IN SITU AVOIDANCE RESPONSE OF ADULT ATLANTIC SALMON TO WASTE FROM THE WOOD PULP INDUSTRY

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Abstract. An accidental release of non-toxic waste from decommissioned wood pulp industry in the River Numedalslågen, Southern Norway, occurred in the upper part of the accessible stretches for anadromous fish during a study of migration behaviour of radio tagged Atlantic salmon (*Salmo salar*, $n = 32$, body length 51–99 cm). The fish had completed the migration phase and initiated the resident phase characterised by little movement until spawning. When the wooden fibres and pulp were released, 16 of 32 (50%) salmon showed an immediate avoidance response. Six (19%) salmon moved upstream and 10 (31%) salmon moved downstream. Of the salmon moving downstream, eight (25%) moved all the way to sea (average 14.8 km). Four re-entered the River Numedalslågen, two entered a neighbouring river and two were not recorded later. Fish moving downstream but without moving to the sea, moved on average 5.3 km during the episode, whereas those moving upstream moved on average 6.7 km. All fish recorded after the episode ($n = 30$) survived until the spawning season. The study demonstrates that fish in nature may show an evident avoidance response, even to non-toxic contaminants. For Atlantic salmon, the size of the spawning population may be reduced by fish leaving the river (13% left the river and never came back). Moreover, the dispersal of salmon to other rivers may increase, and the distribution of the spawning population within the contaminated river may shift.

Keywords: Atlantic salmon, avoidance behaviour, avoidance response, pulp, *Salmo salar*, spawning migration, upstream migration, wood fibres

1. Introduction

Fish respond to environmental stressors in a variety of ways (e.g. Pickering, 1981). Sublethal exposures may, for instance, induce a behavioural response to avoid the stressor. The ability of fish to avoid physical and chemical stressors and seek out areas of more favourable conditions can have significant effects on survival rates in their natural environment (Gray, 1990).

Numerous studies have demonstrated that fish can avoid various chemical and physical components of the aquatic environment, such as gas supersaturation, thermal effluents, metals, low pH and aluminium (e.g. Gray, 1983; Atchison *et al.*, 1987; Åtland, 1998). However, avoidance behaviour in fish has been demonstrated mainly through laboratory studies (but see for example Åtland and Barlaup, 1995; Goldstein *et al.*, 1999; Cooke *et al.*, 2004), and extrapolating results from simplistic laboratory environments to complex natural conditions may be misleading.

An accidental release of waste from decommissioned wood pulp industry in the River Numedalslågen, Southern Norway, occurred during a field study of the migration behaviour of radio tagged Atlantic salmon (*Salmo salar* L.) returning from the sea to spawning grounds in the river. An immediate avoidance response to the wood pulp waste, by up-and downstream movements, was recorded for 50% of the radio tagged salmon. This *in situ* avoidance response is described and discussed in this paper.

2. Methods

The River Numedalslågen is situated in southern Norway (catchment area 5670 km^2, mean annual outlet water discharge 120 m^3/s). Atlantic salmon can migrate 72 km upstream from the river mouth, with Atlantic salmon spawning activity concentrated in the first half of November.

Wild Atlantic salmon were caught during their spawning migration in bag nets in the sea 3 km from the river mouth. The fish were tagged with radio transmitters, such that their movements could be monitored. When the release of waste occurred, 32 of the tagged salmon (mean total body length 71 cm, range 51–99, tagged and released during 22 May – 19 August 2003) were present in the river. Fifteen salmon were tagged with external radio transmitters (Model F2120 from Advanced Telemetry Systems Inc., ATS, USA, flat with outline dimensions of 19 × 50 × 9 mm, weight in air of 15 g), attached with steel wires through the musculature below the dorsal fin, using the method described in Økland *et al.* (2001). Seventeen salmon were tagged with surgically implanted transmitters (Model F1830, ATS, cylindrical with outline dimensions of 12 × 53 mm, weight in air of 15 g), using the method described in Thorstad *et al.* (2000). Before surgery, the fish were anaesthetised by a 3-min immersion in an aqueous solution of 2-phenoxy-ethanol (EEC No 204-589-7, 0.5 ml/l water).

The fish were positioned every third day from entering the river until 1 October 2003, using a portable receiver (R2100, ATS) connected to a 4-element Yagi antenna (the fish were positioned 22 and 25 September, the day before and after the release of wooden fibres and pulp). During 1 October – 26 November 2003, the fish were positioned once a week. In addition, the fish were continuously monitored using automatic listening stations (DCCII, ATS) installed 6, 19, and 45 km from the river mouth.

