course of the season both salmon and sea trout passage showed higher frequency during light hours and was distinct decreased at dark. (Example in fig. 3.)

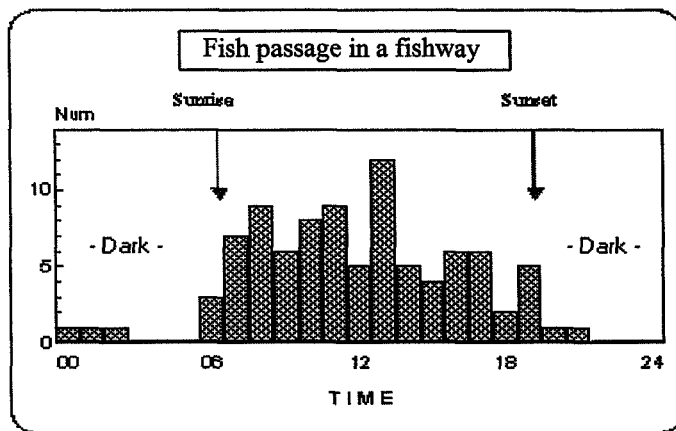


Figure 3. Fish passage during day and night in a fishway at Lilla Edet. (Observations during a period of three weeks in September.) Fish noted at top of the fishway by automatic counter.

Observations with radio telemetry revealed, however, that fish were active during both night and daytime. Also the fishcounter indicated that fish were active at night and then escaped from the fishway. Comparison with data from similar investigations during September in R. Emån and R. Ätran (also situated in the southern part of Sweden) shows that only about 1-2 % of the total number of fish that were counted, passed during the dark hours. (Limit of light hours : one hour before sunrise and one hour after sunset.)

Salmon and sea trout preference of fishways at Lilla Edet

Salmon and sea trout displayed different migration and search patterns in the river close to the fishways at Lilla Edet, which resulted in that salmon more frequently preferred one of the fishways (the old one) and sea trout the other at the same dam. An example, from the period 1993-95, shows the difference. (Table 1.)

Table 1. Distribution of salmon and sea trout passage in two fishways at Lilla Edet, R. Göta älv. (Average number per year during the period 1993-95.)

	<u>Old fishway</u>	<u>New fishway</u>	
Salmon	~ 630	~ 320	individuals / year
Sea trout	~ 175	~ 400	individuals / year

Migration differences between salmon and sea trout are known also from other rivers and knowledge about their behavior in a certain river is important for planning well functioning

fishways. The difference may motivate special and different kinds of fishways, adapted to each species, to obtain optimal function.

Fish escape from fish trap in a fishway.

At one of the fishways at Lilla Edet counting of fish passages was made during two years by both automatic counting* and ordinary manual counting in a fish trap. (Figure 4. *Norwegian "Kilvik-counter".) From the data that were collected in the automatic fishcounter, compared with what was noted in the fishtrap in the upper part of the fishway, it could be seen that several fishes attended to the top of the fishway, but after some minutes to some hours escaped downstream. It was also noted that a number of small fishes, probably sea trout, were able to escape upstream through the barrier.

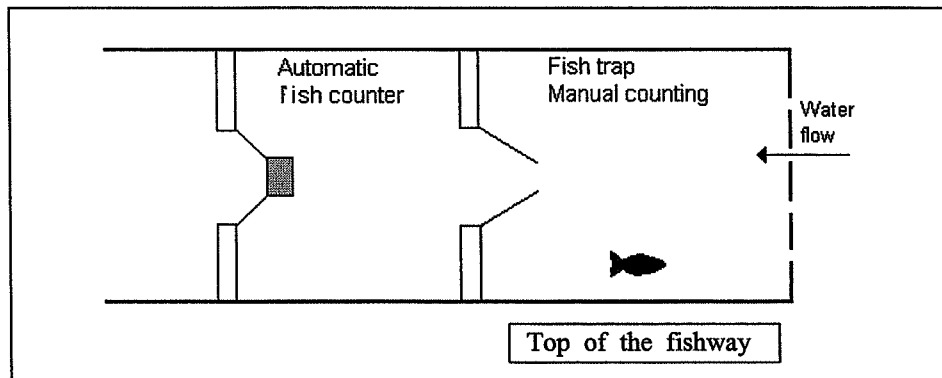


Figure 4. Fish counting in a fishway at Lilla Edet. Automatic fishcounter gives number of fish passage upstream and downstream. It also gives data about fish size and time for fish passage.

The counting system was checked several times by putting a known number of fishes in the fishtrap. Some of those fishes escaped downstream within just a few minutes and it was obvious that they could find their way out if they were frightened. Also as a test the upper barrier was opened for some days. During this time only upstream passage was noted in the automatic counter, which shows that the trapping at the top of the fishway probably was the reason of the escape reaction downstream.

The fishtraps in Lilla Edet are designed to allow passage and trapping of both salmon (2-18 kg) and sea trout (0,3 - 6 kg). For instance the entrance of the fishtrap is rather wide, and it was found that small fishes rather easily were able to find their way out. The traps at Lilla Edet are normally controlled in the afternoon. Data from the automatic counter showed that many fishes attended the fishway during late afternoon, but then often escaped during evening and night.

Analysing data from a period

By using data from a period of several years, it becomes possible to analyse patterns and problems that are difficult to study with just one year's data. Variation in river flow and water temperature often seem important in fish migration and examples from analysing those parameters according to fish passage in fishways, are shown.

- Flow and fish passage -

In R. Mörrumsån the fish migration, with some variation, often seemed to follow a general pattern. (Figure 2.a-d.) From the sport fishing it was also experienced that the river flow has

an influence on the salmonide migration from the sea. When the efficiency of the fishway in Marieberg was discussed a coherent dataset of several years was used to get an overview of flow conditions and fish passage at the fishway. The results pointed out that both the salmon and sea trout passage was low at some flow conditions, especially in the interval between 20 and 28 m³/s. (Fig. 5.) Unfortunately, it is not uncommon that the river flow reaches this interval at autumn during an intensive migration period.

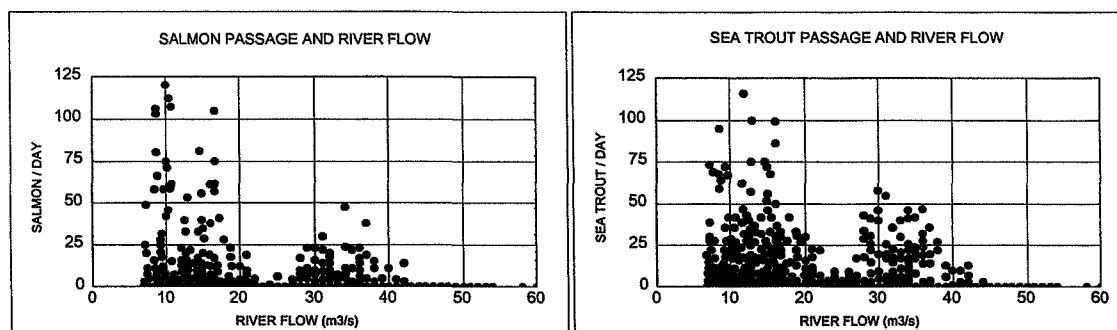


Figure 5. Observed salmon and sea trout passage in the fishway at Marieberg in relation to the river flow. (The minimum flow in R. Mörrumsån, at this site, is ~7 m³/s.)

