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Short communication

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Abstract – The smolt run of anadromous brown trout (*Salmo trutta*) in a Norwegian river was studied for three consecutive years. The main run occurred in a period of 7–10 days in the middle or second half of May. Support was found for the hypothesis that high water discharge and temperature triggered the run. Few smolts descended when the discharge was low (<50 $m^3 \cdot s^{-1}$) and the water temperature was below 4°C. The maximum number were caught when the discharge was moderate (70–150 $m^3 \cdot s^{-1}$) and the water temperature high (6–8°C). The relative importance of these factors varied from year to year. The first-year discharge explained 38% of the variation in the number of smolts migrating. Discharge and temperature together explained 61% in 1992 and 28% in the second and third year, respectively.

Key words: anadromous brown trout; *Salmo trutta*; smolt migration; water discharge; temperature

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Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

Anadromous salmonids exhibit significant habitat shifts through their lives. The breeding areas are mostly found in small streams to large rivers as well as lentic environments. Most anadromous salmonids spend from 1 to 7 years in the breeding areas before they undergo smoltification (Hoar 1976) and migrate to the sea. Migration and habitat shift are essential in anadromous salmonids. The feeding conditions improve considerably in the new environment, but the change of habitat is probably also the most critical during their lifecycle. The ontogenetic habitat shift implies physiological constraints and increased predation risk (Hoar 1976).

Several environmental factors are correlated with the onset of the seaward migration of salmonid smolts (Jonsson 1991). Water discharge and water temperature have been identified as the most important factors correlated to migration. Several studies have shown among-year variations in the relative importance of various environmental factors affecting smolt migration (Österdahl 1969; Hvidsten et al. 1995). This suggests the existence of other important stimuli for the smolt run of anadromous salmonids.

The smolt migration of anadromous brown trout (*Salmo trutta*) is poorly documented. But some studies are done. Bohlin et al. (1993) found a positive relationship between the probability of migration per day and the number of degree-days, changes in water level and temperature during the preceding week. Solomon (1981) found that downstream movements were correlated with water level. The latter two studies were carried out in relatively small streams and did not demonstrate common lower values of the factors initiating the onset on migration of brown trout smolt. However, other authors have observed a lower threshold temperatures for salmonid smolt migration; i.e. 10°C (Österdahl 1969), 10–12°C (Solomon 1978b) and ~2°C (Hvidsten et al. 1995).

In this study, we evaluated whether the timing of a brown trout smolt run in a large Norwegian river was environmentally induced. In particular, we tested the hypothesis that there existed threshold values of water discharge and water temperature for the smolt run explored over three consecutive years.

Material and methods

This study was carried out during the years 1991–1993. It took place in the River Stjørdalselva (63°20′N, 10°55′E) in central Norway. The River's outlet is in the southeastern part of the fjord Trondheimsfjorden. The catchment area is 2130 km^2, and the mean annual discharge is 29 m$^3 \cdot$ s^{-1}. During the spring flood in May, the discharge normally reaches about 450 m$^3 \cdot$ s^{-1}. The river width varies between 20 and 80 meters. Anadromous *S. salar* and *S. trutta* may ascend 47 km upstream to Meråker, situated at 100 m a.s.l.

A trap was operated from Sona bridge, 15 km upstream from the river mouth. Two electric winches were used to lower the trap into the river. The trap consists of two 7 m long net pouches (mesh size 9.5 mm) fastened to a steel frame (1×2 m in 1991, 1×1 m in 1992 and 1993). The trap was submerged just beneath the surface in the main current. Previous studies of Atlantic salmon smolts have shown that fish chiefly migrate in the main current (Fried et al. 1978; Hesthagen & Garnås 1986). The method is further described by Hesthagen & Garnås (1986).

The trap was operated from 2000 to 0800 hours, and the pouches were emptied at 2400, 0400 and 0800 hours every night during the study. It also operated during the day, from 0800 to 2000 hours throughout the period in 1991 and for 5 days in the 1993 period. A total of 482 smolts were captured in the trap from 28 April to 30 May in 1991, 29 April to 31 May in 1992 and 26 April to 7 June in 1993. The number of brown trout smolts was counted each time the trap was operated. Daily recaptures in 1991 were divided by two, to equate the catch per effort data recorded in the following 2 years. The discharge (m$^3 \cdot$ s^{-1}) was monitored daily at Hegra, 5 km downstream from Sona bridge, by the Norwegian Water Resources and Energy Directorate (NVE), which also monitored the water temperature at dawn and dusk at Øverkil, some 3 km upstream from Sona bridge.

