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TIMING OF SMOLT MIGRATION OF ATLANTIC SALMON (*Salmo salar* L.) IN ICELANDIC RIVERS

by

Thorolfur Antonsson, Sigurdur Gudjonsson, Thor Gudjonsson, Sigurdur Mar Einarsson and Tumi Tomasson

Institute of Freshwater Fisheries, Vagnhofdi 7, 112 Reykjavik, Iceland

Abstract

The timing of smolt run in four Icelandic rivers is primarily controlled by river water temperature. Increased water flow also stimulated the smolt run in rivers in south Iceland but not in north Iceland, where precipitation is mainly associated with cold arctic winds causing decrease in river temperature. Large year to year variation in the timing and duration of the smolt run in the same river can be observed depending on the elevation of river temperature. The smolt run is generally 3 to 4 weeks earlier in rivers in south Iceland than in north Iceland. The smolts migrated mainly during night. As elevated river temperatures are correlated with elevated ocean temperature they seem to be environmental stimuli for smolt migration that is likely to increase the overall survival of smolts in Icelandic rivers.

Key words: Atlantic salmon, smolt, migration, Iceland.

Introduction

Fisheries for Atlantic salmon are of great economic importance locally in Iceland. Salmon runs vary greatly among years, in particular in the eastern and northern rivers, and to a lesser extent in the southern and western rivers (Scarnecchia 1984, Gudbergsson 1995).

Much money and resources are spent on propagation measures, but for these efforts to be fruitful and improve, one must understand the underlying causes for the fluctuations. For this reason, three long term tagging programmes of wild smolts were initated in different parts of the country in 1987-89. Prior to that, one long term study had been carried out in 1947-70 in a fourth river.

In this paper we compare and contrast the timing of the outmigrating smolt runs in these four rivers and relate migrational patterns to general climatological and hydrological events.

Rivers in this study

Of the four rivers in this study, two are located in the south-west of Iceland, one in the north and one in the north-east of the country (Fig. 1). River Ellidaar is spring fed and has a catchment of 286 km^2 and an average flow of 5 m^3/sec (Rist 1956). The catchment is characterized by porous lava fields and underground flow. As other spring fed rivers it is stable in flow. River Ulfarsa is lake fed and also drains an area of relatively young bedrock. It has a catchment of 54 km^2 and an average flow of 1.6 m^3/sec (Rist 1990). The two northern rivers are both classified as wetland heath streams. They originate on flat moraine heaths with extensive lake- and wetland systems between moraine ridges (Gudjonsson 1990). They are relatively stable and fertile and the catchment is well vegetated. River Nupsa is a tributary to River Midfjardara, with a catchment of 98 km^2 and average flow of 2.5 m^3/sec. River Vesturdalsa has a catchment of 190 km^2 and an average flow of 5.0 m^3/sec. All these rivers, therefore, have a similar flow but are relatively small (Table 1).

Atlantic salmon is the dominating species in the more fertile rivers in Iceland, but only five species of fish occur naturally in fresh water on the island, all of which may have anadromous or catadromous life histories (Gudjonsson and Mills 1982). Conductivity measurements can be used as an indication of the fertility of rivers (Gudjonsson 1990). Salmon rivers in Iceland usually have conductivity ranging from 50-130 μS/cm. The rivers in this study range from 76-126 μS/cm (Table 1).

The climate in Iceland is wet and cool. Oceanic influences on the climate are strong (Einarsson 1976). Water temperatures in rivers may be as low as 0 °C to 2 °C for up to 8 months of the year when the rivers are frozen over. There are however major differences between districts. Climate is milder and more temperate in the south due to the moderating influence of the relatively warm sea. Winds from the south-west are prevalent during summer time. These bring relatively warm and wet weather in the south, but dry, sunny and still warmer weather in the north. Spells of northerly winds bring precipitation to the north, but usually sunny and dry weather in the south. The severity of these spells depend to some extent on the distribution of cold polar sea off the north and east coast of Iceland.

A considerable part of the precipitation falls as snow, especially in the north. In south Iceland snow is 5-7% of the precipitation in the winter months (October - April), while in the north about 50% of the annual precipitation is snow and 85 -97% of winter precipitation is snow (Einarsson 1976). Snow cover in the spring is thus generally much more extensive in the norhern areas of the country. This in turn affects runoff characters of rivers in the different districts and the arrival of spring in the rivers.