The explanation of the pattern in this case is probably that while the waterflow through the turbines increases, the outflow from the fishway then becomes more difficult to find. (Maximum turbine flow: ~24 m³/s. Flow through fishway: ~1m³/s.) When the river flow increases even more and reaches ≥ 28 m³/s, the extra water flows close to the fishway and the salmon and sea trout will again have better possibilities to find and enter the fishway. The results have been used when the the flow pattern at the fishway was modified during 1997, and it seems that an improvement was reached.

- Low water temperature -

Some fishways in Sweden are closed during wintertime to minimize waterlosses and to prevent damage from ice etc. When to open and close a fishway is often discussed and sometimes economical arguments are compared to biological. While fish migration shows variation it is important to have good information from the actual watersystem and site.

Low water temperature has an influence upon fish activity and migration, and often the passage of salmonides through fishways seems to decrease at temperatures below 8-6°C. A dataset from a period of several years was used to analyse salmon migration at low temperature during late autumn in the fishways at R. Göta älv and R. Mörrumsån. (Fig. 6.)

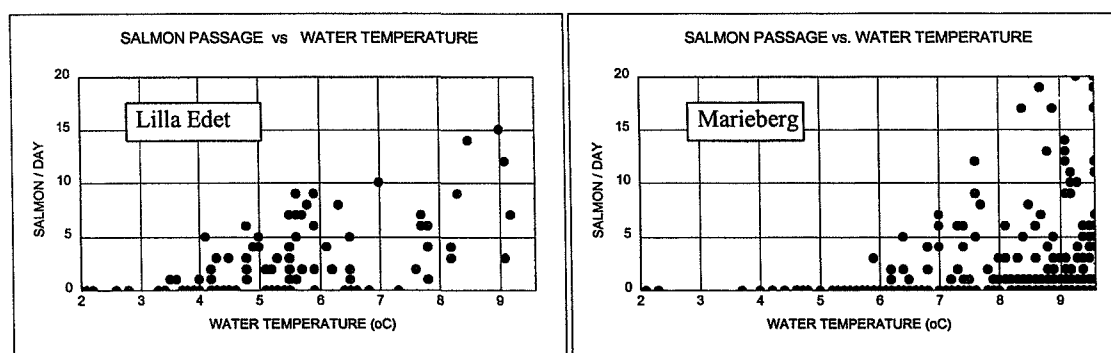


Figure 6. Observed salmon and sea trout passage during late autumn in the fishways in R. Göta älv (left) and R. Mörrumsån (right), versus the water temperature.

The results showed that salmon passage decreases in both river systems at low water temperatures, but while almost no salmon are observed in the fishway at Marieberg below water temperature of 6 °C, quite a few salmon still passed the fishways at Lilla Edet in the temperature interval between 6 and 4 °C. The analysis points out that there are some differences between the two salmon populations and the two riversystems. The results may also be compared with the migration patterns that have been observed in the two river systems. (Fig. 2.a,b.) It could then be noted that in R. Mörrumsån salmon passage usually stops at the end of October when spawning period begins. In R. Göta älv, where the spawning period of salmon normally starts some weeks later, salmon passage continues also during November, even if the water temperature goes below 6 °C.

A final warning

To achieve well functioning fishways the knowledge of fish migration and other certain circumstances is important. Counting fish passages often give valuable data, though it has several times been experienced that the counting may lead to different kinds of problems. Those problems often show up when the counting system includes some kind of obstacle to the fish migration. (Which can occur both at manual and automatic counting.) Trapping of fish may also lead to stress reactions and sometimes fish also is injured by the barriers in the trap. When counting is going on observation of different kinds of problems is important, and as has been described above the trapping and counting of fish passages at the fishway in R. Mörrumsån was decided to stop when problems showed up some years ago.

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GUIDING SALMON TO FISH TRAPS, APPLICATION FOR FISHWAYS

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ABSTRACT

Fish migration is an ecological phenomenon and thus, an *ecological principle* is needed to meet the fish for passing them at an obstruction. Seasonal and daily changes of the flow and the weather, including thermal environment, govern fish swimming and thus the flow itself must be adjusted. At fishways, a *behavioural principle* is essential. This is the way that artisan fishermen have worked. In the Kemijoki River, in northern Finland, salmon fishing has been an ancient source of livelihood. It was developed to a trade nearly 500 years ago. The people there invented a large scale gear called 'karsinapato' for fishing the salmonoids. This fishweir includes the salmon pen joined with extended leader fencings. The people had learned to guide salmon as they wanted. The ratio of this type of fish gear is in modifying the river flow so that the fish shoals advancing are hampered to go through the fencing, but given an orientation passed along the leader fencing in the direction of the salmon pen. This is a non-return trap for salmonoids in their migration due to their powerful rheotropism and rheotaxis. To keep themselves in the pen may be seen as a behavioural support by the prey to the people who wisely utilised their resource.

INTRODUCTION

It is notorious that invaluable diadromous fish stocks have been impaired or lost in very many of our rivers and the sea area. First the river fishing of salmonoids got more or less deteriorated by the adverse effects of the timber floating, saw and paper mills and their dams. Before completely terminated in Finland at the middle of this closing century, the fish catching methods as well as the structure and function of the traps used were recorded by the physiocratic ethnologists and Finno-ugric linguists (Sirelius 1906, Hoikkala 1948, Vilku 1975).

Later, the rivers harnessed by water power plants lost their own salmon, sea trout and whitefish stocks. Suitable hydraulic fishways were not put into practice. The compensative stockings of juvenile fish into the estuaries of the Baltic Sea have so far substituted for the previous, natural smolt and juvenile whitefish production.

Today, the restoring of fish migration by aid of fishways has been initiated. The aim of this effort is rendered in difficulties because the sea-farmed salmonoid individuals are not kept like natural ones when escaped and arrived at the fishway. In the Kemijoki River, the restored salmonoids come in abundance below the first power plant where they are subjected to heavy gill netting. The turbines are run unsteadily so that the pattern of river flow is fluctuating. In such a condition enough water flow and space kept steady is needed in the endurance the fish in their shoals require.

Previously the fishermen mastered the knowledge of the fish behaviour for guiding of salmon, trout and whitefish, and the skills to make traps and to build different types of fish weirs in the river. With aid of this, they applied different types of gears and traps to increase landings for living and return. The comprehensive 'karsinapato' salmonweir was developed

aboriginally by the fishermen of the Kemijoki River and it is unique among its group of fish catching methods (Herva 1996).

TRAPS AND SALMON WEIRS IN RIVERS

Every fishing effort includes the phases of catching and landing. This specification is not original, because an ancient fisherman has been a hunter as well. He or she performed individual or group activities in using personal tools, weapons and traps (Figs 1 and 2). The success of such gears depends on the skill or perseverance of the catcher (von Brandt 1984). The trapper is a kind of a hunter who triggers traps e.g. snares for game. In many of the important fish catching methods it is needed that the fish come voluntarily into the trap, as it is in the river fishing of the rheophilic prey. It is more difficult to influence the success of such a 'passive gear', because not all the qualitatively different stimuli affecting the fish species at the gear are not well known. But their knowledge of the varying river and of fish behaviour helped the old fishermen to make the choice of their device and gear in the most effective way.



