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Effect of sudden increase in discharge in a large river on newly emerged Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) fry

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Abstract – Downstream displacement of salmonid fry due to flow increase, from 12–15 m^3/s to >100 m^3/s, was documented in the river Suldalslågen, Western Norway. In May only fry of brown trout (*Salmo trutta*) occurred in the drift, while from the beginning of June only newly emerged Atlantic salmon (*Salmo salar*) were found. The maximum number of Atlantic salmon fry drifting during a single day was estimated to be 17 000 individual. Their density in the drift was higher during the night than during the day, and their appearance in the drift coincided with the predicted period of emergence. Total brown trout numbers in the drift were estimated to vary between 4000 and 16 000 per day. Fry displaced downstream from the lowermost part of the river were lost from the population. The total losses were estimated to be between 75 000 and 100 000 Atlantic salmon fry which represents between 5.6 and 11.1% of juvenile mortality during the first year of life.

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Key words: river; flow increase; drift; fry; Atlantic salmon; brown trout

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

Introduction

Downstream displacement or drift is an important phenomenon in running water, but its aspects have been most intensively studied in benthos (Brittain & Eikeland 1988). Considerable information also exists on downstream movement of fish, but little is known of the reasons and of the consequences for the population, and the results are often contradictory. The emergence of Atlantic salmon (*Salmo salar*) and trout fry (*S. trutta*) occurs at night (Elliott 1986). Moore & Scott (1988) observed both passive and active downstream migration of newly emerged brown trout fry in the evening and throughout the night. Apart from the water velocity, age and condition of the fry seem to be the two other most important factors affecting their downstream movement (Elliott 1987).

The numbers of brown trout fry moving downstream has been found to be positively correlated with water velocity (Ottaway & Clarke 1981; Ottaway & Forrest 1983; Crisp & Hurley 1991a,b), and this relationship was strongest when the fry had just emerged from the gravel. The opposite relationship were found for Atlantic salmon fry, the highest dispersal rate was found at low flows and the lowest dispersal rate at high flows (Crisp & Hurley 1991a,b). Most workers agree that movement of fry to their initial feeding habitat is typically nocturnal for downstream moving fry. Elliott (1987) found that older fry in poor condition and newly emerged fry had the longest drift distances and that newly emerged fry appeared to move downstream passively and mainly at night. Most studies of downstream migration in juvenile salmonid fish have been conducted either in small streams or artificial channels. Studies from large rivers, where the magnitude of flow is much higher, are lacking.

In the large, regulated river, Suldalslågen, the transition from low winter flows (10–12 m^3/s) to high summer flows occurs on 1 May. Then flows increase suddenly to more than 100 m^3/s, and on 1 June to 200–250 m^3/s. Atlantic salmon and brown trout are the two dominant fish species. Most of the brown trout emerge from the gravel before the high flow, while all of the Atlantic salmon fry emerge during high flow conditions. This takes place in the middle of the river, because spawning occurs during low winter flows in December-January.

Study area

The river, Suldalslågen, western Norway, has a catchment area of about 1000 km^2. It is 22 km long, running from the lake Suldalsvatn (65 m a.s.l. and 29 km^2), to the inner part of the Ryfylkefjord (Fig. 1). Suldalslågen produces anadromous fish along its entire length.

Suldalslågen is regulated and during winter, from 15 December to 1 May, the minimum flow is 12 m^3/s. On 1 May the flow is increased to more than 100 m^3/s and further to 200–250 m^3/s on 1 June. From 1 August the minimum flow in the river is 60–70 m^3/s and during late summer and autumn the flow is gradually reduced to the winter minimum flow. During the study period flow was low in April, 15 to 16 m^3/s in 1991 and 1992, but slightly higher in the latter part of April 1993 (Fig. 2). The pattern of flow increase on 1 May and 1 June was different in each year (Fig. 2).

In 1991–1993 the temperature increased from mid-April to the beginning of May (Fig. 2). This increase was followed by a decrease in early May. Thereafter the temperature rose very slowly during May, although followed by a new temperature decrease on 1 June. Reduction in temperature coincided with increase in flow, except in June 1992.