Methods

Smolts were captured with a fyke net in Rivers Ulfarsa and Vesturdalsa, but with fence traps with grid mesh catching smolts larger than approximately 10 cm in the other two rivers. The same method was employed in each river throughout the period of the study. Only a portion of the run is caught in each instance and this may vary with flow regime. The variation within

each season is less and the sampling is assumed to reflect the migration pattern quite well. In some instances sampling has been discontinued for a short period or before the run was completed. Such instances are mentioned in each case.

In Rivers Ellidaar and Vesturdalsa the traps were attended four times daily, at 7:00; 13:00; 18:00 and 23:00. The trap in Nupsa was attended in the mornings and evenings and in River Ulfarsa in the mornings. Water temperatures were recorded each time the traps were serviced and in addition automatic thermometers were used in Rivers Ellidaar and Vesturdalsa from 1989. In those cases temperatures were recorded every four hours. The "arrival of spring" in the rivers was defined as the fifth day (not necessarily consecutively) when the water temperature reached 10°C, termed "Temp-5". Water level was also recorded in the rivers, except River Nupsa, each time the traps were attended. Eight years during the period 1947-1970 with good and complete smolt run data were selected for analysis in River Ulfarsa.

The catch was sorted according to species and the salmon smolts counted. The start of the run is defined as the time when the first smolts are caught, but the run is then divided into three periods, the first 10%, the main run when next 80% are caught and the final 10%. The onset of the main run is thus defined when the first 10% have passed through.

Linear regression was used to correlate the onset of the main run (dependent variable) and the arrival of spring (Temp-5, independent variable). The number of days from the first of May to these two points in time were counted. All years with complete data in all rivers were combined.

Results

The development of the runs

The onset and duration of the total run and the main run was variable between rivers and years (Figure 2). The variation in the onset of the main run in River Ellidaar was about three weeks

for the eight years of study. In 1988 the main run started on 19th of May, but not until 11th of June the following year. There was also considerable variation in the last day of the main run and its length. In 1988 the main run was over by 1st of June but not until the 10th of July in 1990. The duration of the main run was shortest 10 days in 1989 and longest 38 days in 1990. In 1992 the trap was removed before the main run appeared to be over.

In River Ulfarsa there was a 37 days variation in the onset of the main run during this time. In 1956 the main run started on 10th of May, but not until 16th of June in 1949. The difference between the finish of the main run was 29 days in these two years. The duration of the main run varied from 8 days in 1963 to 24 days in 1947 (Figure 2).

The main run in River Nupsa started on 1th of June in 1988, but not until 9th of July in 1989. The main run was over by 30th of June in 1987, but not until 4th of August in 1993, 35 days later than in 1987. The duration of the main run was longest 32 days in 1993.

For the five years of available data, the onset of the main run in River Vesturdalsa was earliest on 8th of June in 1992 and latest on 6th of July in 1994. In 1994 only 46 smolts were caught over a period of 18 days and in 1991 and 1992 the trap was removed before the main run appeared to be over. The summer of 1993 was very cold and only few smolts were caught, in spite of repeated efforts.

There was a large variation in the timing of the runs among years in the same river, as well as between different rivers. The smolt run in the two rivers in the south-west were generally in late May to early June, while in the two rivers in the north and north-east the main runs were generally in late June and July. On average the main run started on 29th of May in River Ellidaar, 28th of May in River Ulfarsa, 27th of June in River Nupsa and 22nd of June in River Vesturdalsa.

Effect of water temperature and level on smolt outmigration

There was a close relationship between the initiation of the main run and when the water temperature reaches 10°C (Figure 3). Linear regression gave the equation:
S-run = 3.97 + 0.91 x Temp-5; $R^2 = 0.88$; $P>0.001$.
where S-run stands for the number of days from 1st of May until the main smolt run commences, Temp-5 is the number of days which pass from 1st of May until the water temperature has reached 10°C five times, R^2 is regression coefficient and P is the level of significance.

Within this general pattern a more close relationship with water temperature has been observed, in particular in the northern rivers where the run will cease during periods of cold spells, after the onset of the main run.

Increased flow have different effect on the smolt run in north and south Iceland. In rivers in north Iceland increased flow was associated with cold precipitation, that reduced the smolt run if it had initiated. On the contrary precipitation in south Iceland is relatively warm and increased flow in the rivers stimulated the smolt run.

Daily migration patterns

In Rivers Ellidaar and Vesturdalsa, where the trap was attended four times a day it was clear that outmigration is picking up in the evening and is most intense during night time (Figures 4a and 4b). This pattern is however more pronounced in River Vesturdalsa.

In Nupsa, where the trap was attended twice daily, most of the run occurred during night time.

