Threshold values of river discharge and temperature for anglers' catch of Atlantic salmon, Salmo salar L

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Threshold values of river discharge and temperature for anglers' catch of Atlantic salmon, *Salmo salar* L.

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Abstract The catch by anglers of adult Atlantic salmon, *Salmo salar* L., was studied over a 5-year period in the River Gaula, Norway. Atlantic salmon were caught over a wide range (23–570 m^3 s^{-1}) of the observed extent of river discharge (13–950 m^3 s^{-1}) and throughout the range of temperature (4–23 °C), but both factors strongly affected catch rate. Significant correlations between the number of Atlantic salmon caught daily, and water temperature ($r = 0.33$) and river discharge ($r = -0.42$) were found in 1987 and 1989, respectively. The highest daily catch occurred between 50 and 150 m^3 s^{-1}, and at temperatures between 13 and 16 °C. Threshold values for water discharge and temperature were found to exist at 250 m^3 s^{-1} and 8 °C, with the highest catches below and above these values, respectively.

KEYWORDS: angling, Atlantic salmon, river discharge, temperature.

Introduction

The annual catch of Atlantic salmon, *Salmo salar* L., by anglers in Norwegian rivers has been relatively constant at 200 t over the last 100 years (Hansen 1988). However, a considerable variation in annual catch is evident within rivers (e.g. Shearer 1992). This variation is caused by several factors. Shearer (1992) showed that the major factor influencing catches of Atlantic salmon in the River Thurso in one period was a decline in fishing effort, whereas a real increase in number of fish available could be the reason in another period in the 100-year data set. A smolt age class results in returns of sexually mature salmon of different sea-age groups. Since the rate of exploitation is less in 1-sea-winter (SW) fish compared with older sea-ages (Hansen 1988), this will affect the number of available salmon each year. Moreover, previous studies have demonstrated the importance of water temperature in the open ocean for the abundance of Atlantic and Pacific salmon, *Oncorhynchus* spp.: the survival of salmon is four times more variable in the marine environment than in fresh water (Reddin 1988).

The catch of Atlantic salmon in several Norwegian rivers has declined during recent years. This could the result of a combination of several factors, such as changes in the marine environment (Antonsson, Gudbergsson & Gudjonsson 1996) and in the watersheds used for spawning (Hesthagen & Hansen 1991; Nehlsen, Williams & Lichatowich 1991), and hybridization between wild and cultured fish (Hindar, Ryman & Utter 1991). The result of

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these changes has been a reduction in the number of spawners in the different populations. Parallel to this decline in wild Atlantic salmon, the production of farmed Atlantic salmon has greatly increased, as has the number of escapees from the fish farms. Thus, the managers of Atlantic salmon populations face a decrease in the number of naturally produced individuals and an increase in number of cultured individuals in the spawning population.

Few data are available describing the river conditions that influence the catch of Atlantic salmon in rivers. River flow is frequently mentioned as the primary factor controlling the rate of upstream migration of salmonids (Banks 1969; Aprahamian & Ball 1995). Alabaster (1970) showed that upstream migrant Atlantic salmon were caught by anglers when river flows were somewhat higher than average and that the highest salmon catch occurred in years with highest water discharge. Some studies have described the regulating effects of water temperature on salmonids surmounting obstacles (Jackson & Howie 1967; Jensen, Heggberget & Johnsen 1986). However, the effect of water temperature on the capture of Atlantic salmon is not well documented.

A detailed knowledge of the flow and temperature requirements of anglers catching Atlantic salmon will improve the formulation of regulations which can protect wild salmon being caught in rivers by anglers. The objectives of the present study were to determine: (1) whether there was any relationship between catch of adult Atlantic salmon, and river discharge and/or temperature in a Norwegian river; and (2) if there were any threshold values below which the anglers' catch was significantly reduced.

Materials and methods

Study site

The River Gaula is situated in central Norway (63° 20′ N, 10° 13′E), near the city of Trondheim. About 110 km is used by anadromous salmonids. The annual mean river discharge is 93 $m^3\ s^{-1}$, although considerable variation exists, with the highest values occurring in May–June and the lowest in the autumn (Table 1). The discharge responds quickly to precipitation because of the low water storage capacity (i.e. few lakes) in the water course.