Material and methods

Drifting fry, in this context used for newly emerged Y of Y, were collected in a net of diameter 1 m, mesh size 1 mm and c. 2.5 m long. The drift net was attached to a wire set across the river. The drift net was held down by weights in position just below the water surface. On account of the turbulent nature of the river, it was assumed that the net position was representative for the total river cross-section. The river depth at the sampling site was 3-4 m at high flows. Sampling time was usually between 5 and 10 minutes, depending on the amount of organic material in the samples. Five replicates were taken during a one hour period. The samples were either sorted in the field or frozen and then sorted in the laboratory. In 1991 sampling only took place in daytime, while in 1992 and 1993 sampling took place throughout the day and night.

To calculate the volume of water filtered for estimating the total number of fish drifting, velocity was measured in the drift net opening using a Höntzsch micropropeller. Data on flow in the river on an hourly basis were supplied by the Norwegian Water Resources and Energy Administration (NVE).

Number of fish drifting pr. minute (N_t) was estimated using the following formula:

$$N_t = n \cdot Q/a \cdot v \cdot t = n \cdot Q/V_s$$

Q = river flow, m^3/s
n = number of fish in sample
a = net opening area, m^2
v = velocity, m/s
t = sampling time
V_s = volume filtered, m^3

Based both on results from sampling of spawning redds and electrofishing in April, it was concluded

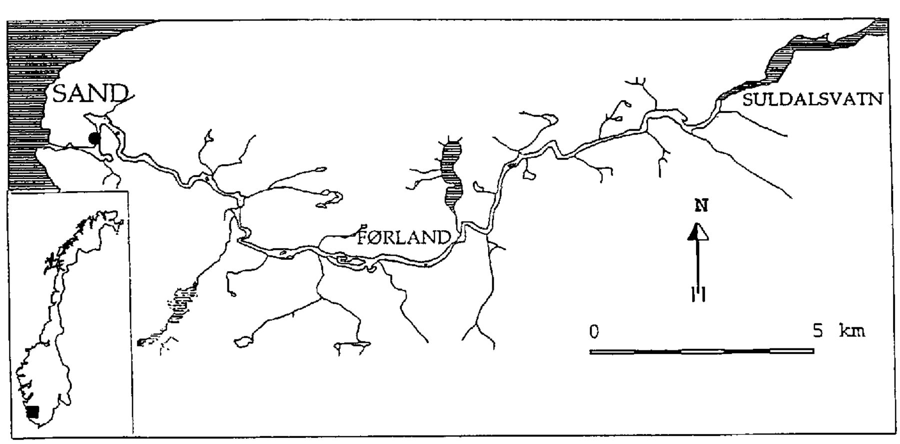

Fig. 1. Map of the river, Suldalslågen, with the sampling locality indicated.