The accidental release of waste from decommissioned wood pulp industry occurred in the upper part of the accessible stretches for anadromous fish, 72 km from the river mouth. This happened when the water discharge increased from 50 to 125 m^3/s during 23–24 September 2003 due to heavy rain during a clean-up

Figure 1. A sample of the wooden fibres and pulp from the closed down wood pulp industry accidentally released into the River Numedalslågen 23–34 September 2003. The unit of the measuring tape is cm.

operation in the old industrial area. Approximately 5000 of 6000 m^3 of wooden fibres and pulp had been removed in the days prior to the water level increase, and the remaining 1000 m^3 was flushed down the river when the water discharge increased. The mass substance consisted of fine-grained pulp and coarser wooden fibres up to 10 cm long (Figure 1). Anecdotal reports indicated that the river appeared stained during this episode. The wooden fibres and pulp were mainly filled in this area during the 1970s, until the wood pulp industry was decommissioned in 1980.

The mass substance did not contain any toxicants, according to analyses of sediments by the Norwegian Geotechnical Institute before release (NGI, unpublished note to the local council). Chlorinated solvents and polychlorinated biphenyls (PCB) were not detected. The concentration of total polycyclic aromatic hydrocarbons (PAH) was on average 1.1 mg/kg dry mass. The mean concentration of mercury (Hg) was 0.09 mg/kg dry mass. The content of total organic matter (TOC, 19–34% dry mass) and concentration of nitrogen (mean tot-N 3500 mg/kg dry mass) and phosphorus (mean tot-P 338 mg/kg dry mass) was relatively high, but the high age of the mass substance indicated that the organic matter was heavily decomposed. The nitrogen and phosphorous were likely combined in the pulp mass. NGI concluded that the danger of toxicants being dissolved in the water during a clean-up operation was insignificant. Analyses at the Norwegian Institute for Nature Research laboratory of the wood pulp mass showed dry mass concentrations of 19 μg/g copper (Cu), 9207 μg/g iron (Fe) and 423 μg/g manganese (Mn).

3. Results

Prior to 23–24 September, the tagged fish had finished the upstream migration phase and initiated the residence period, which is when the salmon stay more or less on the same site until spawning (Økland *et al.*, 2001). When the wooden fibres and pulp polluted the river, 16 of 32 (50%) salmon immediately started moving (examples shown in Figure 2). Six (19%) salmon moved upstream and 10 (31%) salmon downstream. Of those moving downstream, eight (25%) moved all the way to sea.

There was no difference between those moving and those not moving in how far up in the river they were situated on the day before the episode (Mann-Whitney U-test, $U = 110.5$, $P = 0.51$). However, fish with an upstream movement were

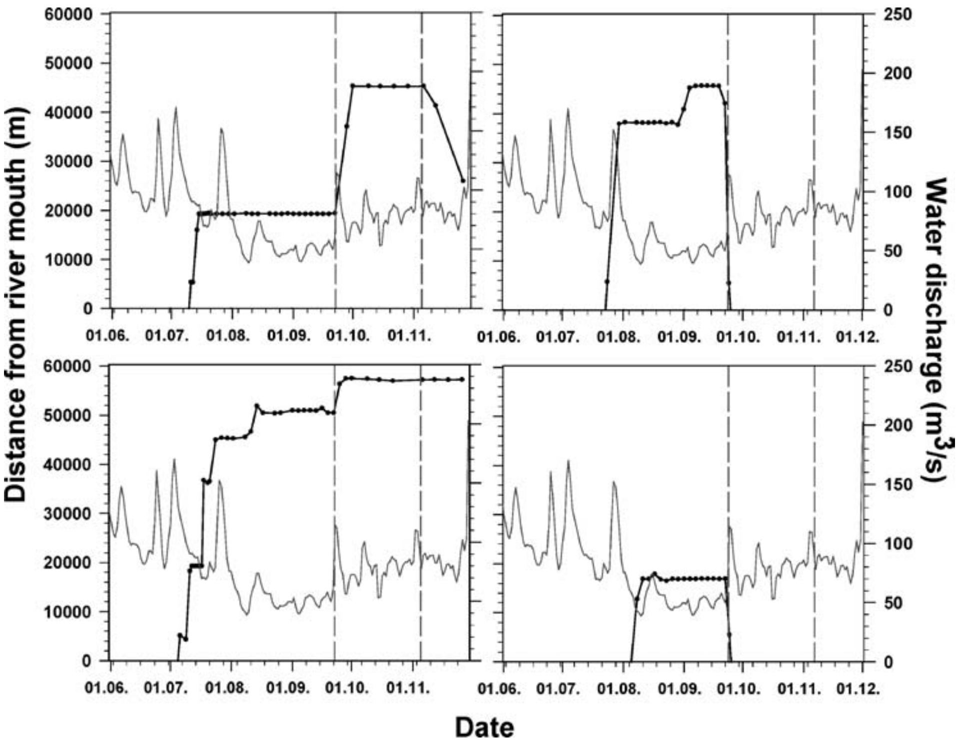

Figure 2. Migration pattern of four representative radio tagged Atlantic salmon (black line) and water discharge (grey line) in the River Numedalslågen from 1 June to 1 December 2003. Small black dots show position of the fish when manually tracked. The release of wooden fibres and pulp (left grey vertical line) and spawning season (right grey vertical line) are also indicated.

situated further upriver than those with a downstream movement (upstream movement: mean 36.6 km from river mouth, range 4.5–53.7, SD $= 20.1$, downstream movement: mean 15.5 km from river mouth, range 2.8–42.1, SD $= 11.5$, Mann-Whitney U test, $U = 10.5$, $P = 0.031$).

