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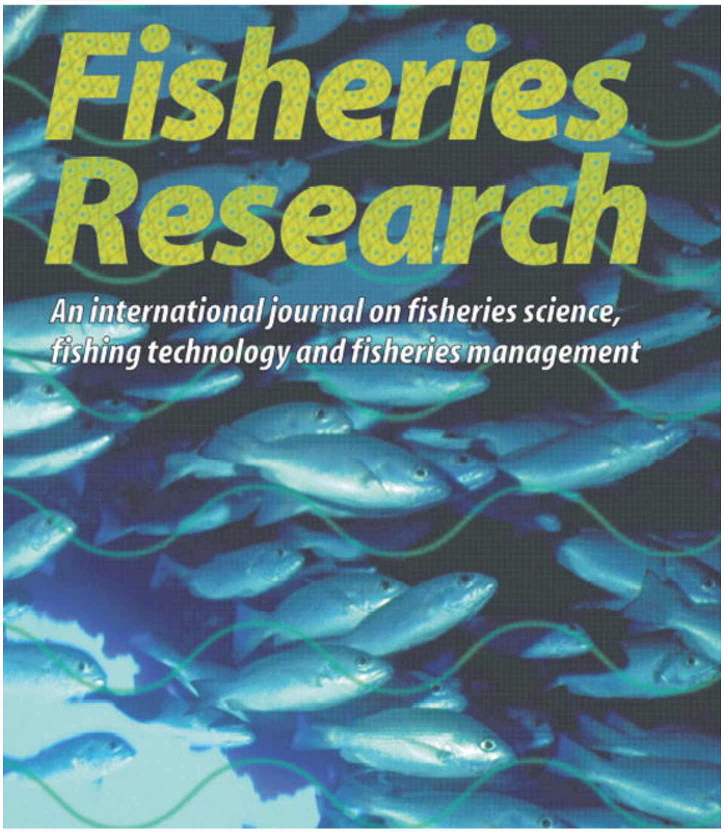

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Short communication

Long-term effects of catch-and-release angling on ascending Atlantic salmon during different stages of spawning migration

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Abstract

Eighteen Atlantic salmon (*Salmo salar*) (total body length 58–110 cm) were radio tagged following angling and then released in the lower reaches of the River Alta, Northern Norway. The aim was to compare the long-term effects of catch-and-release angling on newly ascended salmon (assumed <1 week in freshwater) with salmon from a previous study that were released in the upper reaches of the river at the end of their upstream migration (assumed >1 month in freshwater, $n = 44$, total body length 53–122 cm). All 18 salmon survived the catch-and-release angling event and were recorded in known spawning areas during the spawning period, except one individual not found in the river after 15 August (42 days after tagging). There was no difference in survival rate between salmon caught-and-released in lower (17 of 18, 94%) and upper reaches (43 of 44, 98%), nor in the proportion recorded in known spawning areas (17 of 18, 94%, from lower reaches and 42 of 44, 95% from upper reaches). During the spawning period, four salmon (24%) were recorded downstream of the catch-and-release site (mean 2.3 km, range 0.3–5.7), whereas 13 (76%) salmon were upstream of the catch-and-release site (mean 10.1 km, range 1.9–24.0). Catch-and-release angling may result in a delay in the upstream migration, as the 13 fish recorded upstream of the catch-and-release site during spawning, spent on average 34 days (range 0–94) before they were recorded more than 1 km upstream from the catch-and-release site. This is a longer delay than expected for natural resting periods during upstream migration. In addition, at least 31% ($n = 4$) of the 13 fish recorded upstream of the catch-and-release site during spawning showed an unusual downstream movement immediately after catch-and-release angling.