Discussion

As well known from the litterature (Thorpe and Morgan 1978) smolts migrate mainly during night, although in this study this is more marked in the north than in the south (Figures 4a and b). In River Ellidaar the nocturnal pattern of outmigration is more pronounced during periods of low flow than during elevated water levels which are often associated with increased turbidity. Thus the different reaction to floods explains the observed difference in the degree of nocturnal migration in the north and south of Iceland.

The timing of the onset of the smolt run and its subsequent development appears to be highly dependent on temperature in Icelandic rivers. In the north and northeast of the country, smolt runs are on average 3-4 weeks later than in the southwest. Snowmelt during spring time keeps the water temperatures low. Only when the floods recide and the water temperatures rise does the smolt run start.

In the south there is generally little accumulation of snow in winter time and much of the snow usually melts during sporadic periods of thaw in March and April (Rist 1990). Snow melt has, therefore, little effect on the development of the water temperatures in the southern rivers.

During the period of smolt outmigration, times of elevated flows have markedly different effects in different parts of the country. In the southwest, rain mainly falls when low pressure systems go over the country from the south. The weather is thus relatively mild and there is only a moderate cooling of water temperatures as the level rises. Here increased flow seems to stimulate the smolt migration.

In the north and northeast of the country, heavy precipitation, usually occurs during times of northerly winds which bring arctic air over the country. Increased flow rates are thus usually associated with a sharp decline in water temperatures and the outmigration of smolts is reduced and may cease entirely. It then resumes when water temperatures rise again. These general patterns of smolt outmigration in relation to temperatures and flow rates in the south and the north of Iceland are illustrated schematically in Figures 5a and b. It thus seems that the timing

of smolt run is primarily triggered by elevated temperature in Icelandic rivers, but floods in south Iceland can also stimulate the smolt run. In general, other studies on salmon smolt migration have shown water temperatures to exert a major influence for the onset of the smolt run (Ruggles 1980, Mills 1989, Jonsson and Ruud-Hansen 1985). In some cases though other factors, such as floods, may be more important (Hvidsten et. al 1995).

The observed differences must reflect how different environmental cues relate to survival. Ocean temperatures and productivity is quite variable, in particular to the north and east of Iceland, due to variable distribution of relatively warm and saline Atlantic water and the cooler and less saline polar water (Anon 1994). This affect the survival of outmigrating smolts and consequently the number of returning salmon (Scarnecchia 1984). There is strong significant correlation between ocean temperature and air temperature in the spring (Antonsson et. al 1992). Arrival of spring on land may thus to a large extent also reflect oceanic conditions. These would appear to be more important to the overall survival of smolts than predation during the period of outmigration. Signals indicating favourable oceanic conditions (high temperatures) have thus greater influence on migratory patterns in Icelandic smolts than conditions which provide improved protection from predators (floods).

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Table 1. A comparison of the size, rod catch and conductivity of the rivers used in the present study.

River	Catchment area km²	Discharge m³/s	Length km	Mean salmon catch 1974-94	Conductivety µS/cm
Ellidaar	286	5,0	29	1406	90
Ulfarsa	54	1,6	18	340	78
Nupsa	98	2,5	26	162	76
Vesturdalsa	190	5,0	35	240	126

