FISH KILLS of ATLANTIC SALMON (SALMO SALAR) and BROWN TROUT (SALMO TRUTTA) in an ACIDIFIED RIVER of SW NORWAY

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Abstract. This paper documents population responses of Atlantic salmon and brown trout to fish kills in River Vikedal, an acidified river in SW Norway. The angling statistics show that the adult population of Atlantic salmon in the river has decreased to low numbers during recent years, whereas catches of migrant brown trout have increased in the same period. A total of 659 dead salmon and trout were either collected or observed during spring snowmelt in the years 1982-1985. Parr suffered the highest mortality, and most large specimens. Only a few dead kelts were registered. In the springs of most unfavourable water quality and most severe episods of fish kills (1983 and 1984), salmon parr mortality were significantly higher than that of brown trout. Episodic death of parr in the spring is thought to be an important cause of the reduction in the adult stock of Atlantic salmon in the river during recent years.

1. Introduction

The acidification of freshwaters in Norway has eliminated populations of Atlantic salmon (*Salmo salar* L.) in all major rivers in the southernmost counties (Jensen and Snekvik, 1972; Leivestad *et al*., 1976; Muniz, 1981). The salmon populations in these rivers began to decline at the beginning of this century, and by the 1960's they became virtually extinct.

Eggs, alevins and fry are those life stages at which Atlantic salmon are considered most vulnerable to low pH (Jensen and Snekvik, 1972; Daye and Garside, 1977; Daye, 1980; Muniz and Leivestad, 1980; Haines, 1981; Lacroix, 1985; Lacroix *et al*., 1985). In some cases fish kills involving adult salmon have also been observed (Huitfeldt-Kaas, 1922; Rosseland, 1953; Snekvik, 1975; Skogheim *et al*., 1984).

A severe fish kill of young salmonids was observed in River Vikedal, an acidified river in SW Norway (Figure 1), during snowmelt in spring 1981 (Rosseland and Skogheim, 1982; State Pollution Control Authority, 1983). The angling statistics for