Keywords: *Salmo salar*; Catch-and-release angling; Recreational fishing; Radio telemetry; Migration; Survival

1. Introduction

Catch-and-release angling has been introduced in many salmon rivers, especially in North America and Europe, to reduce the mortality from recreational angling on fish stocks (e.g. Barnhart, 1989; Webb, 1998; Whoriskey et al., 2000). The value of such programmes depends on achieving high survival rates and minimal negative fitness consequences after catch-and-release (Cooke et al., 2002; Cooke and Suski, 2005). Most studies of the effects of catch-and-release angling on Atlantic salmon (*Salmo salar* L.) have focused on physiological effects in an artificial setting, or short-term mortality in enclosures. Only a few studies have recorded long-term effects in a natural environment (e.g., Dempson et al., 2002; Thorstad et al., 2003). Studies of multi-sea-winter Atlantic salmon have also been scarce.

Previous telemetry studies in the River Alta, covering both one- and multi-sea-winter Atlantic salmon in a natural setting with ordinary anglers, showed that a high proportion of the fish survived catch-and-release and stayed in spawning areas during the spawning period (Thorstad et al., 2003). However, the study was performed in the upper reaches accessible for Atlantic salmon, with salmon that had principally ended their upstream river migration. Previous studies found that the physiological disturbance from angling and laboratory mortality was larger for Atlantic salmon that had newly entered the river ('bright' salmon) than for kelts (Brobbel et al., 1996), indicating that the stage of freshwater migration may be important for the effects of catch-and-release. The study in the River Alta was, therefore, followed up by radio tagging Atlantic salmon during catch-and-release angling in the lower reaches. The aim of this study was

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to test the hypothesis that the long-term effects of catch-and-release were more severe at an earlier stage of the freshwater migration compared to previous studies in the upper reaches, by evaluating the effects of catch-and-release angling on survival and upstream migration pattern.

2. Materials and methods

The River Alta, Northern Norway (70°N 23°E) has a catchment area of 7400 km^2 and mean annual water discharge of 75 $m^3 s^{-1}$. The water temperature reaches a maximum of 14–16 °C in August. Atlantic salmon can migrate 47 km upstream from the river mouth. Only one waterfall is not passable by boat along the accessible stretches for Atlantic salmon, but is not considered as a migration barrier for upstream migrating salmon (Thorstad et al., 2003). No man-made migration barriers exist along the stretches accessible for Atlantic salmon. Hence, salmon migration in this river is not influenced to any great extent by migration barriers.

A total of 44 Atlantic salmon (24 females and 20 males, mean total body length 86 cm, range 53–122 cm) were radio tagged during catch-and-release angling in the upper reaches, 41–46 km from the river mouth, during 9 July to 4 September 1999–2001 (water temperatures 10–15 °C). At least half of the fish ($n = 22$) had a distinct brown colour and thick mucus layer, indicative of a long residence in fresh water. Results from 1999 to 2000 ($n = 30$) were published previously in Thorstad et al. (2003). For comparison, in this study 18 Atlantic salmon (16 females and 2 males, mean total body length 96 cm, range 58–110 cm) were radio tagged during catch-and-release angling in the lower reaches, on average 13 km (range 8–16 km) from the river mouth during 2–19 July 2003 (water temperatures 12–14 °C). In the River Alta, almost all salmon up to 4 kg and total body length 70 cm are one-sea-winter salmon, whereas larger salmon are multi-sea-winter salmon (unpublished data based on scale samples from more than 4000 salmon). Hence, the 18 salmon tagged in this study were multi-sea-winter salmon with the exception of one individual (see Fig. 1). The present study focuses on the survival and migration pattern of the 18 salmon caught in the lower reaches. Their survival and presence on the spawning grounds were compared with the salmon previously tagged in the upper reaches.