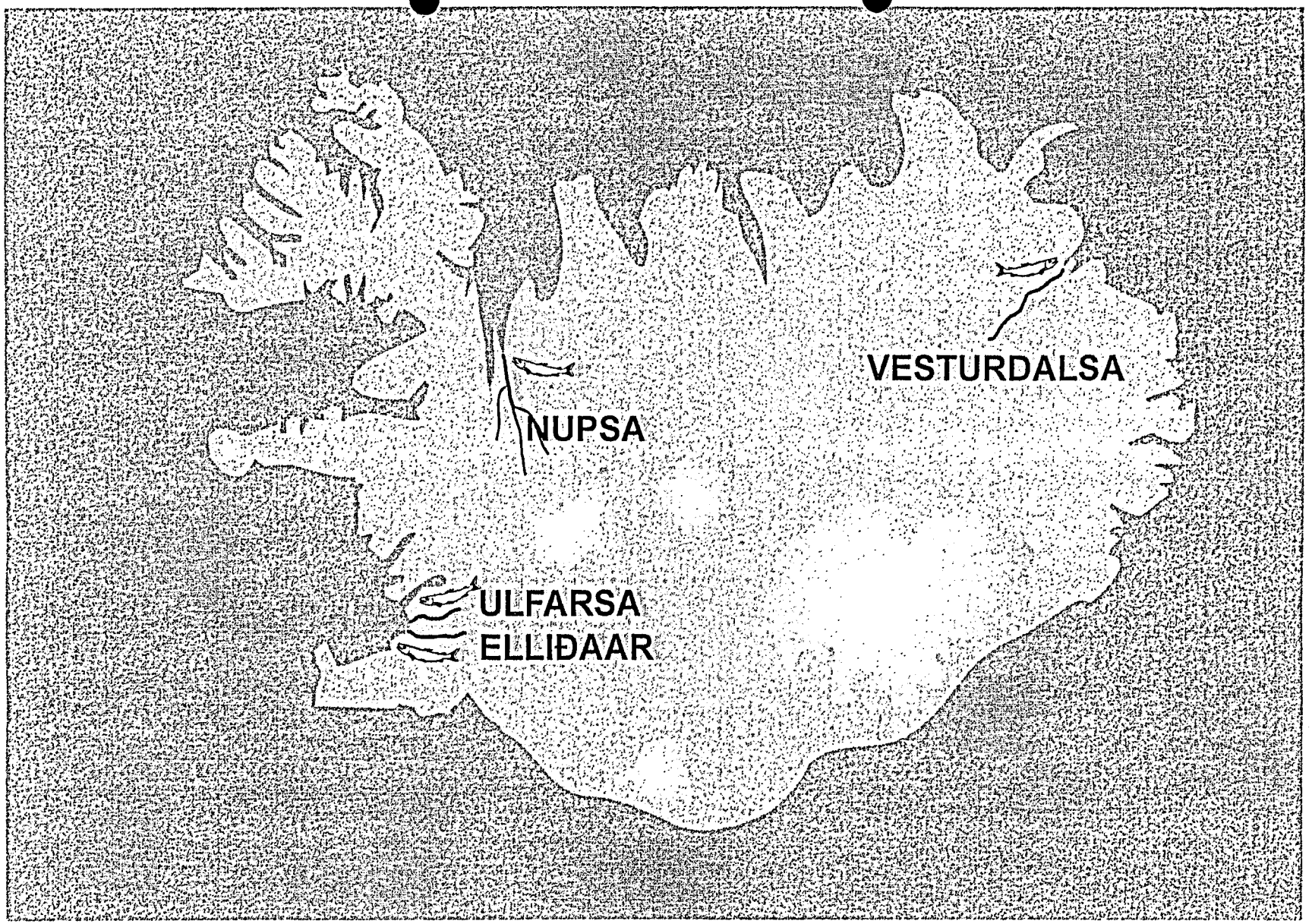

Figure 1. Location of the rivers in the study.