The river supports populations of Atlantic salmon and anadromous brown trout, *Salmo trutta* L., the former having the greatest recreational value. In 1979, the value of the recreational

Table 1. Mean river discharge ($m^3\ s^{-1}$) in the River Gaula at Haga Bridge during the months of the ice-free season from 1987 to 1991

Year	Month						
	April	May	June	July	August	September	October
1987	67	288	315	137	113	132	46
1988	16	340	148	74	39	170	49
1989	142	278	259	84	173	34	70
1990	114	272	180	151	61	62	36
1991	73	160	282	96	45	149	67

fishery in the river was estimated to about £800 000 (Strand 1981). The number of fishing licences sold annually varied little at that time, and if anything, the fishing effort continued to increase until recent years, when a decrease was recorded (Arnfinn Weiseth, The Trondheim Area Fishing Administration, personal communication). According to official Norwegian statistics, the average annual catch of Atlantic salmon in the river was ≈ 15 t, but has dropped dramatically recently. In the River Gaula, angling is allowed from 1 June until 31 August. However, in 1988, angling was prohibited from 18 August.

Methods

Data on 890 adult Atlantic salmon caught by anglers in the river were collected from 1987 to 1991. Most (95%) of the salmon were captured at Melhus about 23 km upstream of the river mouth and the remaining fish were caught in reaches about 50 km further upstream. The time and site where the salmon were caught were recorded individually. The number of Atlantic salmon caught was 115 in 1987, 60 in 1988, 223 in 1989, 240 in 1990 and 252 in 1991.

River discharge and temperature were recorded by the Norwegian Water Resources and Electricity Directorate at Haga Bridge about 45 km upstream of the river mouth. The discharge was recorded daily by an automatic hydrograph, while water temperature was measured daily at 1600 h by an automatic recorder.

The relationships between the number of Atlantic salmon caught daily, and the physical parameters, river discharge and temperature were tested by the least-squares regression method. The effects were judged significant at the $P < 0.05$ level.

Results

The water discharge was generally high at the start of the angling season, and in most years, the maximum discharge exceeded 400 m^3 s^{-1} in the spring floods (Fig. 1). Thereafter, the discharge decreased steadily to about 50 m^3 s^{-1} in June–July. A marked increase in discharge could occur in July–August. Water temperatures increased steadily through June and reached 10 °C from mid-June to early July. In most years, the maximum temperature (≈ 20 °C) was reached by the end of June. The increase in water temperature occurred later in 1987 compared with the other years and 20 °C was reached about 3 weeks later.

The catch of salmon was low in June every year and a peak was reached in July (Fig. 1). In one year (1987), salmon were caught mainly in July, whereas in the other years, salmon were regularly caught from late June until early August.

Angling success was depended on both water temperature and discharge. The frequency of days with catch of salmon reached the highest scores (> 60%) at intermediate (10–17 °C) water temperatures and at low (< 200 m^3 s^{-1}) river discharges (Fig. 2). The numbers of Atlantic salmon caught each day showed considerable variation according to river discharge. High catches were recorded at discharges below 250 m^3 s^{-1} and low catches at higher discharges (Fig. 3). Atlantic salmon were caught throughout the whole temperature range from 4 to 21 °C (Fig. 4). High catches were recorded in the 13–15 °C interval, intermediate catches at temperatures > 16 °C, and low catches at temperatures < 8 °C. A significant relationship was