All 18 fish were caught by ordinary fly fishing anglers who regularly fish the River Alta and are regarded as experienced (mean time from hooking to landing 11 min, range 4–19 min). Tube flies and classical salmon flies were used, with two or three barbed hooks per fly (hook size 4–8). No salmon were deeply hooked, except one fish hooked in the gills. The hook was easy to loosen from the gills, and the fish was not bleeding at the hook wound. Only one salmon, hooked in the upper jaw, was bleeding at the hook wound. The fish were immediately placed in a tube filled with water such that the head and gills were covered by water, externally tagged with radio transmitters and released. The head was placed in the dark end of the tube with the eyes covered by a wet towel, and the fish, thus, remained quiet during tagging. The radio transmitter (Model F2120 from Advanced Telemetry Systems, ATS, USA) was externally attached to the fish with steel wires through the musculature below the dorsal fin, as described in Økland et al. (2001). The transmitters had outline dimensions of 10 mm × 20 mm × 38 mm, weight in air of 14 g, weight in water of 3.4 g, and a guaranteed longevity of 170 days. Similar transmitters and attachment procedures did not affect swimming capacity of Atlantic salmon (L_T 45–59 cm, Thorstad et al., 2000). The transmitters had an activity option, producing extra pulses when the fish were moving to aid in detecting mortality. All fish were exposed to air (*ca.* 0.5–1.0 min) and photographed before release. Four salmon seemed a little exhausted at landing, but all the fish were characterised as in good condition at release. Based on the bright skin colour and thin mucus layer, all fish had recently entered the river. Three salmon had externally attached salmon lice, indicating that they had been in fresh water less than a week (although some salmon lice may survive longer, Finstad et al., 1995). The fish were tracked from land or boat using a portable receiver (R2100, ATS) during 19 surveys before October 2003, four surveys in October (spawning period) 2003, one in January 2004 and one in March 2004 (Fig. 1).

3. Results

3.1. Survival and residence during spawning period

All 18 salmon survived catch-and-release, and 17 fish were recorded in known spawning areas during the spawning period. One individual was not found in the river after 15 August (42 days after tagging). None of the salmon were reported recaptured by anglers. There was no difference in proven survival between salmon caught-and-released in lower (17 of 18) and upper reaches (43 of 44) (Fisher' exact test, $P = 0.50$), nor in the proportion recorded in known spawning areas (17 of 18 from lower reaches and 42 of 44 from upper reaches, Fisher's exact test, $P = 1.0$). During the spawning period (tracking on 14 October), the 17 salmon were recorded on average 19.7 km (range 7.6–35.2 km) from the river mouth. Four salmon (24%) were downstream of the catch-and-release site (mean 2.3 km, range 0.3–5.7 km), whereas 13 (76%) salmon were upstream of the catch-and-release site (mean 10.1 km, range 1.9–24.0 km) (Fig. 1).

3.2. Migration pattern

Four of the 13 salmon (31%) recorded upstream from the catch-and-release site during spawning had an immediate downstream movement (i.e., fall back) after release (Fig. 1). They were recorded on average 800 m (range 175–1300 m) downstream from the catch-and-release site the day after angling. In the spawning period, they were situated 4–24 km upstream from the catch-and-release site (Fig. 1). The remaining fish stayed in the same place ($n = 1$), or moved slightly upstream the first day after catch-and-release ($n = 8$) (Fig. 1).

For the 13 fish recorded upstream from the catch-and-release site during spawning, it took on average 34 days (range 0–94 days) before they were recorded more than 1 km upstream from the catch-and-release site (>9 days for 9 of the individuals) (Fig. 1).