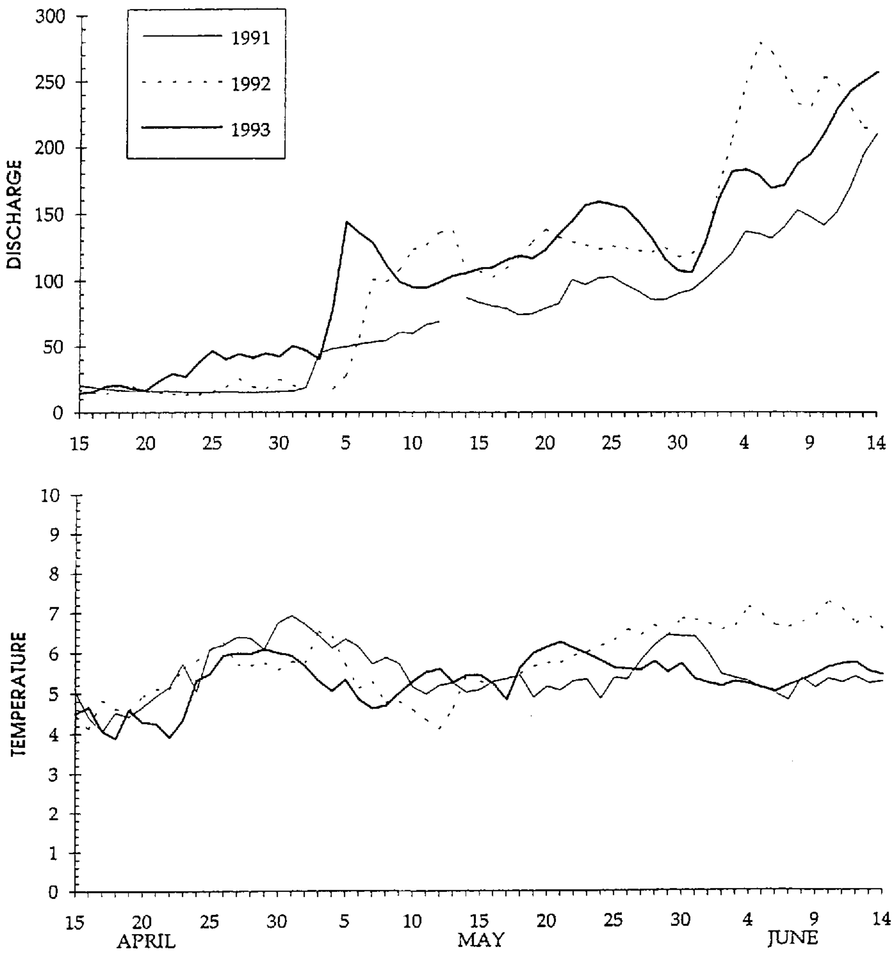

Fig. 2. Mean daily discharge (m^3/s) and mean daily temperature (°C) in Suldalslågen from 15 April to 15 June in 1991, 1992 and 1993.

that most of the brown trout had emerged from the gravel by 1 May. However, all Atlantic salmon fry were still in the redds as eggs or yolk sac larvae. As it was not possible to sample redds after 1 May due to high flows, time from hatching to emergence and first feeding, i.e. "swim up" of Atlantic salmon was estimated to occur from the beginning of June, based on the work of Jensen et al. (1989).

In 1991 the sampling was carried out during two periods; 30 April to 7 May and 31 May to 5 June. In 1992, two periods; 28 April to 8 May and 2 to 4 June were sampled. In 1993, three periods; 3 to 7 May, 27 May to 6 June and 16 to 19 June were sampled.

Results

In all three years studied no fish were present in the drift at low flow in April.

During the first period in May 1991 no fry were collected (Fig. 3), while it was estimated that a total of between 0.2 and 2 fish pr. minute were drifting in the river at the beginning of June, all of them newly emerged fry of Atlantic salmon. The total number for one day was estimated to vary between 290 and 4 300 fish.

During May 1992 both trout and salmon were collected (Fig.3). However, all salmon in May were older than Y of Y and most of them were smolt migrating at night. All trout collected were fry and were present in samples both during the day and night. There was a distinct and rapid increase in drift following the increase in flow. The number of brown trout fry was estimated to vary between 4 and 9 fish pr. minute (Fig. 3), which corresponds to between 7 200 and 13 000 fry pr. day during that period.

In June 1992, all fry in the drift were Atlantic salmon. A clear and strong increase in numbers was observed parallel to the increase in flow. At the beginning of the sampling period no fish were found, but during the period the number increased to an estimated number of 18 fish pr. minute. This corresponds to a total of 17 000 to 26 000 fry pr. day for that period.