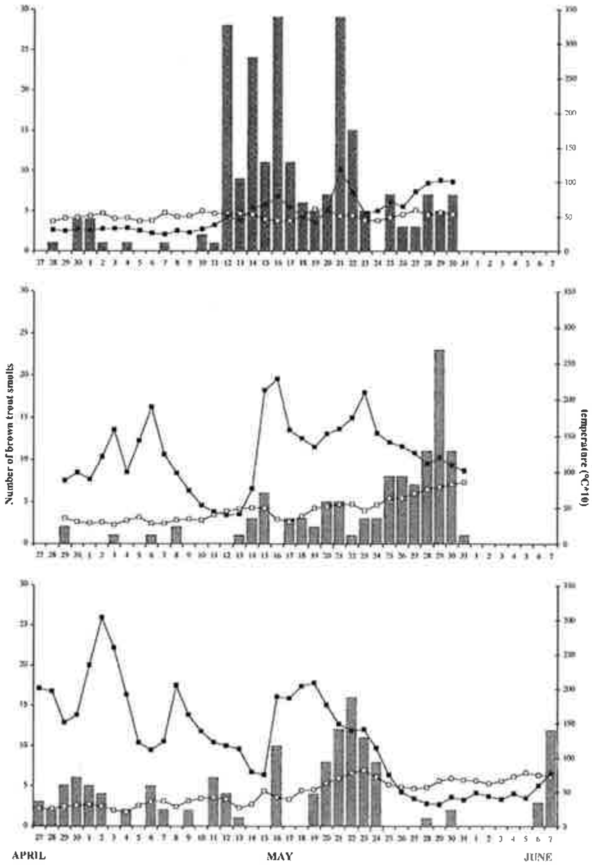

Fig. 1. Number of captured downstream migrating brown trout smolts (▤), water temperature (-□-) and water discharge (-■-) in the River Stjørdalselva for the years 1991–1993

Results

Most smolts were caught during 7–10 days in the middle (1991) or second half of May (1992 and 1993) (Fig. 1). Water discharge varied considerably from year to year. Few smolts descended until about 12 May in both 1991 and 1992 regardless of interannual differences in discharge. In 1991, the discharge was roughly constant at about 30 m$^3 \cdot$ s^{-1} in the period 27 April–12 May, whereas it first increased and then decreased from about 200 m$^3 \cdot$ s^{-1} to 50 m$^3 \cdot$ s^{-1} during the same period in 1992. The water temperature was slightly higher in 1991 (~4.5°C) compared to 1992 (~2.5°C) until 12 May. In contrast, about three times as many smolts were captured during the same period in 1993 when the discharge was higher (80–300 m$^3 \cdot$ s^{-1}) and the temperature was slightly lower compared to the previous years (Fig. 1). In 1993, there was a period (26 May to 5 June) with low discharge (40–50 m$^3 \cdot$ s^{-1}) and few smolts were captured. A rise in the discharge at the end of this period, coincided with an increase in the smolt migration.

Overall, there seems to be a trend towards increased migration at about 50 m$^3 \cdot$ s^{-1} and 4°C (Fig. 1). Below these values, few smolts migrated. The maximum numbers were recorded at intermediate discharge (70–150 m$^3 \cdot$ s^{-1}) and high water temperature (6–8°C). Moreover, at high discharge (e.g. 100 m$^3 \cdot$ s^{-1}) and increased water tem-

Table 1. Results of stepwise multiple regression analysis, using the number of downstream migrating brown trout smolts as dependent variable and water discharge and temperature as independent variable for three consecutive years

Independent variable	Regression coefficient	P	Model F	Model R^2
1991		<0.001	19.23	0.38
Water discharge ($m^3 \cdot s^{-1}$)	0.0089	<0.001		
Constant	−0.0246			
1992		<0.001	23.78	0.61
Mean temperature (°C)	0.1718	<0.001		
Water discharge ($m^3 \cdot s^{-1}$)	0.0023	<0.05		
Constant	−0.6431			
1993		<0.01	7.37	0.28
Water discharge ($m^3 \cdot s^{-1}$)	0.0039	<0.001		
Mean temperature (°C)	0.1088	<0.01		
Constant	−0.5934			
1991–1993		<0.001	20.22	0.28
Water discharge ($m^3 \cdot s^{-1}$)	0.0029	<0.001		
Mean temperature (°C)	0.1236	<0.001		
Constant	−0.4677			

perature, increased numbers of smolts were captured. At <5°C temperature, the number of smolts captured rose with increasing discharge. At higher water temperatures most smolts were captured at 100–150 $m^3 \cdot s^{-1}$.

In 1993, there was an interrelation between discharge and temperature, but this did not occur in the other two years. Multiple regression analysis indicated that discharge explained 38% of the variation in the number of smolts migrating in 1991. Discharge and temperature together explained 61% in 1992 and 28% in 1993, respectively (Table 1). Thus, the relative importance of these two factors varied from year to year.

In 1991, most smolts were captured at relatively high water temperatures and low discharge. In 1992 when the discharge was high and the temperature moderate, and in 1993 when the discharge was relatively high and the temperature low. These data suggest that, though their main descent occurred at about the same time each year, a complex set of interactions exists between water discharge, temperature, and the downstream migration of brown trout smolts.