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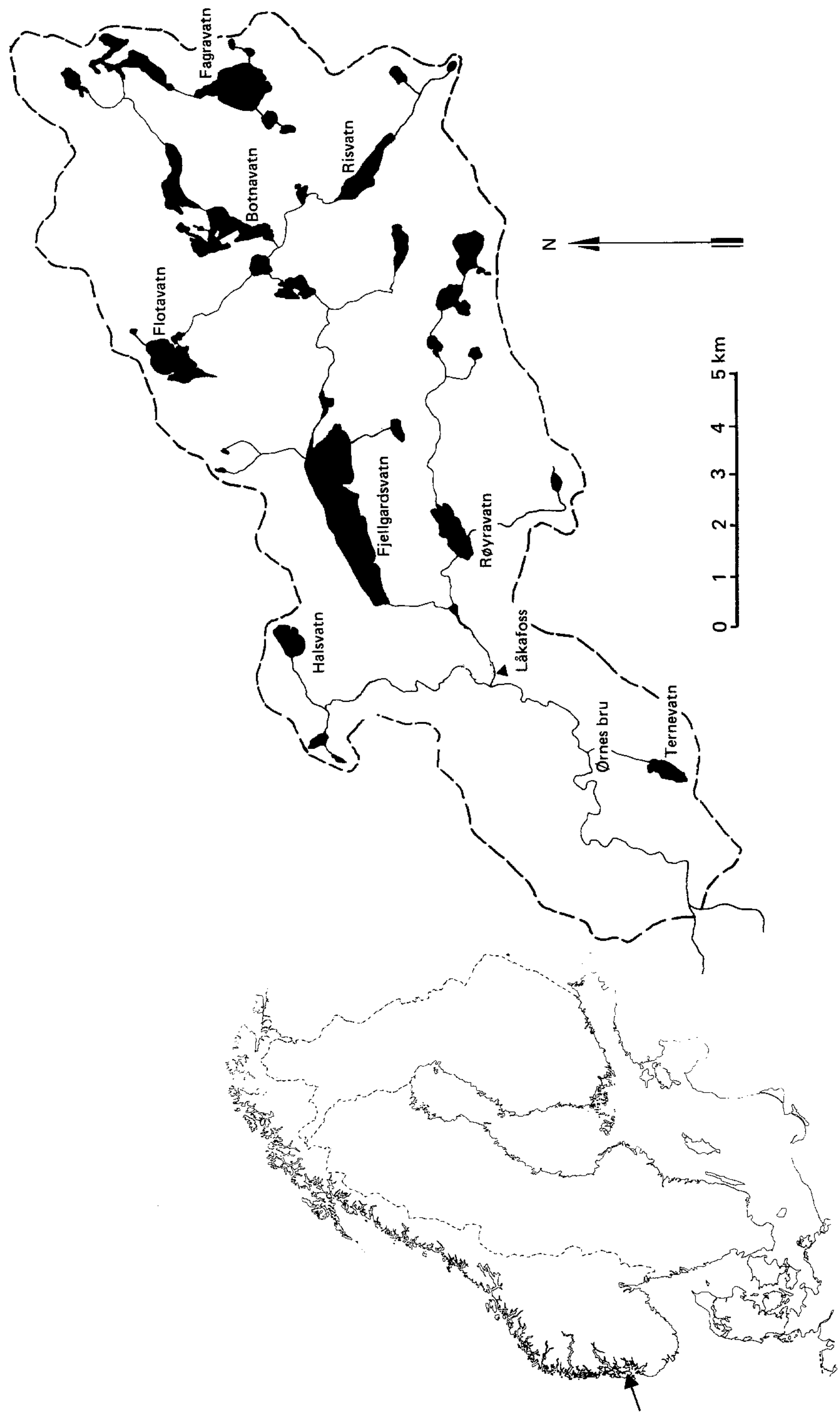

Fig. 1. Geographic location and catchment area of River Vikedal.

this river demonstrate a marked decline in catches of adult Atlantic salmon during recent years, whereas those of brown trout (Salmo trutta L.) have increased during the same period, Figure 2. Compared with the early 1979's, the pH level in the river Vikedal dropped markedly during the late part of this decade (State Pollution Control Authority).

A study which included the collection of dead fish and monitoring of water quality was initiated in spring 1982, in the event that new episodes of fish kill occurred. In addition, electrofishing has been carried out every fall since 1981 in order to assess any changes in the juvenile stocks of Atlantic salmon and brown trout.

Episodic fish kills have been registered every spring during 1982-1985, and based on continuous pH measurements there is evidence to link mortality to low pH effects (Hesthagen and Henriksen ms.). Experiments with captive Atlantic salmon parr in spring 1984, confirmed correlations between fish kill and water quality (Rosseland et al., 1986a).
The objectives of the present study were to determine the species and stages with the highest mortality during these episodes of fish kills, and to document related changes in species composition of juvenile Atlantic salmon and brown trout.

2. Study area

River Vikedal is located in SW Norway at 59°30'N, 5°53'E (Figure 1). The catchment area is 119 km^2, having an axial length of 22.6 km, and 29 lakes $\geq$ 2.4 ha with a total surface area of 812 ha (State Pollution Control Authority, 1984). The drainage area consists mainly of slowly weathering rocks (granite and gneisses), as well as some sparse glacilacustrine and glacifluvial deposits. In the lower part of the catchment, there are 87 farms with a total area of 4 km^2 cultivated land. Mean annual precipitation is 2650 mm. Weighted mean precipitation pH from April 1982 to November 1983 was 4.58, with the lowest value being 3.93. Based on monthly sampling during the last decade, the mean annual pH in the lower part of River Vikedal has ranged between 5.35 to 5.60 (State Pollution Control Authority, 1984). Average waterflow at the river mouth is 9 m^3 s^{-1}, and river width ranges between 20 to 30 m. In addition to Atlantic salmon and brown trout, River Vikedal supports stocks of European eel (Anguilla anguilla (L.)), lamprey (Lampetra planeri, (Bloch)), three-spined sticklebacks (Gasterosteus aculeatus L.) and sand flounder (Platichthys flesus (L)). Anadromous brown trout and Atlantic salmon ascend 10 km of the river system up to the waterfall Låkafossen (Figure 1). No tributary to the river is important with respect to fish production.