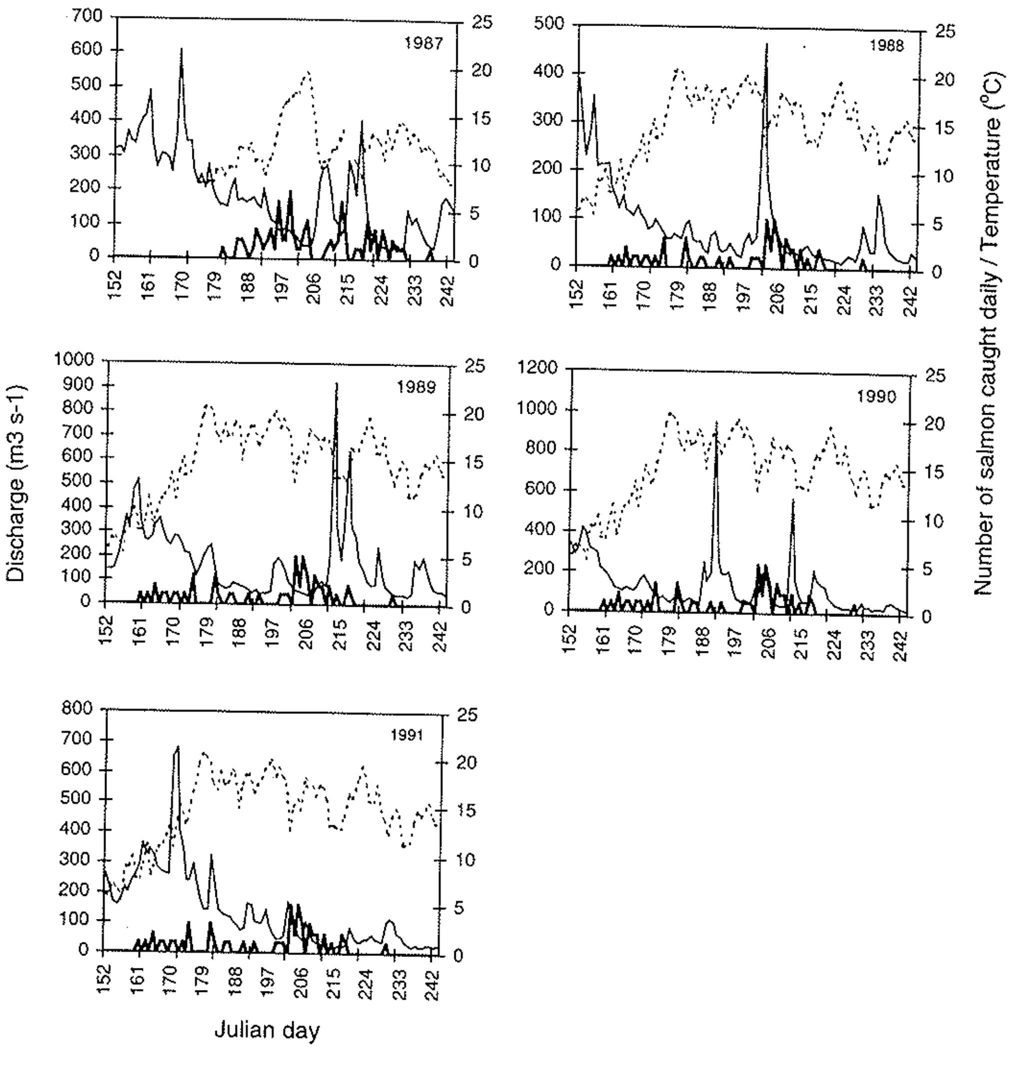

Figure 1. Number of Atlantic salmon caught daily (bold solid line), and daily river discharge (solid line) and temperature (dotted line) in the River Gaula in (a) 1987, (b) 1988, (c) 1989, (d) 1990 and (e) 1991.

found in only two cases between number of salmon caught daily and the abiotic factors, i.e. river discharge and temperature. Significant relationships were found between the number of salmon caught daily and water temperature ($r = 0.33$, $P < 0.05$) in 1987, and between the number of salmon caught daily and river discharge ($r = -0.42$, $P < 0.01$) in 1989. When pooling all years, the correlations decreased considerably to insignificant values of $r = 0.01$ and $r = -0.06$, respectively.

The data set showed threshold values of high river discharge (250 $m^3 s^{-1}$) and low temperature (8 °C) for the anglers' catch of Atlantic salmon. Moreover, at a fixed river

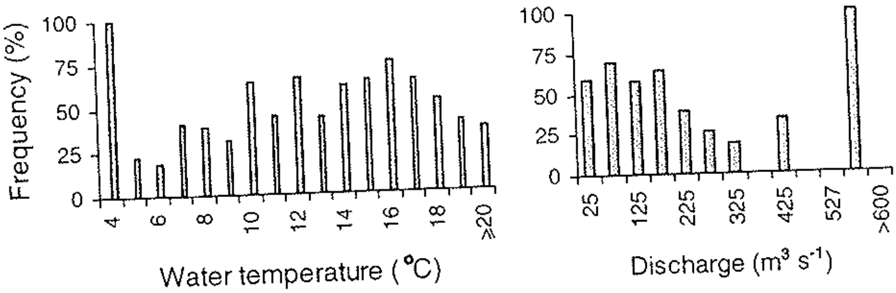

Figure 2. Frequency of days with angling success in relation to water (a) temperature (°C) and (b) river discharge ($m^3 s^{-1}$). The values are given in (b) for the actual discharge are ± 25 $m^3 s^{-1}$. Number of days with angling success are given in Figs 3 and 4.

discharge, an increase in the number of Atlantic salmon caught daily as the water temperature increased was recorded (Fig. 5). Concurrently, the number of salmon caught increased with increasing river discharge at a fixed water temperature. Thus, a combination of high river discharge and water temperature was expected to result in optimal conditions for angling Atlantic salmon in the River Gaula. However, this combination of physical parameters is only theoretical.