Fish moving all the way sea were positioned on average 14.8 km (range 2.8–42.1 km, SD $= 12.9$) from the river mouth on the day before the episode. Four fish returned to the River Numedalslågen (after 7, 7, 15 and 21 days), two were later recorded in the neighbouring River Drammenselva and two were not recorded.

Fish moving downstream without moving all the way to sea, moved on average 5.3 km during the episode (movement between tracking 22 and 25 September, range $= 4.4$–6.2 km, $n = 2$, SD $= 1.3$), whereas those moving upstream moved on average 6.7 km (range $= 1.0$–17.6, $n = 6$, SD $= 5.9$). Only two salmon returned later to the holding position before the episode. All fish recorded after the episode ($n = 30$) survived until the spawning season.

4. Discussion

As adults, Atlantic salmon return from feeding in the sea to their home river for spawning (Hasler, 1966; Harden Jones, 1968; Stabell, 1984). Evidence exists that they return to the same area of the river where they spent their pre-smolt period (Heggberget *et al.*, 1986, 1988). The riverine migration has generally been reported to take place in two successive phases before spawning: (1) steady progress upriver with periods of active swimming alternating with stationary periods, followed by (2) a long residence period (e.g. Hawkins and Smith, 1986; Heggberget *et al.*, 1988; Webb, 1989). A search phase with movements both up and down river at or close to the position held at spawning are performed by some individuals for a short period between the migratory phase and the residence period (Økland *et al.*, 2001). Downstream movements are generally not seen in wild Atlantic salmon during the return migration, except during the search phase (Thorstad *et al.*, 1998; Økland *et al.*, 2001). The residence period is reported to last on average more than 50 days before spawning, with individual fish showing little or no movement (Økland *et al.*, 2001).

The observed movements during the release of wooden fibres and pulp in the River Numedalslågen represented unusual behaviours for wild Atlantic salmon during the return migration, especially since it took place in the residence period when salmon usually do not move. The simultaneous increase in water discharge may in itself have stimulated to movements, but it is not likely that such a change in water discharge can alone explain the observed behaviour. Increases in water discharge may stimulate upstream movements during the migration phase (e.g. Huntsman, 1948; Dunkley and Shearer, 1982; Baglinière *et al.*, 1990), but is not likely to stimulate downstream movements at the relatively low discharges experienced in this study. Also, the responses to increases in water discharge are usually not that obvious, with such a high proportion of individually tagged fish responding immediately (e.g. Thorstad and Heggberget, 1998; Thorstad *et al.*, in press). We have studied the riverine movement behaviour of radio tagged adult Atlantic salmon in 12 other Norwegian Rivers (e.g. Økland *et al.*, 2001; Thorstad *et al.*, 1998, 2004, unpublished reports), and have never recorded behaviour similar to what was observed in the River Numedalslågen during the release of wooden fibres and pulp. Thus, we conclude that the extensive movements were most likely an avoidance response to the fibres and pulp released into the river.

The substance did not seem to contain any toxicants. The high age of the mass substance indicated that the organic matter was heavily decomposed. The short time the wooden fibres were present in the river before the fish were responding also indicates that the response was not towards toxicants, but an attempt to escape the particles in the water, which may have irritated the gills, compromised respiration and affected vision. In laboratory experiments, it has been shown that roach (*Rutilus rutilus*) avoid water with high concentration of suspended particles (Skorobogatov and Pavlov, 1995).

Incidents of such avoidance behaviour have rarely been demonstrated in nature. Skogheim *et al.* (1984) reported that anglers observed Atlantic salmon escaping an event of high pH and labile aluminium levels by downstream movement. Similarly, Saunders and Sprague (1967) reported downstream movement of Atlantic salmon through a counting fence during events of copper and zinc pollution. Interestingly, the present study demonstrated that the salmon not only moved downstream, but that some also moved upstream – and that those moving upstream were situated higher up in the river than those moving downstream. It is possible that an avoidance reaction with upstream movement occurred also during the events described by Skogheim *et al.* (1984) and Saunders and Sprague (1967), but with the methods used in those studies, an unusual downstream movement was easier to detect than an unusual upstream movement. Upstream movement may help fish to avoid a stressor as well as downstream movement, but not during release of contaminants in the upper part of the accessible stretches for the fish, like in this study.

In conclusion, this study demonstrates that fish in nature may show an evident avoidance response, even to non-toxic contaminants. For salmon, the size of the spawning population may be reduced by fish leaving the river (in this study 13% left and never coming back). Moreover, the dispersal of salmon to other rivers may increase, and the distribution of the spawning population within the contaminated river may shift. Increased use of telemetry will likely enable the opportunistic observation of other *in situ* responses of animals to non-experimental pollution events (see Cooke *et al.*, 2004).

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