3. Methods

Surveys for collecting dead fish were generally carried out daily during spring snowmelt in 1982-1985. Three stream

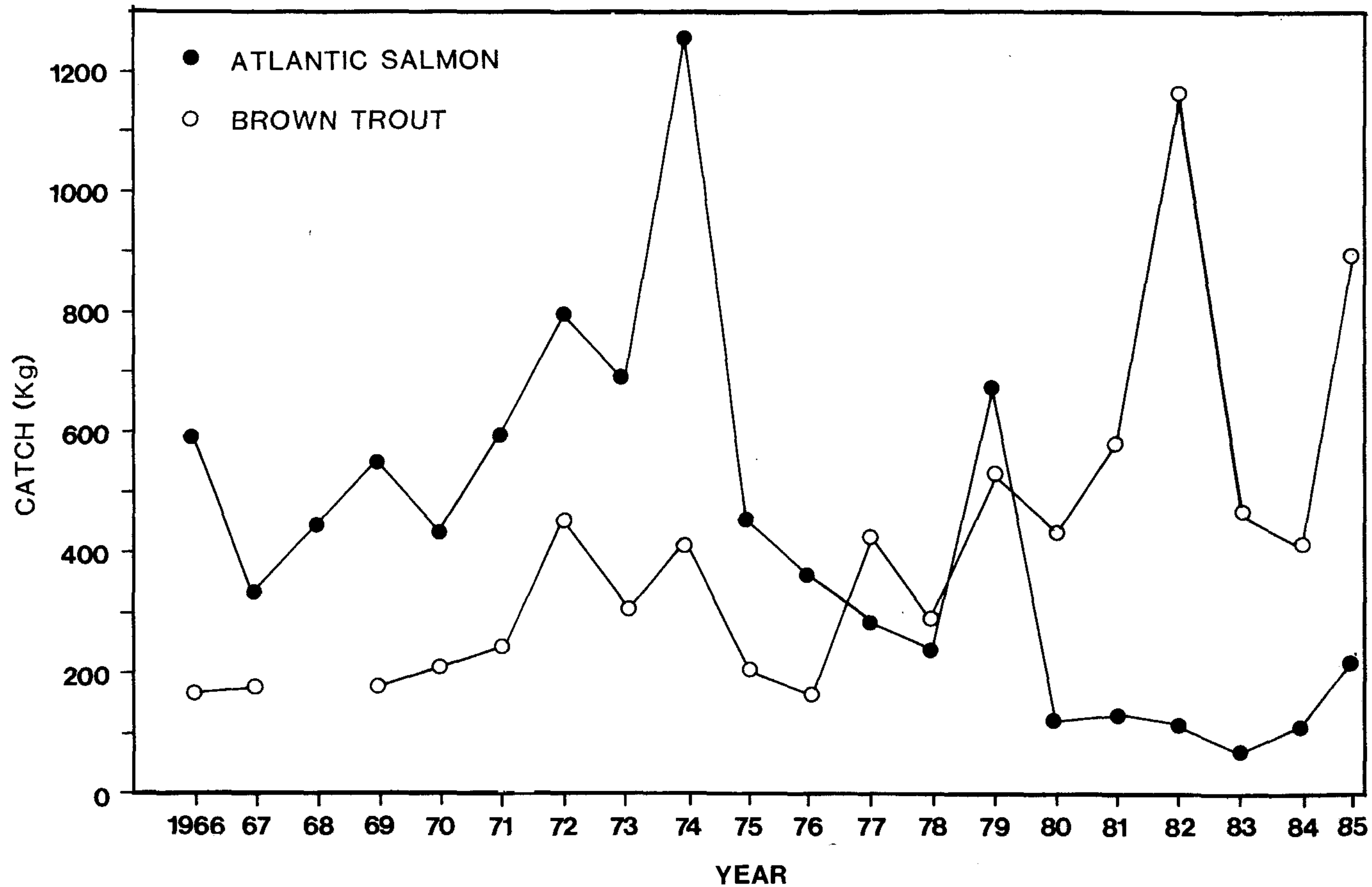

Fig. 2. Official angling statistics (kg) of Atlantic salmon and migrant brown trout caught in River Vikedal during 1966-1984.

stretches of the river and one stretch in the brachish area were included (Hesthagen and Henriksen ms.). Some of the dead fish (salmon or trout) observed could not be collected because they were located in deep areas of the river. Collected fish were frozen shortly after each trip, and the total length (0.1cm) was measured later. Dead salmon and trout with a total length < 20 cm cm were classified as parr, (Hesthagen and Garnås, 1984). Bigger specimens were classified as kelts if they showed sea-growth in their scales.

Juvenile fish density was calculated at three stations in fall 1981 (total area 585m^2), at five stations in 1982-1984 (642 m^2), and at 16 stations in fall 1985 (1712 m^2). Sampling was done with an electrofishing apparatus (1600 V, D.C. unloaded) at sites located in areas which included suitable rearing habitats for both fry and parr.

All fish caught during electrofishing were measured for total length (0.1cm).
Statistical analysis of difference in frequencies was carried out by testing equality of two percentages (Sokal and Rohlf, 1969).

4. Results

4.1. Size of fish found dead and caught by electrofishing