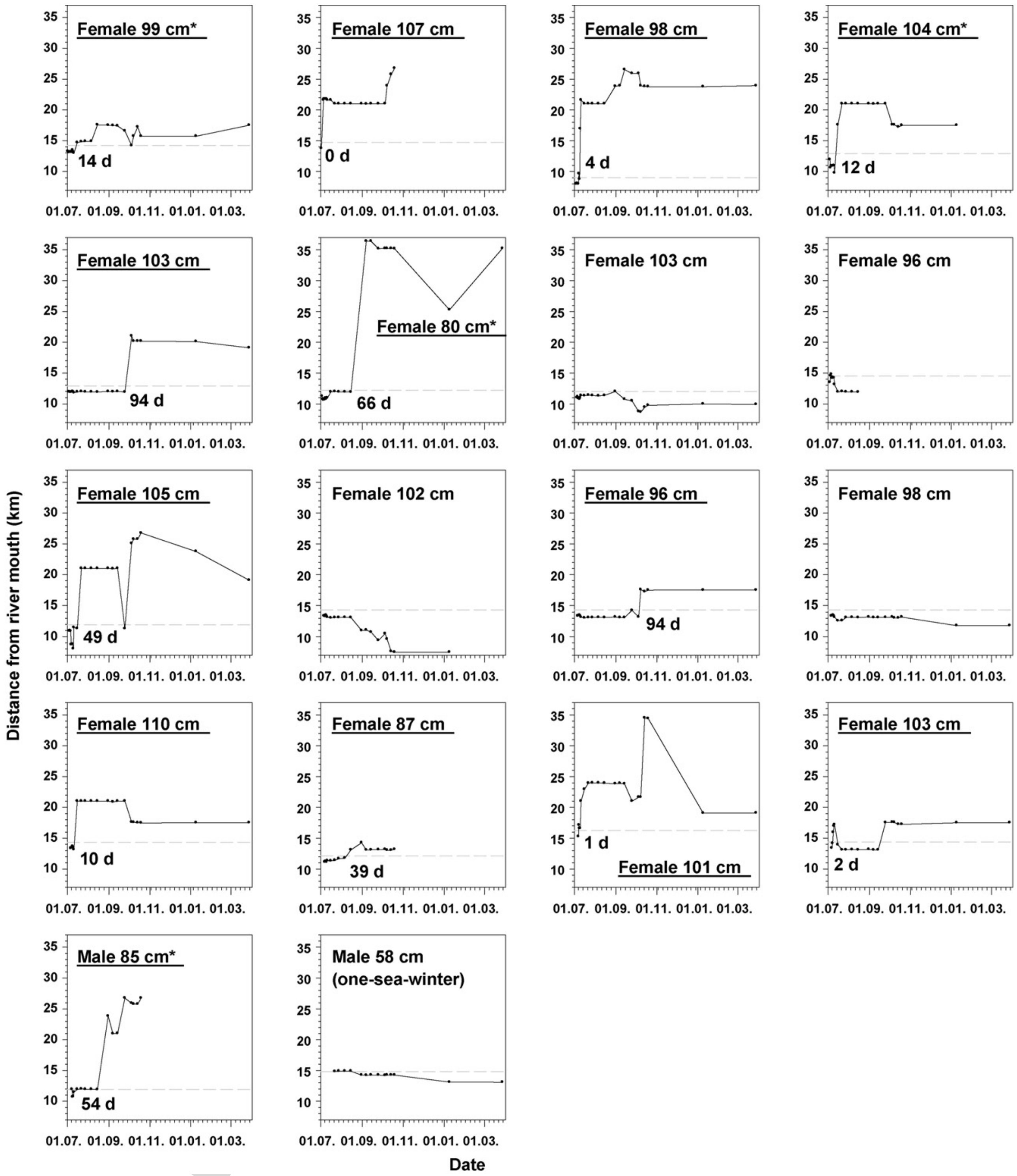

Fig. 1. Movements of radio tagged salmon after catch-and-release in the River Alta in 2003 (black lines). The first point shows the catch-and-release site, and the other points positions from manual tracking. Dates are given as dd.mm. The 13 salmon recorded upstream from the catch-and-release site during spawning are underlined. The four of these 13 salmon that had an immmediate downstream movement during the first day after release are indicated with an asterisk. The horizontal reference lines (grey, dashed) indicate 1 km upstream from the catch-and-release site, and the number of days from catch-and-release until recorded further upstream than 1 km are also indicated.