The drift pattern of fry of trout was the same in

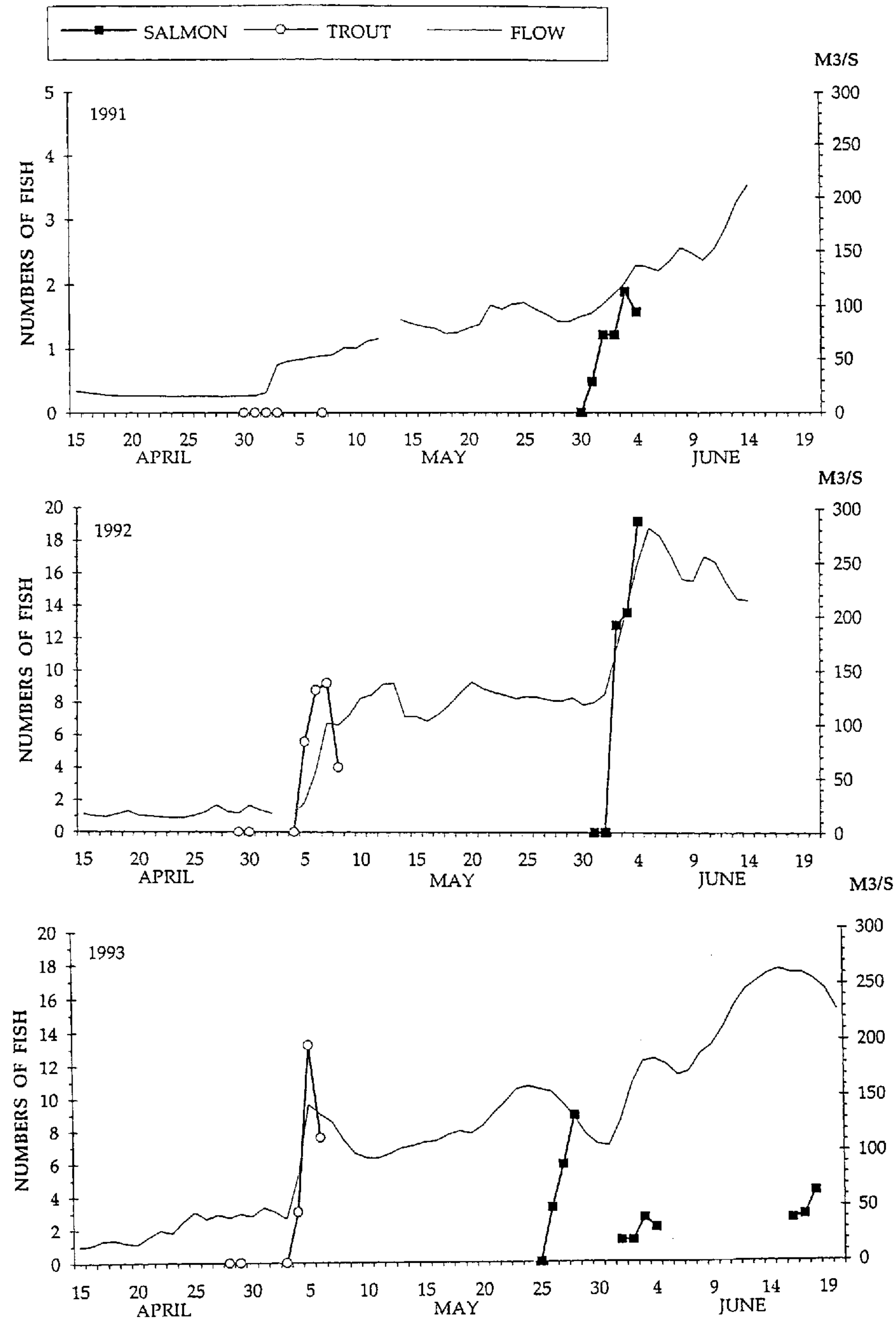

Fig. 3. Numbers (N/minute) of fish yearlings of brown trout and Atlantic salmon drifting in Suldalslågen during different periods from 15 April to 15 June in 1991, 1992 and 1993.

1993 as in 1992, i.e. a clear increase in drift followed the increase in flow. Fish estimates were also similar, c. 4 000 to 16 000 pr. day in the beginning of May.

In 1993 the first fry of Atlantic salmon appeared in the drift in the end of May, and they were found in the drift until mid-June, when sampling was terminated because of too high flows in the river. During the first period drift increased strongly from 0 to 9 fry pr. minute, while between 1 and 4 fry pr. minute were estimated to drift later in June.