Fig. 1. The blade of a salmon spear. The Vefsna River, Norway (by Matti Herva).



Fig. 2. Whitefish is caught by long shafted scoop nets. The Tornio River, Finland (photo by Matti Herva).

Basically, the main devices are original. Archaeologists have in 1995 and later discovered elements of pine splinters like rods, plaited with bark of birch tree to make a guiding fence. The remains of these devices at the Iijoki River in Northern Finland are more than 5000 years old (Koivunen, P. pers.comm). Discovered rests of fishnets are even older. Plaited fences and non-return catching chambers were first used for guiding fish so that the prey was easily landed by personal gears like spears or shafted scoop nets (Fig. 3). The lamprey trap still used show the type of the Kemijoki construction (Fig 4).



Fig. 3. Skilled anglers and an old type catching chamber with a guiding fence of plaited splinters (painting of T.G. Tuhkanen)

A view of the river fishing unfolds when the yearly progress of the different fishery efforts are followed during the 'season of the salmon' from the spring through the mid-summer. After the ice-break in May, in cold and abundant flows, all fishing was carried along the shores by shorter fences equipped with funneled traps (Fig. 5) and bag-shaped nets. Also short seines were dragged downstream in strong flows near the shores by one boat and an otterboard. Weaker fish were caught by seining on the shore by one boat. The salmon weirs with extended guiding fences were built up immediately after the high flood levels and water velocities in the flow had decreased sufficiently. That is because spring salmon were ascending at the same time. Actual fishing began when the discharge was about the triple of the mean and the yield was abundant during the middle discharges.

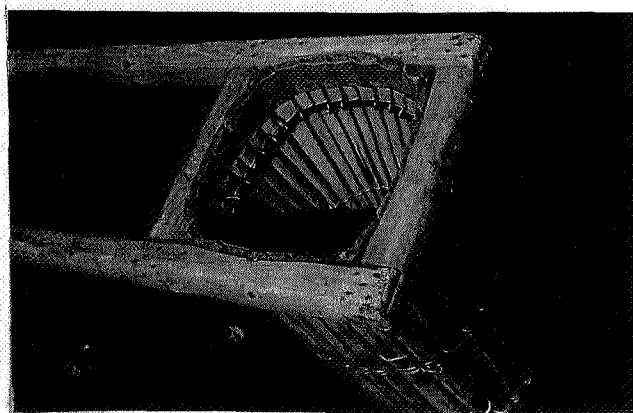


Fig 4. The lamprey trap (photo by Matti Herva)



Fig. 5. The funnel trap of a salmon weir (photo by Jaakko Heikkilä)

THE SALMON PEN OF THE KORVA SALMON WEIR

Building of the largest and most yielding 'Korva salmon weir' (Fig. 6) from materials ready on site took about ten long days of 58 men with riverboats, altogether 600 man-days. The project had the framework of wooden posts and rods stabilised with a heavy stone cover on the top. Eight thousand slender birch trees were needed yearly to thicken the extended fences by putting them upside down on the upstream side of the frame. The salmon pen was built to be 18 m broad and 40 m long and it got a stream lined and curved base figure. To pass enough flow, lateral sides and crucial points of the upper fence were of vertical lattice elements plaited together with rods of fir tree. The flows through the pen and via the entrance, 'the salmon gate', were intentionally enhanced by the shape of the pen and the fences attached to it (Fig. 7).

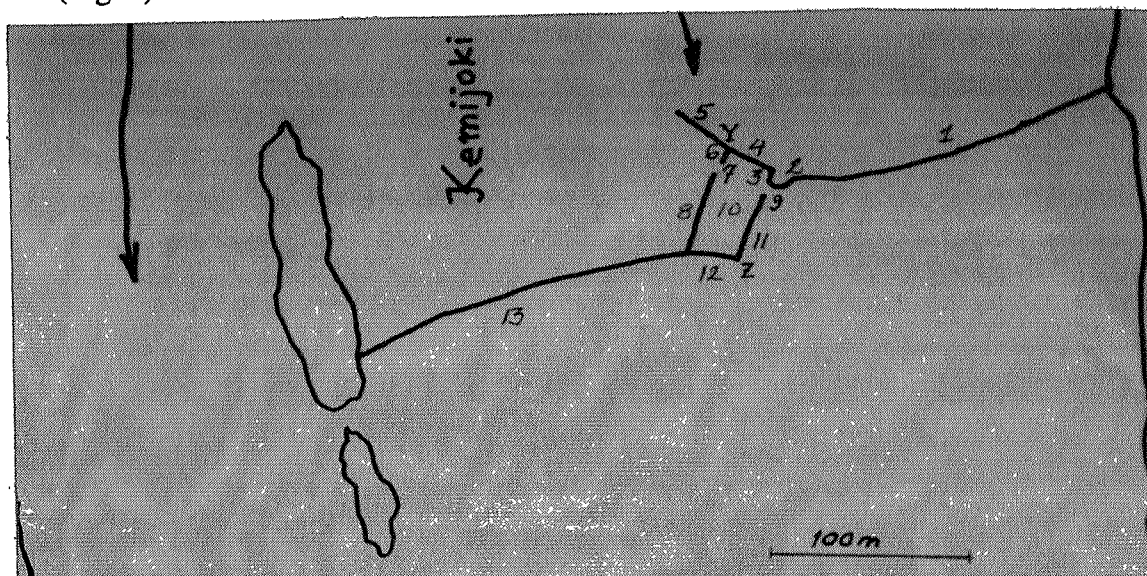


Fig 6. The salmon pen in the Korva salmon weir.



Fig. 7. The approach flow at the salmon gate of the Korva salmon pen (photo by T.H. Järvi).

In fishing, a trap means a non-return device to catch the prey. The salmon pen is a non-return device even though the entrance has no arrangement to hinder physically fish from escaping. It is just the water velocity in the pen which keeps the salmonoids in the trap after behaviourally drawing them into it. From the pen, salmon, trout and whitefish were landed by brailing them in between two nets and by removing them into boats (Fig. 8).

According to von Brandt (1984), old artisan commercial fishermen had a 'striking superiority gained from their fundamental understanding of the behaviour of their prey'. On the contrary, the people in highly industrialised fisheries have lost 'the knowledge of fish behaviour which has fallen into oblivion'.



Fig. 7. Landing of the catch in the salmon pen (photo by Lauri Siikala)

AN APPLICATION TO FISHWAYS

The fish traps used in rivers have shape and size enough to room the amount of fish caught during a period of time. In this respect its function is continual, fundamentally dissimilar to such traps or gears as snares in hunting (and in fishing as well) which after releasing are out of work. The salmonoids migrate in shoals. Both a fish trap and a fishway must have room enough to fulfil their function.

Analogically to the function of each fish trapping effort - catching and landing - the flow at the entrance of the fishway attracts and possibly confines individuals to shoals. Inside the fishway, rheophilic fish can be seen or taught to be conveyed upstream by the flow in the fishway. Whole the phenomenon is based on optic or other specific sensory motorics of these fish. The designer of a fishway may have something to learn from old artisanal commercial fishermen; to claim complete success in passing fish at obstructions.