A total of 560 dead Atlantic salmon and brown trout were collected during the years 1982-1985. The mortality was highest in the spring of 1984 (172 salmon and 31 trout), and lowest in the spring of 1985 (1 salmon and 21 trout). In addition, 99 dead salmon and trout were observed during the same period, the majority being registered in 1984 (72 fish). The frequency of kelts among these specimens was high (42.5%).

Generally, juvenile fish between 4-19 cm in length were most abundant among dead fish for both salmon and trout (Figure 3). Only a few dead brown trout kelts were collected (8 specimens). The size of fish caught by electrofishing in the fall prior to springs fish kill showed that fry (age 0+) were dominant (length between 3 to 7 cm), indicating that large parr suffered a higher mortality than small parr. However, taking into account the growth between fall and spring, the size of dead brown trout in the springs of 1984 and 1985 seems merely to reflect the length frequency distribution in the population in the fall of 1983 and 1984, respectively.

4.2. Species composition for dead fish and for fish caught by electrofishing

Proportions of Atlantic salmon (68%) and brown trout (32%), found dead in the spring of 1982, did nor differ significantly from the salmon/trout ratio among live fish obtained by electrofishing in the previous fall (X^2=0.56, p>0.05). However, in the springs of both 1983 and 1984 salmon suffered the highest mortality of these species ($p < 0.05$, X^2=8.39 and