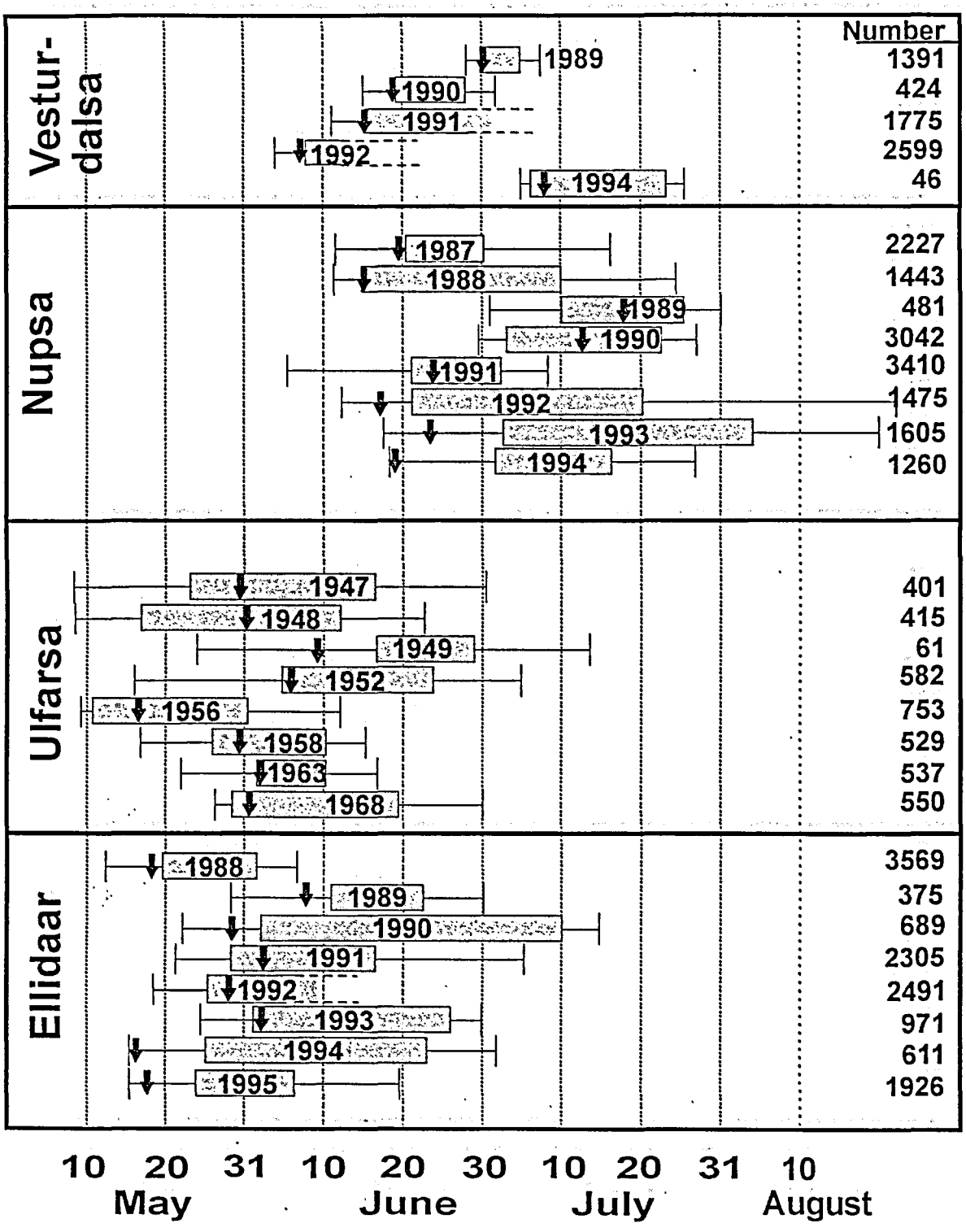

Figure 2. Timing of the smolt run in different years in four Icelandic rivers. The arrows indicate the date when river temperature reaches 10°C for the fifth time in a given year. The shaded boxes indicate the time when 80% of the smolts were caught. Dashed line show occasions when traps operation was terminated before it was apparent that smolt run had ceased.

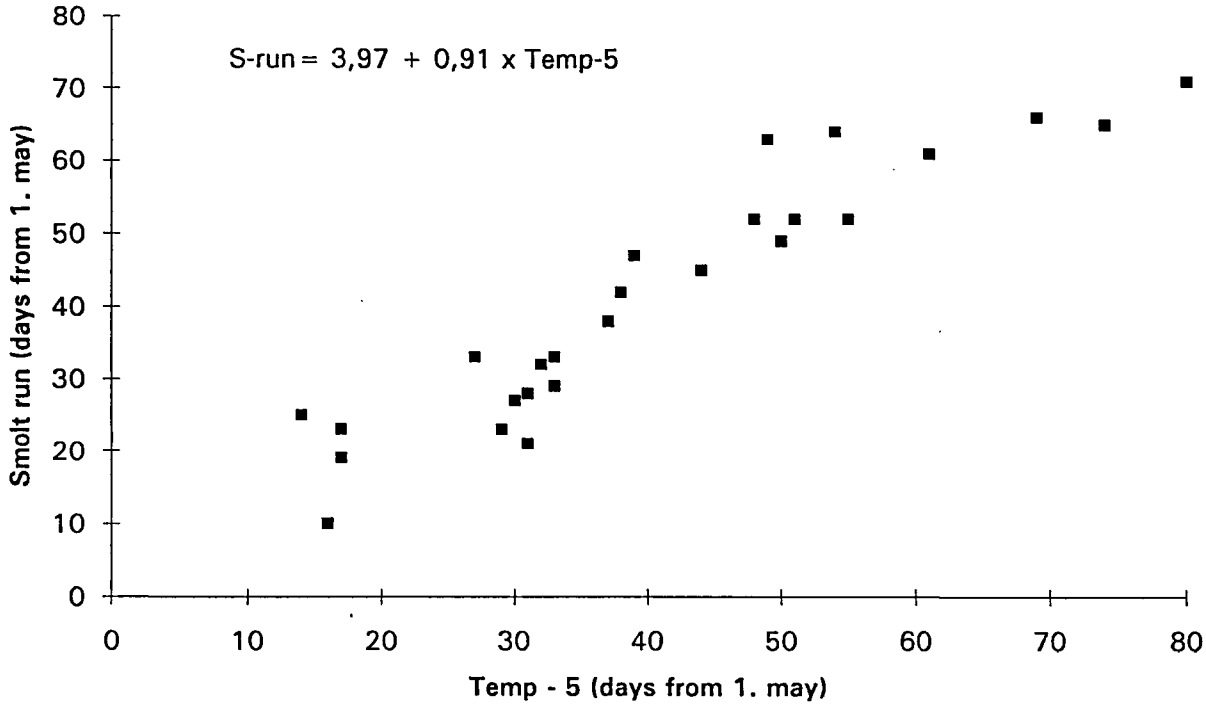

Figure 3. The relationship between water temperatures and the onset of the main smolt run in of Atlantic salmon in four Icelandic rivers.