4. Discussion

Between the two studies, at least 97% (60 of 62) of the salmon survived catch-and-release angling and were still alive during the spawning period 1.0–3.5 months later (Thorstad et al., 2003; this study). One fish either died or lost its transmitter (Thorstad et al., 2003), and signals from one fish disappeared before the spawning season (present study), indicating that it had either left the river, been recaptured without being reported or the transmitter failed. This is among the highest survival rates reported from studies of the effects of catch-and-release in Atlantic salmon. The high survival is probably related to (1) the relatively low water temperatures of 10–15 °C, (2) the study design recording survival in the natural environment instead of keeping fish in enclosures, which may increase the stress (Dempson et al., 2002; Thorstad et al., 2003), and (3) the good handling conditions. Catch-and-release angling induced mortality seems to be low at least until water temperatures around 16–18 °C, whereas higher water temperatures may increase mortality (Wilkie et al., 1996, 1997; Dempson et al., 2002; Thorstad et al., 2003). The high survival was obtained despite exposing the salmon to additional stress by radio tagging compared to a natural catch-and-release situation, and despite all the fish in the present study being held in air and photographed. Lengthy air exposure has been revealed as one of the most detrimental factors of catch-and-release angling (Ferguson and Tufts, 1992; Cooke and Suski, 2005). However, experienced anglers and guides ensured a short air exposure during photography, and generally careful handling of the salmon in the River Alta. Furthermore, fish caught by fly have less hooking injury and mortality than those caught by live bait (Muoneke and Childress, 1994; Cooke and Suski, 2005). A high proportion of the fish (95%) was recorded in known spawning areas in the spawning period (Thorstad et al., 2003; this study). Despite intensive angling (2994 salmon equalling 16.2 tonnes were caught during 1 June to 1 September 2003), none of the salmon in the present study were reported recaptured by anglers, confirming a low recapture rate during catch-and-release (4%, Thorstad et al., 2003).

There was no difference in survival or proportion of fish recorded in known spawning areas during the spawning period between salmon caught-and-released in the lower and upper reaches. Thirteen fish in the present study were recorded upstream (up to 24 km) from the angling site during spawning, indicating that they were caught and released during their upstream migration. For the four fish recorded downstream from the angling site during spawning, it is not known whether they had terminated migration and were actually caught close to the intended spawning area, or whether the migration was interrupted by catch-and-release. Based on appearance and salmon lice, the fish in the present study had recently entered the river when they were caught and released, but the exact time is not known. Mean migration speed from tagging in the fjord near the mouth of the River Namsen until passing an automatic listening station 11 km upriver was 20 km per day (Thorstad et al., 1998). This river resembles the River Alta in the lower part, and the results indicate that most of the salmon in the present study may have reached the catch-and-release site in less than 24 h after entering the river. A study in the River Alta indicated slower speeds at this stage of the river migration (mean 2.6 km per day), but these speeds were probably underestimated because they were based on manual tracking of the fish (Heggberget et al., 1996). However, results of Heggberget et al. (1996) confirm that most of the fish in the present study may have reached the catch-and-release site in less than a week after entering the river. Accordingly, the fish caught-and-released in the upper reaches of the river had, on average, stayed in the river longer than one month (Heggberget et al., 1996).

Thus, the present study confirms that salmon caught-and-released during upstream migration shortly after entering the river (average <1 week) had a high survival and were present in known spawning areas during spawning. The results are in accordance with salmon caught-and-released in the upper reaches, and we reject the hypothesis that the long-term effects of catch-and-release were more severe at an earlier stage of freshwater migration. The salmon from the upper reaches had for the most part ended their upstream migration and stayed for a longer period in freshwater when caught-and-released (average >1 month) (Thorstad et al., 2003; this study). Fish entering fresh water from sea are exposed to large changes in ambient salinity levels, and salmon that had newly entered the river had poorer osmoregulatory abilities and higher mortality than kelts after catch-and-release (Brobbel et al., 1996). However, in the study of Brobbel et al. (1996), the newly entered salmon were collected in a fish trap below the high tide level and may have been less adjusted to fresh water that the salmon in the present study. They may, therefore, have been more vulnerable to catch-and-release.