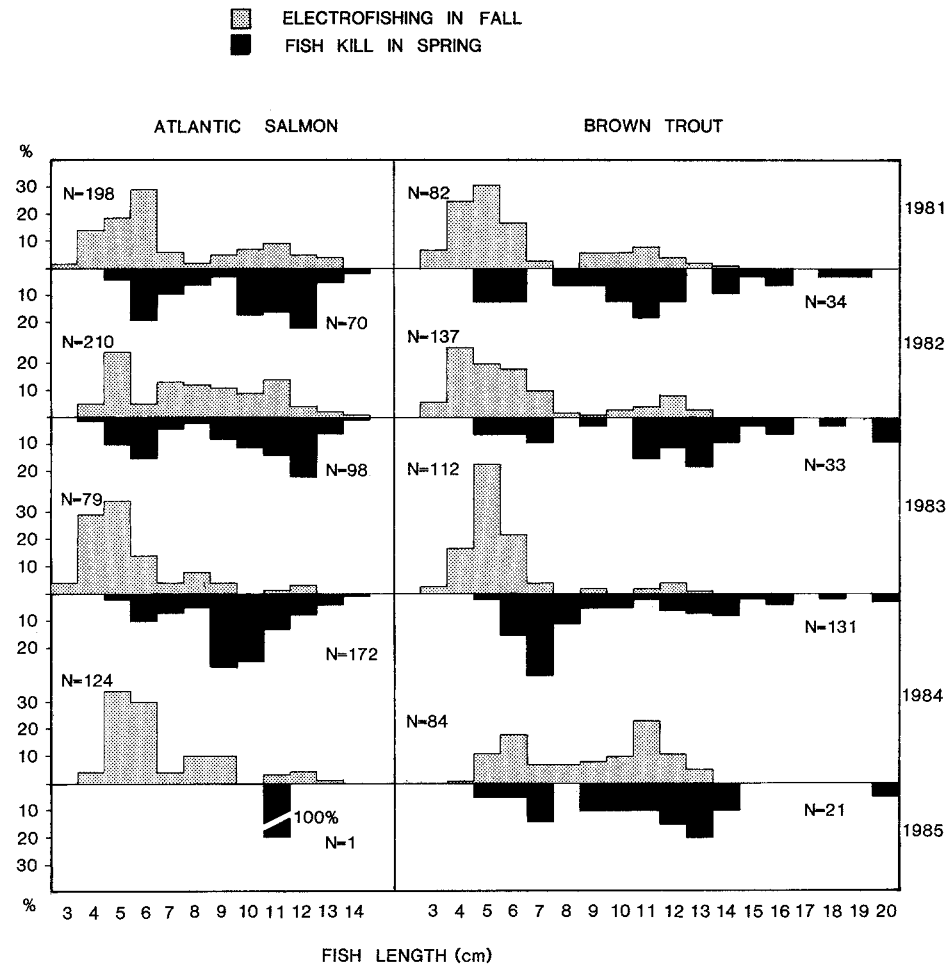

Fig. 3. Length-frequency distribution (%) of juvenile Atlantic salmon and brown trout caught by electrofishing in River Vikedal in fall and that of dead specimens collected next spring. Data from 1981-1985. N=Number of fish.

11.12, respectively). The proportion of juvenile salmon in the river decreased gradually from 1982 (75%) to 1984 (41%). However, in the fall of 1985 the number of young salmon was significantly higher (58%) than that of brown trout ($p < 0.05$).

5. Discussion

Fish kills involving mainly juvenile Atlantic salmon and brown trout were documented every spring from 1982-1985 in River Vikedal, SW Norway. The catches of adult Atlantic salmon have been reduced drastically during the 1980's, while those of migrant brown trout have increased during the same period.

Generally, large parr of both Atlantic salmon and brown trout suffered a significantly higher mortality than small parr. Some of the large parr are assumed to be potensial smolt that year (cf. Elson 1957). For Atlantic salmon, this difference in tolerance to acid water between fish in these two stages (parr and pre-smolt) has also been verified in laboratory experiments (Rosseland and Skogheim, 1982; 1984; Rosseland et al., 1986b. Furthermore, smoltification does not proceed normally in Atlantic salmon subjected to low pH (< 4.9) (Saunders et al., 1983). The lack of recaptures of released smolts of Atlantic salmon in acidic rivers in southernmost Norway also indicates that fish in this stage are sensitive to acidic water (Hansen, 1982).