The designer has in his choice the ecological principle as well. This is needed to attract and pass fish during all the seasons of the migration. The mission is coped with the flow in disposal by using several coincidental approach areas and entrances. Larinier (1998) discusses the flows needed for attraction. In more recent fish facilities attraction flows of 1 to 5 % of the competing flows are recommended. In larger rivers, this means several or tens of cubic meters per second. The minimum ecological flow stated by law in the USA is 10 % of the mean annual flow. By this flow, the ascending fish could possibly be attracted and kept at the obstruction when approaching the entrance, just like the fish in the pen of a big salmon weir.

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GUIDING DOWNSTREAM MIGRATING FISH AT WATERPOWER PLANTS

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ABSTRACT

Studies were performed on the possibilities of using strobe light to divert migrating fish in Älvkarleby (laboratory experiments) and Norrtäljeån (field research). The laboratory experiments indicate that strobe light can be suitable for diverting migrating silver eel, salmon smolts and brown trout.

The field research was conducted during 1994 and 1995. At the silver eel experiments a diverter that consisted of 16 strobe lights were used. The diverter was placed diagonally across the river. 290 silver eels were used, of which 109 were recatched. The catches were three times bigger when the lights were turned off. 27 % of the silver eels did use the alternative spillway gate when the device was turned off compared to 60 % when the device was in use.

During the experiments with salmon and seatrout smolts, lights were placed in the front of and on the sides of the main spillway gate. 1161 salmon smolts and 960 seatrout smolts were used. The catches varied between 4-48 % salmon and 0-64 % seatrout. No big difference in migration route could be seen whether the lights were turned on or off.

1. BAKGRUND

Fiskspärrsprojektet vilket fortfarande pågår initierades redan i slutet av 1980-talet av Vattenfall Vattenkraft. Några av de frågor som då var aktuella var problem i Luleälven dels genom predation från lake på utsatt laxsmolt, dels genom att laxsmolt utsatt uppströms Bodens kraftstation tycktes tveka innan de passerade genom stationen – en hypotes om anledningen till smoltens tvekan var att de på något sätt skrämdes av turbinljudet från kraftstationen.

En annan utgångspunkt för fiskspärrsprojektet var problemen för utvandrande ål i Motala ström. På sin väg ut i havet måste fisken (här främst ål) passera ett antal kraftstationer där de riskerar att förolyckas i turbinerna. Behovet av fiskspärrar har även diskuterats även vid en rad andra anläggningar, som exempelvis vid Sikfors kraftverk i Piteälven (utvandrande smolt) och Stornorrfors i Umeälven (uppvandrande lax och havsöring samt utvandrande smolt).

Elspärren vid Stornorrfors - Andra typer av fiskspärrar än olika typer av galler har dock funnits på repertoaren även tidigare. Redan när Stornorrfors kraftverk byggdes i början av 1960-talet installerades en elspärr som skulle hindra uppvandrande lax och havsöring att gå upp i utloppskanalen. Spärren fick närmast motsatt effekt. Fisken passerade spärren på sin väg upp men föreföll ha betydligt svårare att passera förbi spärren då den skulle återvända.

2. PROJEKTPLAN – LITTERATURSTUDIE

Vid projektstarten fanns en uttalad målsättning att överföra såväl inhemska som utländska kunskaper om att kunna styra eller leda fisk förbi olika slags vattenkraftanläggningar och att i samband med smoltutsättningar kunna skrämman bort rovlevande fisk.

Vid den litteraturgenomgång och probleminventering som gjordes konstaterades att problemen och tänkbara lösningar varierade mellan olika anläggningar. Utöver de olika slags behov som kan finnas vid vattenkraftanläggningar fastslogs vidare att fiskspärrar också kan behövas vid t ex kärnkraftverkens kylvattenintag. I ett vidare perspektiv kan också finnas behov att utnyttja fiskspärrar både inom fiskevärden och i samband med yrkesfiske eller fiskodling.

Med utgångspunkt från den litteraturgenomgång som gjordes beslöts att det fortsatta arbetet skulle inriktas på olika typer av beteendepåverkande spärrar ("behavioral barriers"). Denna typ av spärrar tar fasta på att förändra eller utnyttja det naturliga beteendemönstret genom att locka eller skrämma fisk. I första hand skulle undersökningarna omfatta ljus och ljudspärrar.

I projektplanen ingick att bygga upp en experimentmodell för grundläggande tester med utgångspunkt från de behov som kunde finnas vid Vattenfalls anläggningar. Förutom ål och laxsmolt föreslogs tester även på öring och röding i olika åldersstadier. Vidare beslöts att experimenten skulle utföras i flera faser efter nedanstående schema. Endast om lovande resultat erhöles i en fas skulle projektet fortsätta med nästa fas.

Fas 1: Laboratorieförsök och beteendestudier för aktuella fiskgrupper.

Fas 2: Mer verklighetsnära laboratorie- och/eller fältförsök.

Fas 3: Fullskaleförsök i fält.

3. LABORATORIEFÖRSÖKEN I ÄLVKARLEBY

En laboratorieanläggning som möjliggjorde tester med blankål, öring, laxsmolt och eventuellt även röding byggdes i Älvkarleby för tester med stroboskopljus. Om möjligt skulle också försök genomföras med lågfrekvent ljud.

Försöken genomfördes i två etapper under perioden september 1989 till mars 1991. Den första etappen omfattade försök med stroboskopljus på blankål och insjööring i stillastående vatten. Ansvarig för försöken i Älvkarleby var Lars Karlsson vid Laxforskningsinstitutet.

Stroboskopen placerades 1.1-2 meter över vattenytan. De riktades snett nedåt så de belyste halva försöksgården fram till den ljustäta mellanväggen. Varje försöksgrupp testades med samtliga använda frekvenser av stroboskopljus; 2.1, 6.0, 15.0 och 160 Hz i slumpmässig ordning. (Varje stimuli kombination förekom i två olika försöksblock under olika dagar). I de flesta fall upprepades exakt samma behandling med två olika fiskgrupper och varje stimulikombination förekom därför i totalt fyra försöksblock. Eftersom varje försöksblock bestod av fyra försöksperioder, baserades resultaten vanligen på fiskens beteende i 16 försöksperioder. Fiskens beteende registrerades var 1.6 sekund med videokameror.

Följande huvudmål ställdes upp för försöken i första försöksomgången:

- ♦ Att undersöka undvikandereaktionens snabbhet och styrka.
- ♦ Att studera vilka intensiteter av stroboskopljus som krävs för en undvikandereaktion.
- ♦ Att undersöka om olika frekvenser av stroboskopljus har olika effektivitet.
- ♦ Att undersöka om bakgrundsljus påverkar stroboskopljusets effektivitet.
- ♦ Att undersöka graden av acklimering (tillvänjning) till stroboskopljuset vid upprepad kontakt.

I den andra etappen undersöktes beteendet i strömmande vatten hos laxsmolt som utsattes för stroboskopljus.