A stronger diurnal variation was found in the drift of Atlantic salmon than in the drift of brown trout (Fig. 4). A larger number of newly emerged fry of Atlantic salmon were found drifting during the night than during the day. The difference between day and night was highly significant ($P<0.001$, Chi-squared distribution). No statistically significant difference between day and night observations was found for brown trout. Atlantic

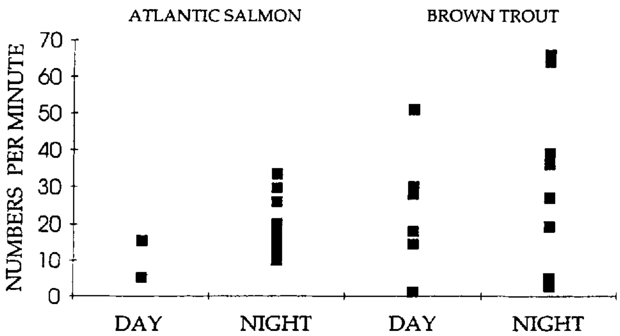

Fig. 4. Diurnal variation in drift of brown trout and Atlantic salmon in Suldalslågen based on data from 1992 and 1993, shown as numbers of fish per minute in single samples.

salmon fry were only collected during daytime in 1992 during the short period when flow increased rapidly and strongly on 1 June.

Discussion

Egg development is directly correlated with water temperature and no local adaptions in egg development exist in Norwegian salmon populations (Wallace & Heggberget 1988). However, the late spawning of Atlantic salmon in Suldalslågen; in December and January, is an adaptation to the higher winter temperature in the river, giving an optimal hatching time in April-May (Heggberget 1988). Thus, the spawning of salmon in Suldalslågen occurs at minimum flows.

The time from hatching to emergence from gravel and the first external feeding, is strongly temperature dependent (Brännäs 1988, Crisp 1988, Kane 1988, Jensen et al. 1989). At temperatures between 5 and 7°C the larvae spend between 60 and 39 days in the gravel, as calculated from the equation of Jensen et al. (1989). Hatching from 15 April leads to the first swim up from 1 June. However, hatching also occurs as late as 1 May and therefore emergence of Atlantic salmon takes place throughout most of June. Previous observations of newly emerged fry of Atlantic salmon in Suldalslågen have been at the end of May or the beginning of June, with fish still having remains of their yolk sac (Lillehammer 1973).

The increase in flow influences fry of brown trout and Atlantic salmon in a different manner. When flow suddenly increases on 1 May, brown trout are already in their external feeding stage. The appearance of the brown trout fry in the drift is probably due to active swimming trying to colonize new habitats or that they are removed from their positions by the increased water velocity. When the flow has stabilized at a higher level, no trout fry appeared in the drift.

Crisp & Hurley (1991a) showed that brown trout display a tendency for downstream dispersal with increase in water velocity. Brown trout yearlings are active only during the night at low temperatures (Heggenes et al. 1993). Therefore if drift was due to active movement, relatively more fish should be present in the night samples. However, there was no difference in drift abundance between day and night, which may indicate a passive displacement of brown trout in Suldalslågen. Crisp & Hurley (1991b) showed that trout had a higher dispersal rate during the night at constant low velocities, but not at constant high velocities. They also did not find it surprising that the rapid changes in flow they exposed their fish to, had a major effect on downstream dispersal. These changes were of a speed and magnitude which can occur in tailwaters during the opening of sluices in hydroelectric dams. Irvine (1986) concluded that if it was desirable to keep the yearlings within rivers, flow had to be reduced.

For Atlantic salmon the situation is different as they emerged during the high flow from the middle part of the river at high velocities and far from the shore. For fry entering the free-feeding stage critical velocities were found to be between 0.10 and 0.25 m/s, the critical velocity increasing with temperature (Heggenes & Traaen 1988). Emergence occurs at night (Elliott 1986; Moore & Scott 1988), and the fry are probably easily caught by the current immediately after emergence when trying to colonize new areas along the shoreline, containing the preferred habitats for age 0 Atlantic salmon (Heggenes 1990). This is underlined by the large diurnal variation in drift, most of the fry being found at night, except for the period around 1 June when salmon fry also drifted during day owing to the new strong increase in flow. During daytime fry are also better at holding their position, losing their visual cues during the night (Crisp & Hurley 1991b). Crisp & Hurley (199lb) showed that salmon had a higher dispersal rate by night than by day at constantly high velocities, but not at constantly low velocities.