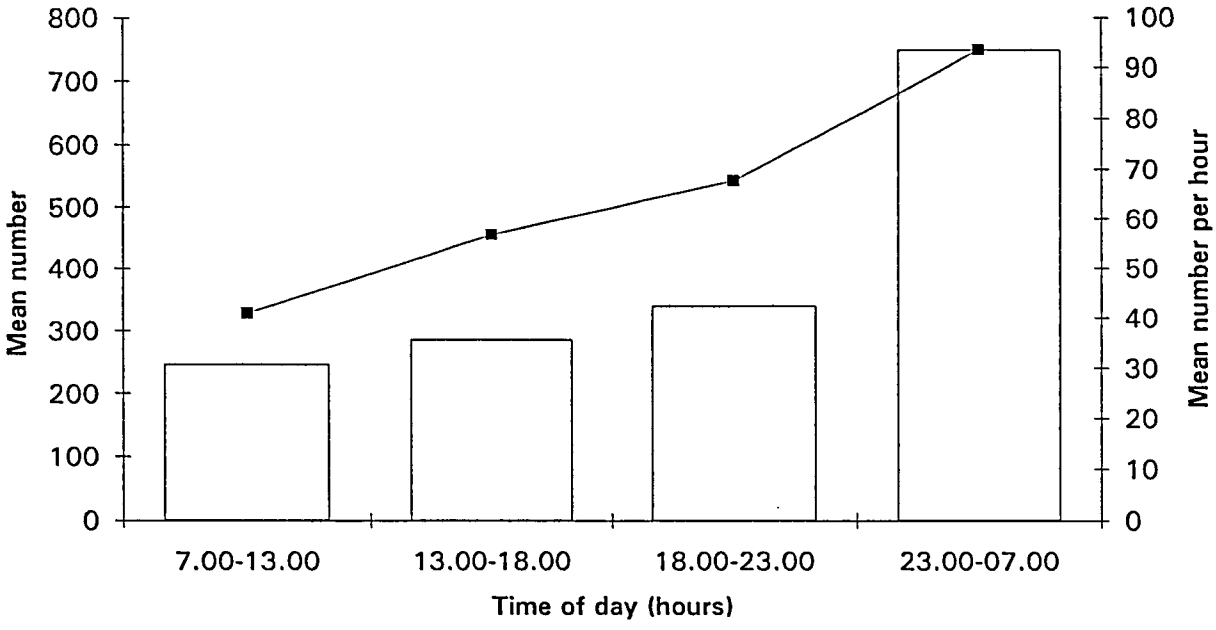

Figure 4a. The mean number of salmon smolts caught during different times of the day (bars) and calculated number per hour (line) in River Ellidaar in 1988-95.