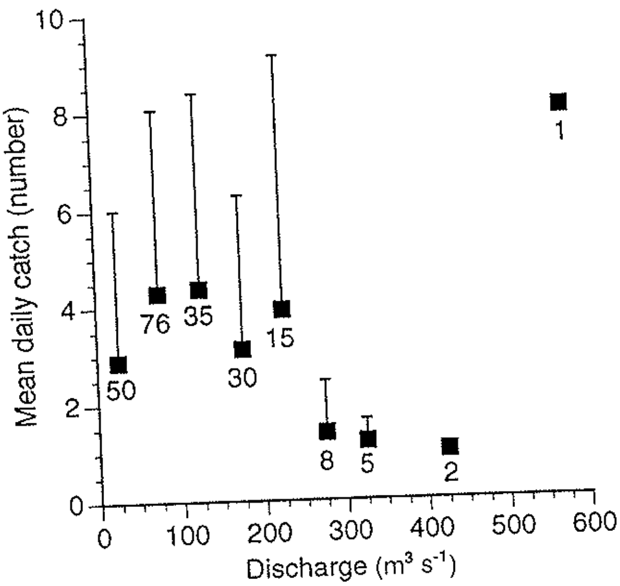

Figure 3. Mean number of Atlantic salmon caught daily in relation to river discharge in the River Gaula from 1987 to 1991. The values are given for the actual discharge ± 25 $m^3 s^{-1}$. The standard deviation and number of observations are indicated.

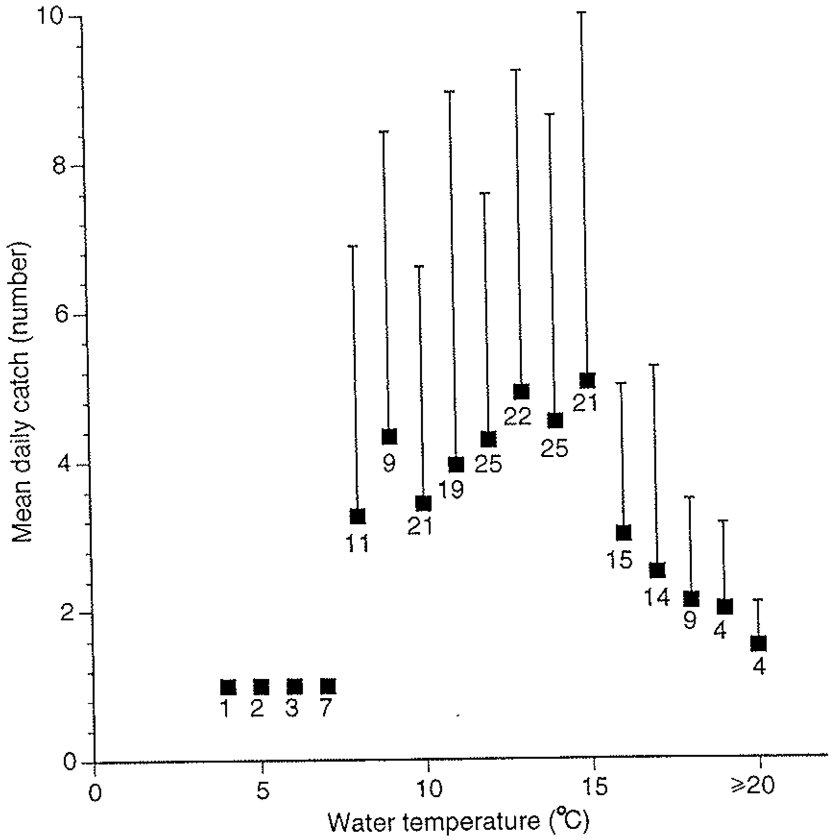

Figure 4. Mean number of Atlantic salmon caught daily in relation to water temperature in the River Gaula from 1987 to 1991. The standard deviation and number of observations are indicated.

Discussion

McLean, Smith & Wilson (1990) experimentally demonstrated that a large portion of the sea lice, *Lepeophtheirus salmonis* Kroyer, attached to the fish held in fresh water were lost during the first 48 h. Observations on the presence of salmon lice on several Atlantic salmon throughout the River Gaula (Aspås 1994) indicated rapid ($\approx$ 40 km day^{-1}) upstream migration after entering the river. Thus, there are reasons to believe that the capture of Atlantic salmon in River Gaula reflects the ascent of salmon, although Atlantic salmon exhibit behavioural responses.