Huvudmålet i den andra försöksomgången med stroboskopljus i strömmande vatten var:

- ♦ Att undersöka om en del av smolten som stoppades upp då trågets hela bredd exponerades för stroboskopljus.
- ♦ Att undersöka om det gick att styra smolten ifrån den ena sidan till den andra genom att utnyttja olika stroboskopljus (använda ett i taget).

- ♦ Att undersöka betydelsen av strömhastighet och bakgrundsljus för effektiviteten av stroboskopljus som spärr.

Samtliga försök i strömmande vatten är baserade på att utnyttja det beteende som laxungar har under smoltifieringsperioden om våren då de vandrar ut ur vattendragen. Om de under denna tid hålls i odlingsstråk med vattenström simmar de medströms. Under resten av året håller de istället en position i tråget genom simning motströms eller genom att vila på botten. Båda etappernas försök utfördes under den normala utvandringsperioden både vad gäller ål och lax, dessutom kompletterades undersökningarna i stillastående vatten även med tester på röding.

Under den andra försöksomgången gjordes också experiment med ljudstimuli, som försöksfisk användes då blankål, insjööring och röding.

Målet för ljudförsöken var:

- ♦ Att hitta lämpliga metoder att mäta fiskens reaktion för ljud av olika karaktärer.
- ♦ Att testa olika ljud för att finna stimuli som gav upphov till starka reaktioner.

Resultat Laboratorieförsök Älvkarleby

Försöken med blankål och insjööring under den första försöksomgången kan sammanfattas enligt följande:

- Blankålen undvek inte stroboskopljus med en intensitet av 0,03 lux i mörker, medan intensiteterna 0,4 och 8,7 lux undveks. Vid 8,7 lux undveks 80-90 % av fisken ljuset.
- Blankålen reagerade svagare i svagt bakgrundsljus, 9 lux. Då intensiteten på stroboskopljuset ökade till 18 lux, steg reaktionen till 80-90 %.
- Insjööring undvek inte stroboskopljus lika starkt som blankål, möjligen på grund av aggression mellan olika individer i försöksgruppen. Reaktionen var starkare i svagt bakgrundsljus, 5 lux, än i mörker. Vid ett bakgrundsljus på 200 lux, stroboskopljusintensitet 18 lux reagerade fisken inte.
- Undvikande reaktionen startade inom några sekunder efter exponering för stroboskopljus.
- Både öring och blankål acklimerades till svaga intensiteter av stroboskopljus, men inte till intensiteter som de undvek starkt.
- Frekvenserna 6.0 och 15.0 Hz var effektivare som undvikandestimuli än frekvenserna 2.1 och 160 Hz.

Resultaten från försöken med laxsmolt och stroboskopljus i strömmande vatten kan sammanfattas enligt följande:

Fisken som testades i det mindre tråget (11,5 m²) varierade mycket i beteende mellan olika tillfällen. Ofta simmade fisken motströms och höll position i tråget. Sedan släppte den sig bara nedströms kortare sträckor innan den stannade upp igen. Försöken visade att antalet smolt som vandrade nedströms minskade avsevärt i stroboskopljus. Genomsnittligt över alla försök passerade 64,7 % så många individer genom stroboskopljuset som under kontrollperioder.

Minskningen var större under försök utan bakgrundsljus än med bakgrundsljus, ANOVA $p < 0.05$. Dessutom var regressionen mellan strömhastighet och minskningens storlek signifikant, $p < 0.05$, vilket visade att effekten var starkare vid lägre hastigheter. Minskningen var starkast vid strömhastigheten 2 dm/s, t test $p < 0.05$.

Även utan ström simmade många individer genom stroboskopljuset. Det föreföll som smolten blev irriterade av stroboskopljuset, men trots det inte hade förmågan att omedelbart simma bort från det. Med vattenström var förhållandet ett annat; en del laxungar undvek helt klart att komma in i stroboskopljuset, medan andra simmade genom det belysta fältet utan att reagera märkbart.

Försöken att styra smolt från sida till sida med hjälp av stroboskopljus visade också på en viss effekt av stroboskopljuset. Genomsnittligt simmade 40,5 % av all fisk genom stroboskopljuset och alltså 59,9 % på den icke belysta sidan. Bästa resultatet erhöles vid frekvensen 15 Hz. Proportionen som simmade genom stroboskopljuset varierade med strömhastigheten och beroende på om det fanns bakgrundsljus eller inte. (Strömhastigheten 20 cm/sekund var bättre än vid strömhastigheterna 40 och 60 cm/sekund).

Slutsatserna från laborieförsöken i Älvkarleby redovisas i nedanstående tabell (tabell 1).

Tabell 1: Summary of results from the laboratory experiments in Älvkarleby

Fish	Strobe light	Strobe light Dim background light	Sound	Sound Dim background light
	Dark		Dark	
Silver eel	Yes	Yes	No	No
Brown trout	Yes	Yes	No	No
Salmon smelt	Yes	Yes	-	-
Arctic char	No	No	?	Yes?

3. FÄLTFÖRSÖK MED BLANKÅL I NORRTÄLJEÅN

Laborieförsöken i Älvkarleby visade att stroboskopljus kan vara lämpligt som fiskspärr. För att klarlägga detta mer i detalj rekommenderades ytterligare försök under mer realistiska former. För det fortsatta arbetet beslöts att fältförsöken enbart skulle omfatta försök med stroboskopljus.

Omfattning – Metodik

Som försöksområde valdes Norrtäljeån, ett mindre vattendrag beläget ca 7 mil norr om Stockholm med en medelvattenföring på ca 2,4 m³/s. Fältförsöken i Norrtäljeån genomfördes dels med blankål under september 1994 och med lax- och havsöringsmolt under våren april-maj 1995.

Försök med blankål - Följande mål sattes upp för fältförsöken med blankål:

- ♦ Att belysa ålens rörelseaktivitet under dygnet, i ett mindre vattendrag.
- ♦ Att studera ålens reaktion på stroboskopljus mot bakgrund av olika bakgrundsljus (dag/nattförhållanden, gryning/skymning).
- ♦ Att i försöken även beakta faktorer som skillnader i vattenföring och strömhastighet vid olika utskov. Om möjligt också beakta inverkan av grumlingar samt val av blixtfrekvens.
- ♦ Att studera utrustningens driftsäkerhet och hanterbarhet under försöksperioden.

Transport, förvaring och märkning av ål - Blankålen till försöken fångades i ryssjor utanför södra Vaddö. Totalt levererades 260 ålar med en medelvikt av 1,2 kg. Transport till Norrtälje ägde rum vid 5 olika tillfällen under perioden 29 augusti till 7 september. Vid transporten förvarades ålen i träsumpar fyllda med färsk blåstång. Tiden för aklimatisering i förvaringssumparna varierade mellan 5-26 timmar. All återfångad ål placerades i en större förvaringssump nedströms försöksområdet. En mindre del (30 stycken) användes dessutom vid nya försök.

Förvaringssumpar för försöksfisk - Sumparna bestod av tre separata enheter, varje sump hade en volym av ca 1 m³. Sumparna var fästade vid en pontonflotte ca 400 meter uppströms ljusspärren. Efter andra transporten flyttades sumparna och placerades istället ca 200 meter uppströms spärren. Alla sumparna var öppningsbara, dels ovanifrån för påfyllning av fisk, dels genom att en sida kunde dras upp. Avsikten var att på så sätt möjliggöra spontanutvandring av försöksfisken.