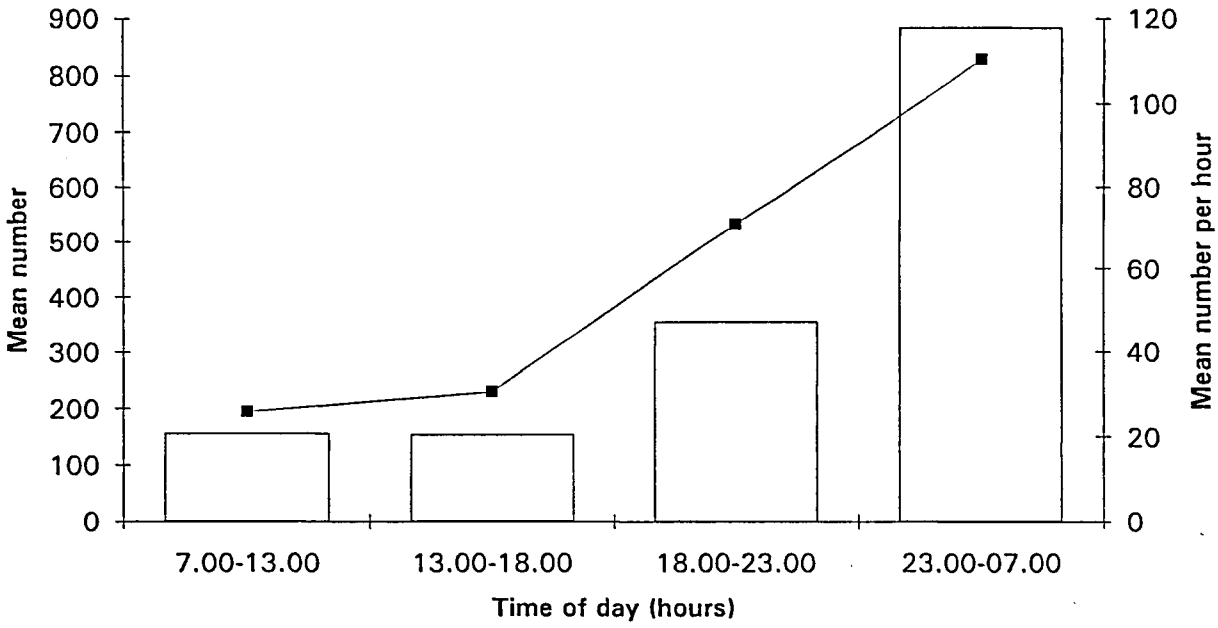

Figure 4b. The mean number of salmon smolts caught during different times of the day (bars) and calculated number per hour (line) in River Vesturdalsa in 1989-92.

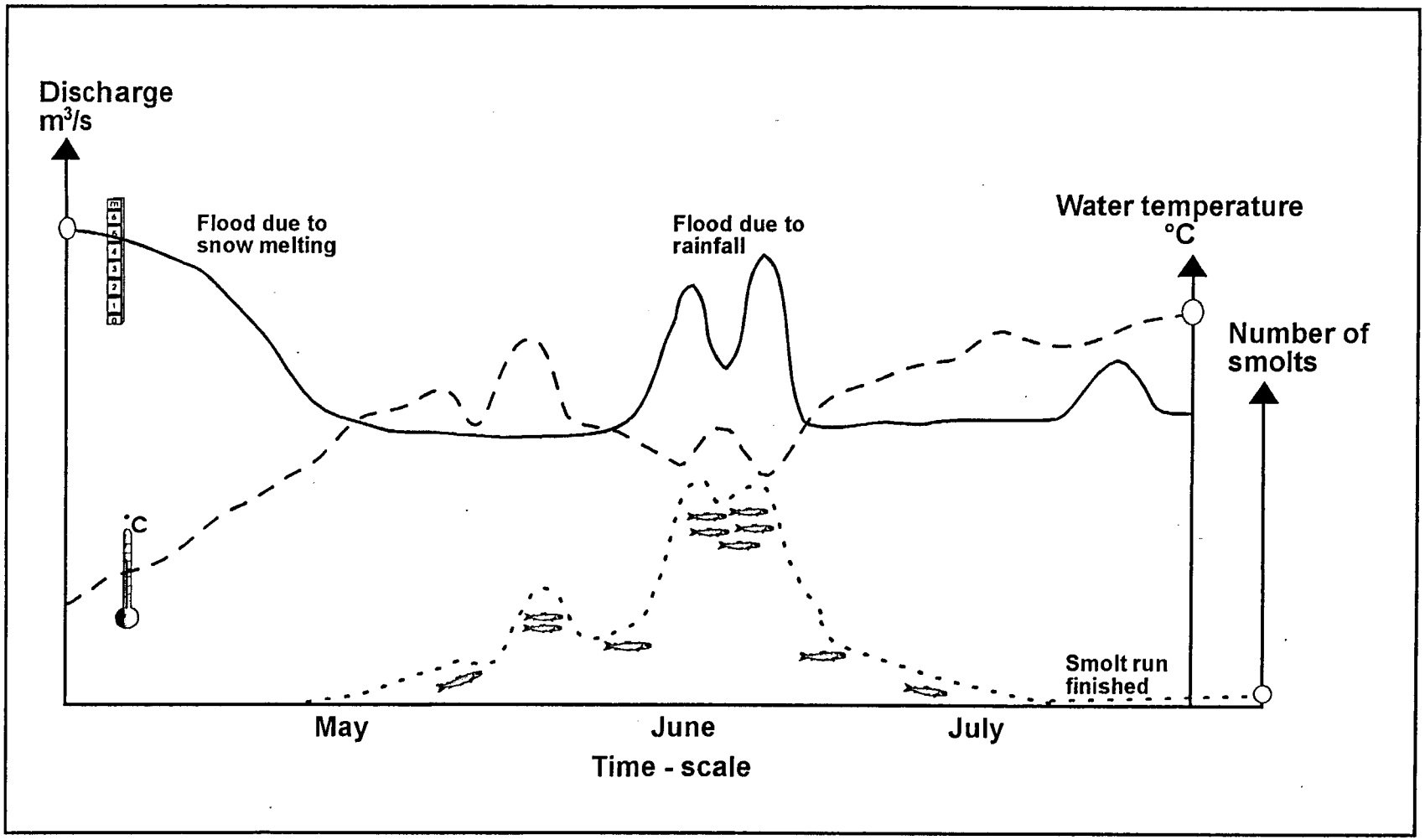

Figure 5a. A schematic representation of the development of the smolt run in salmon rivers in southern Iceland in relation to water temperatures and river flow.