River discharge is the factor most frequently mentioned as controlling the rate of upstream migration (Banks 1969). Based on data from several rivers, Alabaster (1970) and Cragg-Hine (1985) showed that the total number of Atlantic salmon entering traps increased with increasing water flow. Furthermore, Alabaster (1970) found a tendency for the catch of salmon to increase with increase of median annual flow. By contrast, Thorpe (1988) showed that Atlantic salmon ascended the River Dee independently of water discharge, except for extremely high

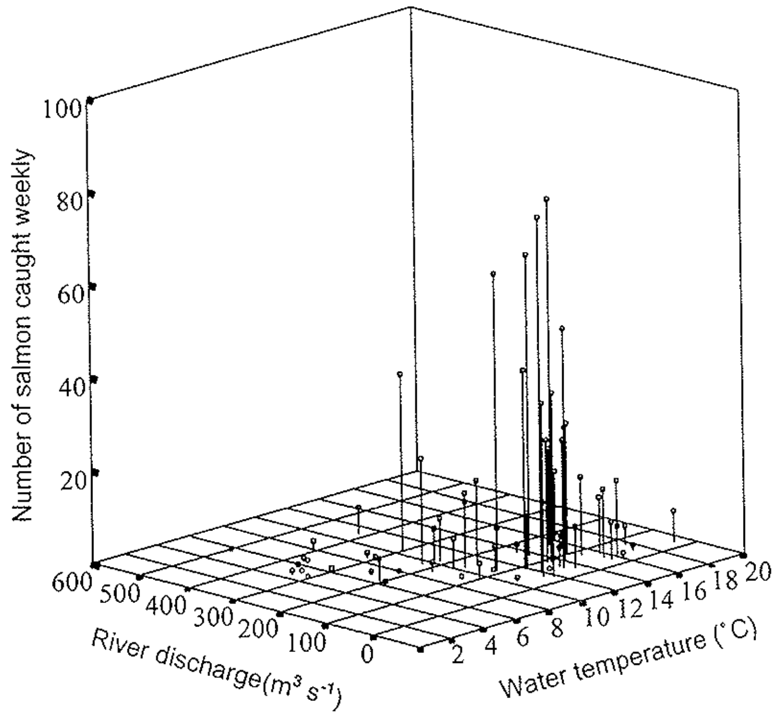

Figure 5. Number of Atlantic salmon caught weekly at different river discharges and temperatures in the River Gaula from 1987 to 1991.

discharges. In their 6-year survey of Atlantic salmon entering River Erne, Jackson & Howie (1967) found no direct connection between rainfall and daily migration of fish, but in six cases, an increased level of migration followed some days after heavy rain. A similar trend was found in one year in the present study, since the river discharge negatively affected ($P < 0.01$) the number of Atlantic salmon caught daily in this year. However, Alabaster (1970), Thorpe (1988) and Smith, Smith & Armstrong (1994) were unable to detect any threshold value in water discharge for ascending or catch of Atlantic salmon, but Smith *et al.* (1994) showed that river discharge played a significant role in modifying the response of Atlantic salmon to changing flows. The present study supports the idea of threshold values of river discharge and water temperature in relation to angling catches of adult Atlantic salmon in a Norwegian river.

In the River Vefsna, Jensen *et al.* (1986) demonstrated that Atlantic salmon passed the fish ladder at Laksforsen waterfall at discharges between 70 and 300 m^3 s^{-1}. A similar range of discharges (100–300 m^3 s^{-1}) was found for Atlantic salmon passing a fish ladder on the River Målselv, Norway (Andersen & Langeland 1971). In both studies, the passing was correlated with increase in water discharge. Hayes (1953) showed that artificial freshets triggered the entry and ascent of Atlantic salmon in the Lehavre River. Moreover, the above author pointed out that the size of a freshet could inhibit salmon ascending a river by being too low but not by being large. In contrast, Huntsman (1948) showed by experimental freshets in the Mose River that ascent mainly occurs at decreasing discharge after a freshet. In the present study, high catches were recorded at decreasing water levels, although a freshet in 1990 resulted in an increase in catch. Moreover, the present results show that water discharge also strongly affected the anglers' catch of Atlantic salmon. The capture of Atlantic salmon in River Gaula was low at river discharges higher than 250 m^3 s^{-1}. Thus, there seems to exist corresponding values of water discharge for salmon surmounting obstacles and for anglers' successful catch. However, the discharge and physical conditions of obstacles varies considerably among rivers. Thus, this coincidence is most probably an artefact (see Aprahamian & Ball 1995). A 35-year study of the Atlantic salmon catch in River Exe, England, demonstrated the complexity of river discharge and rod catches (I. Cowx, University of Hull, personal communication), and found a strong causal relationship between flow and rod catches for certain months. However, the discharge affected the rod catches in various months differently. In spring, an upper threshold value seemed to exist at 3000 ML day^{-1}, whereas in summer and autumn, the catches were distributed across all flow conditions except those below 100 ML day^{-1}. In general, spates resulted in increased movements and better catches.