Ljusspärren- vid ålförsöken bestod av en blyxtljusanläggning med inställbar blyxtfrekvens 5-15 Hz. Efter några inledande tester användes enbart frekvensen 10 Hz under försöken. Vid ålförsöken användes sammanlagt 8 drivenheter med 2 armaturer per drivenhet (16 runda bilreflektorer) med 45° ljusspridning. Ljuskäglan var riktad rakt mot strömriktningen.

Spärren placerades diagonalt över ån på en sträcka av ca 25 meter, avståndet mellan reflektorerna varierade mellan 95-190 centimeter. Lamporna placerades 60-65 cm under ytan (försök 1-12). Under andra försöksomgången (försök 13-39) justerades avståndet mellan lamporna till 85 cm. Alla lampor placerades också ca 30 cm ovanför botten. Sektionerna närmast land stängdes också av med specialtillverkade finmaskiga avstängningsnät, ca 2,40 meter mot vänster strand och ca 1,60 meter mot höger sida. Vattendjupet vid lamporna varierade mellan 91-167 cm.

Återfångstanordningar och utskov - Försöken byggde på förutsättningen att all blankål som passerade ljusspärren eller den alternativa öppningen vid sidan om spärren skulle återfångas. Blankålen hade två möjliga vägar att passera dammen. Dels via en fisktrappa belägen bakom stroboskopljuset och dels via ett sidoutskov beläget ca 4 meter på höger sida om sista lampan i ljusspärren.

Återfångsten skedde i finmaskiga nätstrutar placerade i fisktrappan och utskovet på sidan om spärren. Under första försöksomgången var nederkanten på öppningen till sidoutskovet placerat ca 80 cm under ytan (djup 180 cm), under andra försöksomgången placerades öppningen istället ca 30 cm ovanför botten. Försöken avbröts när vattenföringen ökade så det inte längre gick att garantera återfångsten.

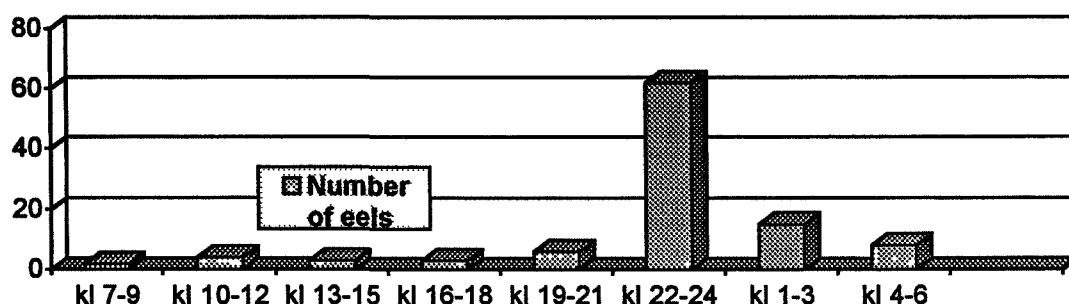
Vattenföringen - under försöksperioden uppgick till mellan 0,75 m³/s till ca 3,5 m³/s. Ca 0,3 m³/s gick hela tiden i den alternativa öppningen på sidan om spärren. I utskoven bakom stroboskopljuset passerade vattnet dels genom fisktrappan och vid högre vattenföringar även via ett gallerförsatt överfall vid sidan av fisktrappan. Försöken pågick i princip dygnet runt (vittjning varannan timme under två veckors tid).

Resultat Ålförsök

Under försöksperioden användes sammanlagt 290 blankålar som sattes ut 200-400 meter uppströms ljusspärren. Av de 290 blankålar som användes i försöken återfångades 109 stycken, (38 %) under den tid försöken pågick.

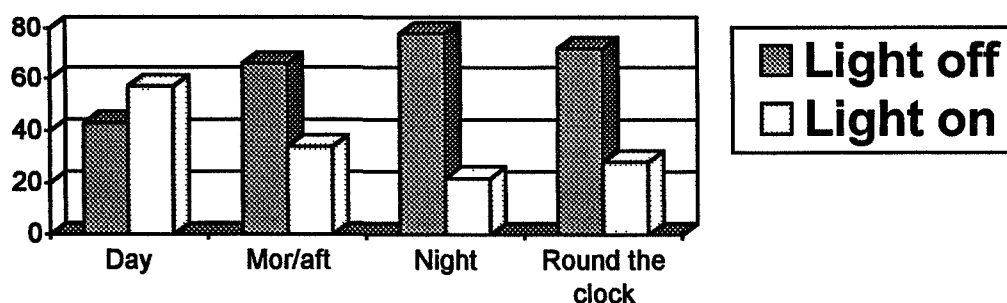
Aktivitet under dygnet - Som väntat var blankålen aktivast under dygnets mörka timmar. Den huvudsakliga återfångsten skedde dessutom under en relativt kort period mellan klockan 22.00-24.00, då över 60 % av all blankål återfångades (75 % under tiden 22.00-03.00). Under dagtid (kl. 07.00-18.00), dvs 11 timmar återfångades endast ca 12 % av ålarna. Även i skymning (19.00-21.00) och gryning (04.00-06.00) skedde en del återfångster 6 respektive 8 procent.

Figur 1: Recatched (number) silver eel during diffrent times of the day

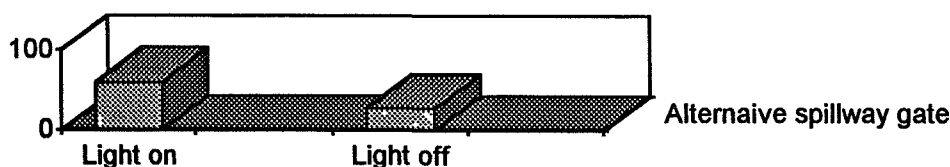


Blankålens reaktion på stroboskopljuset var också kraftig särskilt under de mörkaste timmarna (22.00-24.00) då ca 80 % av ålen fångades när lamporna var släckta. Fördelat över hela dygnet fångades 72 % när lamporna var släckta. Under dagtid (då mycket få ålar fångades) reagerade blankålen ej på stroboskopljuset, det var t o m några fler ålar som fångades när stroboskopljuset var på.

Figur 2: Recatched silver eel (%), during diffrent times of the day when the lights were turned on or off



Ålen reagerade alltså tydligt på lamporna, det förelåg också en signifikant skillnad vid valet av utvandringssväg. Då lamporna var släckta valde 27 % av ålarna det alternativa utskovet vid sidan av ljusrampen medan 60 % av ålen valde denna då lamporna var tända. En intressant iakttagelse i sammanhanget var också att ljusen sannolikt var så starka att ålens rörelseaktivitet även till sidoutskovet hämmades av stroboskopljuset.



Figur 3 : Recatched silver eel (%) in the alternative spillway gate when the lights were turned on or off

4. FÄLTFÖRSÖK MED LAX OCH HAVSÖRINGSMOLT I NORRTÄLJEÅN

Försöken genomfördes under april-maj 1995. Som försöksfisk användes 2-årig laxsmolt (Dalälvsstam) och 2-årig havsöringsmolt (Åvaåöring) från Näs laxodling i Dalarna.