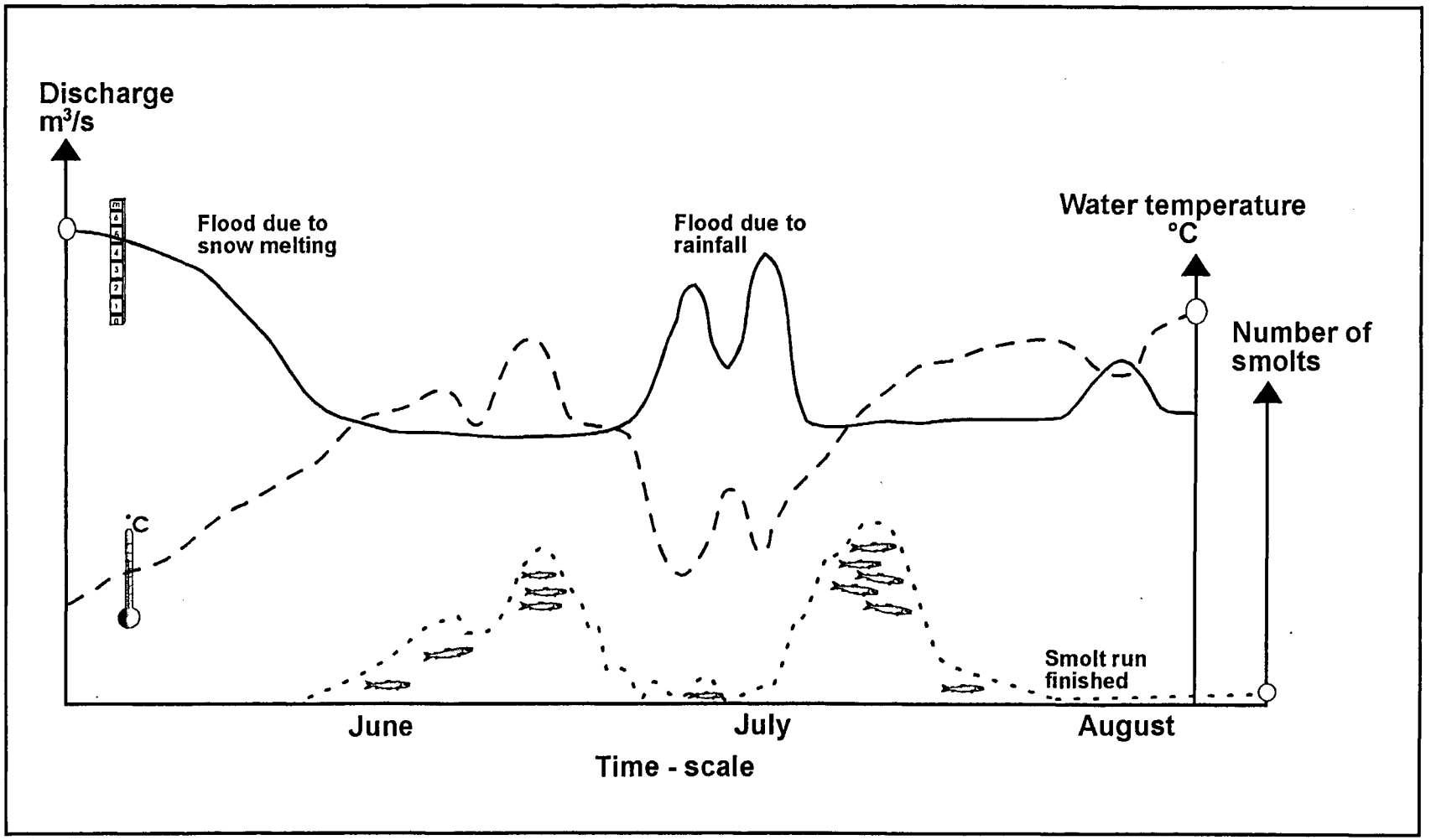

Figure 5b. A schematic representation of the development of the smolt run in salmon rivers in northern Iceland in relation to water temperatures and river flow.