Discussion

The daily number of descending smolts captured was significantly correlated with the mean discharge in all three years. Very few smolts descended when the discharge was low (<50 $m^3 \cdot s^{-1}$) and water temperature <4°C. However, when either of these variables remained constant, the number of smolts captured rose with the increasing value of the other variable. Thus, the smolts seemed to react to discharge and temperature in combination. However, the maximum intensity in the smolt run occurred during 7–10 days in the second half of May. Similar period of maximum movements was shown for reared brown trout smolts in an experimental tank at Laukaa (62° 27′N) in Finland (Pirhonen et al. 1998).

A positive correlation between the downstream migratory fish and increased water discharge has also been demonstrated in several other studies of salmonids (Österdahl 1969; Solomon 1981; Hartman et al. 1982; Irvine 1986; Greenstreet 1992; Bohlin et al. 1993). The downstream migration of smolts would not necessarily be initiated by water discharge but also by changes in environmental conditions connected with water discharge, such as turbidity (Solomon 1978b; Greenstreet 1992).

A rise in water discharge and changes in water chemistry can be the proximate factor to initiate smolt migration mainly in two ways. These are either passive or active downstream migration. Solomon (1978a) suggested that the smolt migration of Atlantic salmon is an active process as a response to environmental conditions. A consequence is that the smolt is able to distinguish between optimal and suboptimal environmental conditions through their downstream migration, thus enabling them to reach the sea when conditions are favorable (see Heggberget et al. 1993). Other authors have hypothesized that smolt migration is a passive process in salmonids (Crittenden 1994; Pirhonen et al. 1998). In that case, we had expected that high or increased discharge early in the study period had resulted in higher numbers of smolts. Our results have shown that water discharge is an important proximate factor for initiating smolt migration, but low catches at high water discharge in early May both in 1992 and 1993 suggest that the smolt runs may be an active process.

Moreover, our results indicate a threshold temperature (4°C) for the major descent of brown trout smolts. In the period 29 April to 11 May 1992, few smolts descended in spite of relatively high water discharge (>50 $m^3 \cdot s^{-1}$) and low temperature (2–4°C). Österdahl (1969) and Solomon (1978b) observed that the downstream migration of Atlantic salmon was initiated when the temperature reached 10°C. In contrast, in the River Orkla, which is located in the vicinity of the River Stjørdalselva, Hvidsten et al. (1995) observed that the Atlantic salmon smolt migration was initiated at 2–4°C. We did not sample when the temperature was <2°C, but we caught smolts on the first day we sampled every year. There are indications that the smolt migration of anadromous brown trout is initiated at temperature of >2°C in the River

Stjørdalselva and that there is an increase in the number of descending smolts when the temperature exceeds 4°C. In an experimental test of movements of reared brown trout smolts, Pirhonen et al. (1998) found no threshold temperature as downstream displacement increased as soon as temperature started to rise. The temperature varied between 2°C and 16°C in their study. However, the latter and our study showed most intense movements between 6°C and 8–10°C, but somewhat lower than reported for smolt movements of trout populations further south (Chelkowski et al. 1994; Moore & Potter 1994).

In the Stjørdalselva, we found a significant positive correlation between the water temperature and the number of downstream migrating smolts in 1992 and 1993. This coincides with fish species descending rivers (White 1939; Solomon 1978a, b; Haraldstad et al. 1985; Irvine 1986). Also, White (1939) observed a positive correlation between the number of downstream migrating Atlantic salmon smolts and water temperature during a period of stable water discharge. For 3 years, we found similar behavior in anadromous brown trout smolts. An explanation for this may be that the positive reothaxis decreases with increasing water temperature, as Hoar (1976) observed in chum salmon (*Oncorhyncus keta*) fry. This may also indicate that the downstream migration in smolts is an active behavior.

Resumen

1. Durante tres años consecutivos, estudiamos el descenso de smolts de de una población de *Salmo trutta* anádroma de un río noruego. El mayor descenso se produjo durante un período de siete a diez días de la mitad, o de la segunda mitad de Mayo. Los datos obtenidos son consistentes con la hipótesis de que incrementos en el caudal y en la temperatura estimulan el descenso.

2. Algunos individuos descendieron a bajos niveles de caudal ($<50\ m^3 \cdot s^{-1}$) y a bajas temperaturas (<4°C), pero el máximo número fué capturado a niveles moderados de caudal (70–150 $m^3 \cdot s^{-1}$) y altas temperaturas (6–8°C).

3. La importancia relativa de estos factores cambió de año en año. La primera descarga del año explicó 38% de la variación en el número de smolts migrando aguas abajo, mientras que el caudal y la temperatura juntas explicaron el 61% en 1992, y el 28% de la variación en el segundo y en el tercer año de estudio.

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