Omfattning, metodik

Sammanlagt användes 1161 laxsmolt och 960 havsöringsmolt i försöken. Fisken sattes ut i grupper om 50-100 fiskar per grupp. Försöken delades in i dag och nattförsök, totalt 17 försök.

Ljusspärre - Stroboskopljuset placerades denna gång inte diagonalt över ån såsom i ålförsöken. Istället placerades spärren ett par meter framför och på sidan om huvudutskovet. Den alternativa utvandringsvägen var i de 5 inledande försöken placerad vid samma sidoutskov som i ålförsöken (fast ca 0,4 m under ytan). Efter det femte försöket ändrades uppställningen så att även fiskvägen kom att ligga utanför stroboskopljuset.

Vattenföring/vattenhastighet - Vattenföringen under försöksperioden varierade mellan 2,5 m³/s till ca 8 m³/s. Vattenhastigheten uppmättes vid två olika tillfällen dels vid Q 2,5 m³/s och dels vid Q 5,8 m³/s. Vid den lägre vattenföringen uppgick vattenhastigheten till ca 10 cm/s framför sidoutskovet på höger sida. Vid utskovet bakom stroboskopljuset var hastigheten något högre, ca 11-17 cm/s. I en övre sektion ca 8 meter uppströms var hastigheten 11-13 cm/s mitt för stroboskopljuset samt 0-5 cm/s på höger sida (vid Q 5,8 m³/s).

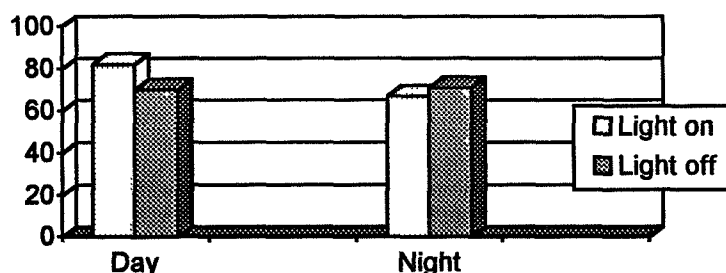
Från början byggde även dessa försök på att all fisk skulle kunna återfångas i något av de tillgängliga utskoven. På grund av att vattenföringen hela tiden ökade var man tvungen att tidvis (i huvudsaken mellan försöken) bottentappa i ett utskov efter vänster strand. Någon total kontroll av antalet utvandrande fisk erhöles därför ej.

Resultat Lax- havsöringsmolt

Laxens - rörelseaktivitet var störst under grynings och skymningstimmarna (inräknat i nattförsök). Någon påtaglig effekt av stroboskopljuset när det gäller återfångst vid de olika utskoven, med tända respektive släckta lampor kunde inte noteras för lax. Vid dagförsöken passerade 82% av laxen stroboskopljuset när lamporna var släckta, när stroboskopljuset var tända passerade 70% av fisken denna väg (N=40).

Vid nattförsöken med lax var spridningen något större mellan olika utskov, förhållandet mellan tänt och släckt var dock omvänt. När lamporna var släckta valde 67% av laxen att passera vid utskovet bakom ljusrampen. När lamporna tändes ökade andelen som passerade förbi lamporna till 71% (N=372).

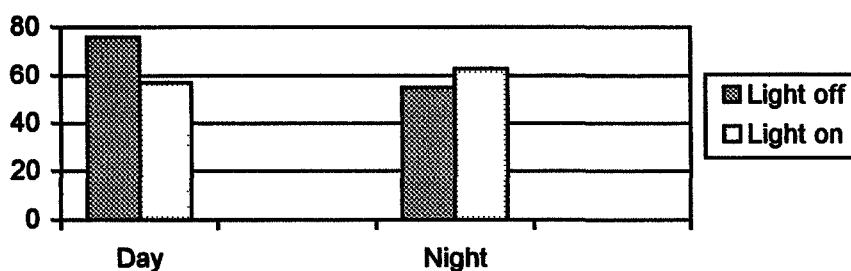
Figur 4 : Share of (%) Salmon smolts passing the strobelight barrier, during night or day and with lights on or off.



Öringens – rörelseaktivitet var likartad laxens. Stroboskopljuset hade dock en bättre effekt vid dagförsöken än för laxen. När lamporna var släckta passerade 76% av öringen genom dammutskovet med ljusrampen. När lamporna tändes sjönk andelen fisk som passerade denna väg till 57% (N=42).

Precis som för laxen var dock förhållandet det omvända vid nattförsöken. När lamporna var släckta passerade 55% av öringen genom ljusrampen, när lamporna var tända ökade passagen genom stroboskopljuset till 63% (N=239).

Figur 5: Share of (%) Sea trout smolt passing the strobelight barrier, during night or day and with lights on or off.



5. DRIFTSÄKERHET, HANTERBARHET

I fältstudien ingick också att studera stroboskop utrustningens driftsäkerhet och hanterbarhet under försöksperioden. I stort fungerade utrustningen i enlighet med de uppställda kraven. En lampa fick bytas efter ålförsöken. Förmodligen var den skadad av inträngande fukt. I ytterligare några armaturer kunde noteras små tendenser till korrosion på reflektorerna efter det att försöken avslutats.

Särskilt under vårförsöken med lax och havsöringsmolt noterades en påtaglig beläggning av slam på lampglasen.

The Use of Acoustic Sources In Britain for Guidance of Downstream Migrants

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Abstract

The sensitivity of fish to underwater noise can be used to repel or guide fish as a substitute for physical guidance methods using screens. Two main acoustic sources are used for this purpose in Britain. One uses underwater loudspeakers and is known as a Sound Projector Array (SPA) system. The other, known as the Bio-Acoustic Fish Fence (BAFF) uses electronic or pneumatic transducers to excite sound in a bubble curtain, creating a 'wall of sound'. Fish diversion efficiencies of the order 70-90% are typical for down-migrating fish. Advantages over physical screens include low capital and running costs and no interference with the water flow. With ongoing improvements in design and application knowledge, even better results are likely in the future.

INTRODUCTION

In Britain, as in Scandinavia, there is considerable interest in restoring fish migrations in rivers that have been degraded and altered by urban and industrial development. Fish passage problems arise from many causes, including weirs, dams, culverts, power schemes, water abstractions and reduced river flows, and may affect both upstream- and downstream-migrating fish. Solutions therefore, must cater for migration in both directions. For downstream migrants, the need is to direct fish along a safe route that avoids them inadvertently descending into turbines, abstractions or other forms of hazard or blind alleys. Fish screens or barriers¹ are required to prevent these 'wrong turns'. Behavioural barriers, provided that they can deliver acceptable fish deflection rates, potentially offer a very practical fish protection solution which has minimal impact on the operation of water offtakes.

The present paper describes fish barriers that use an acoustic stimulus for this purpose, a solution that is being increasingly employed in British rivers and estuaries.