In spite of all the information on fish downstream movements, little is known on the distance travelled by fry and the time taken for displaced fish to return to the stream bottom. Elliott (1987) stated that age and condition of the fry is of great importance in affecting their downstream movement. Newly emerged fry of trout appeared to move passively downstream 30–40 m at a surface velocity of 0.52 m/s. Elliott (1987) did not consider population losses in the first month of life to be caused by emigration of trout out of the stream, but due to mortality within the stream. In Suldalslågen the magnitude of flow is far higher than in small streams and the effect of downstream movement on the fish population may therefore be more adverse in a large river.

The sampling locality in the Suldalslågen is situated less than 500 m from the sea. Therefore, it is assumed that most of the fry drifting in the lowermost part of the river and passing the study site are lost from the population. Those drifting in the upper part are not lost, but colonize new areas, although no increase in density of fish in the lowermost part has been observed (Saltveit 1990, unpubl. results). Based on results from 1992 and 1993, losses were estimated to be in the magnitude of 75 000–100 000 Atlantic salmon fry each year. Based on counts of spawning redds and estimated numbers of spawners in the river, the total number of emerging Atlantic salmon fry is between 1 and 1.5 million. Drift therefore accounts for about 5–10% of those emerging from the gravel. At the end of the first growth season the total number of 0+ fry was estimated to be a total of 100 000–150 000 individuals. Of the fry mortality during the first year of life drift accounts for 5.6–11.1%.

Before the regulation of Suldalslågen, high natural spring flows also occurred during May and June probably affecting fish emerging from redds in the middle of the river. Drifting fry and loss due to high flows is therefore probably not a regulation phenomena in Suldalslågen. Rivers having spawning redds in the middle of the river due to low flows during spawning time and emergence of fry during high spring flows, will probably be more adversely affected and have lower densities of juveniles than rivers where differences between winter and summer flow are less or where emergence takes place before the peak in the spring spates.

With a dam on the river and the possibility of interbasin water transfer, it is now possible in Suldalslågen to manipulate the flow and by this to reduce the fish drift caused by high flow, such as reducing flows in spring until the fish have emerged and started external feeding.

Resumen

1. Es conocido que los aumentos de caudal de agua afectan a los movimientos aguas abajo de los jóvenes de salmónidos. En éstos, la magnitud del caudal, y la edad y la condición de los jóvenes también son importantes. Hasta la fecha, no hay estudios sobre estos movimientos en grandes rios donde la magnitud de los flujos, sus variaciones y las velocidades del agua son muchos mayores que en ríos pequeños o que en canales experimentales.
2. En el río Suldalslagen (Noruega), cuando los juveniles de Trucha (*Salmo trutta*) y de Salmón (*S. salar*) emergen de la grava, el caudal de agua asciende desde los minimos de invierno (12–15 m^3/s) hasta los 100 m^3/s o más. En este rio regulado hemos estudiado los movimientos aguas abajo de juveniles de estas dos especies debidos a incrementos del caudal de agua.
3. En Mayo, solo aparecieron juveniles de Trucha en la deriva mientras que al empezar Junio solamente aparecieron juveniles de Salmón. El número máximo de juveniles de Salmón derivando en un mismo dia fué 17.000 ind. Su densidad en la deriva fué mayor durante la noche que durante el día y su aparición en la deriva coincide con el período de emergencia de la grava. Los números totales de Truchas en la deriva variaron entre 4000 y 16000 por día. Estos movimientos aguas abajo resultan en la pérdida para la población de los juveniles ubicados en las zonas más bajas del rio. Las pérdidas totales fueron estimadas en 75.000–100.000 juveniles de Salmón cada año, lo que representa entre el 5.6 y el 11% de la mortalidad de los juveniles durante el primer año de vida.

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