Salmon were caught at both low (4 °C) and high (21 °C) water temperatures, but a threshold value was evident at 8 °C. Studies of salmon passing fish ladders or waterfalls have shown a similar threshold value (9–11 °C, Andersen & Langeland 1971; 10 °C, Gjøvik 1981; 11 °C, Mills & Graesser 1981; 8 °C, Jensen *et al.* 1986; 10 °C, Johnsen *et al.* 1997). However, Atlantic salmon have been reported to pass obstacles in rivers in the UK at lower temperatures (≈ 5 °C, Jackson & Howie 1967). In a recent study, Smith, Johnstone & Smith (1997) found no indication that a weir did not affect salmon migration to any extent at water temperatures higher than 8 °C. However, since this was the minimum water temperature, Smith *et al.* (1997) were unable to detect any threshold value. Similar threshold values of water temperature for anglers' catch and salmon surmounting obstacles may indicate a general behavioural change in Atlantic salmon when water temperature exceeds 8 °C. Water temperature will greatly influence swimming performance (e.g. Brett 1967), and thereby, affect the migration within the river and the possibility of capture. Moreover, juvenile Atlantic salmon change activity pattern and become nocturnal below this temperature (Fraser, Heggenes, Metcalfe & Thorpe 1995).

The highest catches were at intermediate temperatures (13–15 °C). The low catches at temperatures below 8 °C may be a result of a restricted number of salmon which had ascended the river. On the other hand, reduced catches at high temperatures may indicate a negative effect of temperature, as has been found for salmonids generally (Taylor 1978; Thorpe 1988; Alabaster 1990; McMichael & Kaya 1991). Alabaster (1990) estimated that the rate of migration to be reduced to about 50% of the average at a mean weekly maximum water temperature of 19.5 °C. High temperatures were recorded in July and August in the present study, and at this time, the availability of Atlantic salmon for the angler was presumed not to be a limiting factor. McMichael & Kaya (1991) found maximum catch rates of brown trout and rainbow trout, *Oncorhynchus mykiss* (Walbaum), at lower temperatures (8–12 °C) than in the present study. One reason for this difference may be that Atlantic salmon is the less cold-tolerant species with respect to initial feeding time of alevins, optimum temperature range and geographic distribution (see Jensen, Johnsen & Saksgård 1989 and references therein; Lura & Sægrov 1993).

The ascent of Atlantic salmon into rivers varies within restricted geographical areas. In the UK, salmon ascend throughout the whole year (Shearer 1992), whereas in Norwegian rivers, the ascent occurs from spring through to autumn. Thus, one could conclude that the primary factor in salmonid migration is season (Hellawell 1976). A genetic component was demonstrated in the seasonal return of adult Atlantic salmon by transplanting smolts from different populations (Hansen & Jonsson 1991). The present data are in accordance with this finding, but climatic variation among years may modify the exact timing of the ascent, and thus, catchability in rivers.

Discharge and temperature may be a powerful tool to reduce anglers' catch of Atlantic salmon from threatened stocks, in some rivers at least. It is possible to exclude angling in periods of the year when these two factors are known *a priori* to have optimal values for angling Atlantic salmon, especially where the river discharge may be river-specific, but the water temperature probably more generally causes metabolic constraints. However, the situation is probably more complex, and general regulations are impossible. For instance, restricting angling to periods when water temperature is less than 8 °C may put the fish presently being protected (i.e. spring fish) at greater risk in some countries, since these animals are mostly caught during times of lower water temperature. Moreover, the exploitation rate on multi-sea-winter fish at such times is usually very high. Since the present situation for many Norwegain Atlantic salmon population is critical and the ascent in rivers occurs in a more restricted period than farther south, water temperature could be considered as an option to regulate Atlantic salmon angling.

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