PRINCIPLES OF ACOUSTIC BARRIERS

Fish detect sounds and vibrations via the lateral line organ and the inner ear. The main frequencies detectable lie between a few Hertz (Hz), in the human 'infrasound' region, to two or three kiloHertz (Sand and Karlsen, 1986; Hawkins, 1981). Within these audible bands, some sounds have been found to be repellent to fish when generated at sufficiently high levels relative to the ambient noise. Generally, pure tones need to be substantially above background levels, whereas certain more complex signal patterns can cause repulsion at relatively much lower levels. An analogy may be drawn with the noise of an ambulance or police car siren, which is particularly disturbing to the human ear: a number of signal types that have proved effective against fish share the characteristic of a wailing frequency shift (Turnpenny *et al.*, 1993), which perhaps make neural adaptation more difficult. It remains to be seen whether the use of biologically-significant sounds (e.g. predator-related noises) would make even more effective deterrents.

Sensitivity to sound pressure varies among species, depending on the presence (sensitive) or absence (less sensitive) of a fully-formed swimbladder and also any special hearing adaptations which improve

¹ A screen is here defined as a physical grating which precludes the entry of fish, whereas a barrier is a device which repels or guides fish using a behavioural rather than physical principle.

the coupling between the swimbladder and the inner ear (Hawkins, 1981). For example, the dab (*Limanda limanda*) is a flatfish with a vestigial swimbladder and is relatively insensitive. The cod (*Gadus morhua*) has a normal swimbladder is moderately sensitive but is a 'hearing non-specialist'. The catfish (*Ictalurus nebulosus*) is a 'hearing specialist' and has a swimbladder that is closely connected with the inner ear, conferring high sensitivity over a wide frequency range. Auditory sensitivity, understandably, will affect the success of any acoustic barrier and, in particular, will determine the power level required to elicit the required response. The salmon (*Salmo salar*), a species of particular interest in the present context, is relatively insensitive to sound and requires the use of comparatively high sound source levels.

While acoustic fish deflection systems based on signals within the infrasound (Knudsen *et al.*, 1994) and audible (to humans) sound (Loeffelman *et al.*, 1991; Lambert *et al.*, 1997) frequencies have been developed, experience in Britain is mainly with systems that use the audible 20-600 Hz frequency band.

TYPES OF ACOUSTIC FISH BARRIER

The majority of acoustic fish barriers used in Britain today are of a type known as Sound Projector Array (SPA) systems. Here, an arrangement of underwater loudspeakers, known as 'sound projectors', is placed in front of the water offtake to create an insonified area that is repellent to fish. The sound projectors are connected to a powerful, electronic audio-frequency amplifier. The sound signal is stored in an EPROM microchip and is fed into the amplifier. The whole set-up is analogous to a public address or hi-fi system, therefore. In systems that are used to form a barrier against resident fish populations, alternative signals can be switched in periodically to reduce the risk of fish becoming habituated to the signal.

A newly developed acoustic barrier, known as the Bio-Acoustic Fish Fence (BAFF), works on a different principle. In the BAFF, the sound is generated using either electronic or pneumatic transducers and is fed into the base of a bubble curtain. Owing to the physical properties of the air/water mixture, sound becomes diffracted into the rising bubble sheet and is hence trapped. This creates a repellent 'wall of sound' that is much more similar in form to a mesh screen. The bubble sheet can be contoured to create a line of guidance that not only blocks the path of fish but also guides them into a fish pass or alternative bypass channel. The BAFF is particularly suited to situations where it is required to divert fish from a major to a minor flow, e.g. into a bypass at a hydro-electric plant.

EFFECTIVENESS OF ACOUSTIC BARRIERS

A number of scientific trials in Britain have demonstrated that high fish deflection or diversion rates (typically 70-90%) can be achieved using acoustic barriers. Table 1 summarises results from a number of these studies. The method of testing normally employed involves comparing numbers of fish entering an offtake fitted with an acoustic barrier during alternating periods with the sound switched on and off. Fish are sampled either with nets placed behind the acoustic barrier or on the tailrace of a turbine (e.g. Wood *et al.*, 1994; Anon., 1995); on thermal power stations, samples may be taken from the cooling-water filter screens (e.g. Turnpenny *et al.*, 1995). Techniques such as radio-tracking and visual tracking of float-tagged fish also provide useful information on fish behaviour patterns.

OPTIMISING PERFORMANCE

Acoustic fish barriers represent an emerging technology that continues to benefit from technical developments and improved understanding. Early attempts at using sound for fish guidance often suffered from equipment malfunction and unpredictable results. Equipment reliability has now been improved and factors affecting performance are far better understood. Key factors in the success of an acoustic barrier include the underwater acoustic environment (background noise, reflectivity, propagation conditions), the hydraulic conditions, especially as they affect the ability of fish to escape from strong currents, and the design of a bypass entrance that is attractive to fish. The use of numerical modelling techniques to evaluate both the acoustical and hydraulic design aspects of acoustic barriers

has removed much of the guesswork that hampered progress in the early days, leading to the greatly improved results that can be achieved today.

An area that is now being explored to develop even higher efficiencies is the combination of sound with other stimuli, e.g. strobe lighting. Another possibility, where near 100% efficiency is required, is to operate two separate behavioural barriers in tandem. For example, one might be a louvre barrier and the other acoustic.

OTHER APPLICATIONS

Acoustic barriers have generally been used to divert down-migrating fish. A recent Environment Agency project in Britain, on the River Severn at Tewkesbury, is using an acoustic barrier in an attempt to guide upstream-migrating adults into a fish pass. If this application is successful, the technique might be applied in many situations where hydraulic attraction of fish was inadequate.

CONCLUSIONS

Acoustic barriers have developed to a point where they are now widely used in Britain in a variety of applications. While results in the 70%-90% range do not match those of physical screening systems, acoustic barriers represent a cost-effective and practical option for many older water intakes (e.g. of hydro-electric plant) that were never designed to allow the use of fine-meshed screens that would be effective in excluding smolts. They are also used for new intakes where physical screening is not a practical option for reasons of waterborne debris loads, or due to sheer cost.

With ongoing technical developments and available numerical modelling methods that lead to improved overall scheme design, acoustic barriers may play a considerable part in helping to maintain and improve fish migrations in rivers and estuaries.

Table 1 Results from Acoustic Barrier Trials in Britain

Location	Fish Species	Diversion Efficiency	Reference
R. Foss flood relief pumping station, York (32 m ³ .s ⁻¹)	Chub (<i>Leuciscus cephalus</i>), roach (<i>Rutilus rutilus</i>) & other cyprinids	80% for all species	Wood <i>et al.</i> , 1994
Hartlepool nuclear power station (34 m ³ .s ⁻¹)	Herring (<i>Clupea harengus</i>)	79%	Turnpenny <i>et al.</i> , 1995
	Sprat (<i>Sprattus sprattus</i>)	60%	
	Other swimbladder fish	55%	
River Frome smolt census station	Salmon smolt (<i>Salmo salar</i>)	70-88%	Welton <i>et al.</i> , 1995
	Sea trout smolt (<i>S. trutta</i>)		
Blantyre Hydro-electric plant (20 m ³ .s ⁻¹)	Salmon smolt (<i>Salmo salar</i>)	74%	Anon., 1996
	Mixed cyprinid species	92%	

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