For salmon caught-and-released in the upper reaches of the River Alta after the migration had principally ended, catch-and-release seemed to result in a more erratic movement pattern than for undisturbed Atlantic salmon, with up- and downstream movements in the river towards spawning (Thorstad et al., 2003). For salmon caught during their upstream migration in the present study, catch-and-release seemed to result in a delay in the upstream migration. The riverine migration has been reported to take place in three successive phases before spawning: (1) steady progress upriver with periods of swimming alternating with stationary periods, (2) a search phase with movements both up and down river at or close to the position held at spawning, followed by (3) a long residence period (e.g. Hawkins and Smith, 1986; Heggberget et al., 1988; Webb, 1989; Økland et al., 2001). Resting periods during the upstream migration phase usually last 5–8 days (Økland et al., 2001). In view of this, and the upstream migration patterns previously recorded for undisturbed salmon in the River Alta (Heggberget et al., 1996), the migration delay after catch-and-release in the present study (average 34 days) seems long compared to what is expected for natural resting periods.

An unusual downstream movement immediately after catch-and-release was recorded for 31% of the upstream migrating fish in the present study. Downstream movements are generally not seen in wild Atlantic salmon during the return river migration, except during the search phase (Thorstad et al., 1998; Økland et al., 2001; Finstad et al., 2005). The individuals with downstream movements were recorded 4–24 km further upstream during spawning, and the downstream movements were, therefore, not likely part of the search phase. A delay in the upstream migration and downstream movements as a result of capturing and tagging fish has also been observed by Webb (1998) and Mäkinen et al. (2000). Also other catch methods and handling practices than catch-and-release angling may induce downstream movement and delay in salmonids (Bernard et al., 1999; Mäkinen et al., 2000).

The biological importance of delays in the upstream migration and erratic movement patterns as a result of catch-and-release is not known, as long as the salmon arrive on the spawning grounds in time for the spawning season. Atlantic salmon often enter the rivers several months before spawning (Nordqvist, 1924; Hawkins and Smith, 1986), and may hold position on or near the spawning grounds for one to two months before spawning (Økland et al., 2001). As pointed out by Fleming (1996), there is no satisfactory adaptive explanation for the early river entry time of adult Atlantic salmon. If the early river entry is associated with some kind of advantages at the spawning ground, delays during the upstream migration may involve corresponding disadvantages. Migration delays may also increase catches in lower parts of watersheds and decrease catches in upper parts, causing conflicts between stakeholders in lower and upper parts of watersheds. Atlantic salmon apparently return to the same area of the river where they spent their pre-smolt period (Heggberget et al., 1986, 1988), although a few individuals also stray to other rivers (Stabell, 1984; Jonsson et al., 1991). Erratic and unusual movement patterns after catch-and-release angling may cause a shift in the distribution of the salmon population within the river.

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References

Barnhart, R.A., 1989. Symposium review: Catch-and-release fishing, a decade of experience. N. Am. J. Fish. Man. 9, 74–80.

Bernard, D.R., Hasbrouck, J.J., Fleischman, S.J., 1999. Handling-induced delay and downstream movement of adult chinook salmon in rivers. Fish. Res. 44, 37–46.

Brobbel, M.A., Wilkie, M.P., Davidson, K., Kieffer, J.D., Bielak, A.T., Tufts, B.L., 1996. Physiological effects of catch and release angling in Atlantic salmon (*Salmo salar*) at different stages of freshwater migration. Can. J. Fish. Aquat. Sci. 53, 2036–2043.

Cooke, S.J., Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? Biodivers. Conserv. 14, 1195–1209.

Cooke, S.J., Screer, J.F., Dunmall, K.M., Philipp, D.P., 2002. Strategies for quantifying sublethal effects of marine catch-and-release angling: insights from novel freshwater applications. Am. Fish. Soc. Symp. 30, 121–134.