For brown trout, the size dependent mortality was inconclusive. Laboratory experiments seems to confirm this result, showing that brown trout does not exhibit the same difference in sensitivity between parr and pre-smolts in acid Al-rich water (Rosseland and Skogheim, 1982). They found that two-year-old migrant brown trout (pre-smolts) were more sensitive than one-year-old fish in only one of four tank experiments.

Relatively few dead adults of Atlantic salmon/brown trout were observed in the river. These fishes are probably kelts because salmon and trout do not ascend River Vikedal before June.

Compared with other years the lowest pH levels were recorded in spring 1983 and 1984 (Hesthagen and Henriksen ms.), which coincide with the most severe episodes of fish kills. In these two years salmon parr mortality in spring was significantly higher than that of trout parr, Salmon parr densities in the following falls were low indicating that salmon is the most sensitive species to acid water (unpubl. data). Atlantic salmon was the first species to disappear from acidified Norwegian salmon rivers (Jensen and Snekvik, 1972; Leivestad et al., 1976). Data on physiological stress also confirm these results, showing that one- and two-year-old salmon were more sensitive to acidic, Al-rich water than both migrant- and resident brown trout of the same age (Fivelstad and Leivestad, 1984; Rosseland and Skogheim, 1984; Rosseland et al., 1986 b). In comparative studies on the egg and alevin stages, Atlantic salmon experienced also the highest mortality of these two species (Bua and Snekvik, 1972; Johansson et al., 1977; Grande et al., 1978; Skogheim and Rosseland, 1984).

Generally, the density of Atlantic salmon and brown trout fry in River Vikedal have been relatively constant during the study period (unpubl. data). However, for Atlantic salmon, the fry density was higher in 1985 compared with that in previous years. In the spring of 1984, River Vikedal was strongly acidic with pH values between 4.9 to 5.2 during most of the hatching and postemergent period compared with values between 5.3 to 5.6 in 1985 (Hesthagen and Henriksen ms.). Hatching experiments of Atlantic salmon conducted in the river in these two years showed higher survival in 1985 (unpublished data). Thus, some mortality on natural spawned eggs might occur during the alevin stage and hence reduced survival of Atlantic salmon fry (Bua and Snekvik 1972; Johansson et al., 1977; Grande et al.; 1978;

Skogheim *et al.*, 1984). Hence, a partial failure of recruitment in addition to a high mortality of large parr might occur. However, the ultimate population effect (i.e. on smolt production) of such a mortality on young stages is difficult to judge because survival of juvenile Atlantic salmon is density dependent (Buck and Hay, 1984).

The lower return of adult Atlantic salmon compared with that of migrant brown trout may partly be due to difference in exploitation rates. Most Norwegian salmon stocks are heavily exploited in oceanic fisheries, while migrant brown trout are mainly restricted to the fjords, where they are less subjected to fishing. For the salmon in the neighbouring in River Imsa, the exploitation rate of both hatchery reared and wild salmon is estimated at 0.90-0.95 (Hansen, 1986). No such data are available on migrant brown trout, but compared with salmon it is considered to be low. There is also some evidence to suggest that an increase in exploitation for Norwegian salmon has occurred during recent years (Hansen, 1986).

Mortality of parr during spring might not be typical of acidified salmon rivers in other countries. The fish kills in River Vikedal were strongly episodic and occured after rapid changes in water quality due to increased water flow (heavy rainfall or snowmelting) (Hesthagen and Henriksen ms.). In some rivers of Nova Scotia in Canada, the salmon populations now have either disappeared or declined as a result of low pH (Farmer *et al.*, 1980; Watt *et al.*, 1983). These changes have been correlated to high mortality of eggs, alevins and postemergent stages (Lacroix, 1985; Lacroix *et al.*, 1985). However, in these rivers, the minimum pH in spring occurred before the peak flow because snow was higher in pH than rain (Watt *et al.*, 1983).

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