Dempson, J.B., Furey, G., Bloom, M., 2002. Effects of catch and release angling on Atlantic salmon, *Salmo salar* L., of the Conne River Newfoundland. Fish. Man. Ecol. 9, 139–147.

Ferguson, R.A., Tufts, B.L., 1992. Physiological effects of brief air exposure in exhaustively exercised rainbow trout (*Oncorhynchus mykiss*): implications for "catch and release" fisheries. Can. J. Fish. Aquat. Sci. 49, 1157–1162.

Finstad, B., Bjørn, P.A., Nilsen, S.T., 1995. Survival of salmon lice, *Lepeophtheirus salmonis* Krøyer, on Arctic charr Salvelinus alpinus (L.) in fresh water. Aquacult. Res. 26, 791–795.

Finstad, A.G., Økland, F., Thorstad, E.B., Heggberget, T.G., 2005. Comparing upriver spawning migration of Atlantic salmon *Salmo salar* and sea trout *Salmo trutta*. J. Fish Biol. 67, 919–930.

Fleming, I.A., 1996. Reproductive strategies of Atlantic salmon: ecology and evolution. Rev. Fish Biol. Fish. 6, 379–416.

Hawkins, A.D., Smith, G.W., 1986. Radio-tracking observations on Atlantic salmon ascending the Aberdeenshire Dee. Scott. Fish. Res. Rep. 36, 1–24.

Heggberget, T.G., Lund, R.A., Ryman, N., Ståhl, G., 1986. Growth and genetic variation of Atlantic salmon (*Salmo salar*) from different sections of the River Alta North Norway. Can. J. Fish. Aquat. Sci. 43, 1828–1835.

Heggberget, T.G., Hansen, L.P., Næsje, T.F., 1988. Within-river spawning migration of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 45, 1691–1698.

Heggberget, T.G., Økland, F., Ugedal, O., 1996. Prespawning migratory behaviour of wild and farmed Atlantic salmon (*Salmo salar*) in a North Norwegian river. Aquacult. Res. 27, 313–322.

Jonsson, B., Jonsson, N., Hansen, L.P., 1991. Differences in life history and migratory behaviour between wild and hatchery-reared Atlantic salmon in nature. Aquaculture 98, 69–78.

Mäkinen, T.S., Niemelä, E., Moen, K., Lindström, R., 2000. Behaviour of gill-net and rod-captured Atlantic salmon (*Salmo salar* L.) during upstream migration and following radio tagging. Fish. Res. 45, 117–127.

Muoneke, M.I., Childress, W.M., 1994. Hooking mortality: a review for recreational fisheries. Rev. Fish. Sci. 2, 123–156.

Nordqvist, O., 1924. Times of entering of the Atlantic salmon (*Salmo salar* L.) in the rivers. Rapp. P.-V. Reun. CIESM 33, 1–58.

Økland, F., Erkinaro, J., Moen, K., Niemelä, E., Fiske, P., McKinley, R.S., Thorstad, E.B., 2001. Return migration of Atlantic salmon in the River Tana: phases of migratory behaviour. J. Fish Biol. 59, 862–874.

Stabell, O.B., 1984. Homing and olfaction in salmonids: a critical review with special reference to the Atlantic salmon. Biol. Rev. 59, 333–388.

Thorstad, E.B., Heggberget, T.G., Økland, F., 1998. Migratory behaviour of adult wild and escaped farmed Atlantic salmon, *Salmo salar* L., before, during and after spawning in a Norwegian river. Aquacult. Res. 29, 419–428.

Thorstad, E.B., Økland, F., Finstad, B., 2000. Effects of telemetry transmitters on swimming performance of adult Atlantic salmon. J. Fish Biol. 57, 531–535.

Thorstad, E.B., Næsje, T.F., Fiske, P., Finstad, B., 2003. Effects of catch and release on Atlantic salmon in the River Alta, northern Norway. Fish. Res. 60, 293–307.

Webb, J., 1989. The movements of adult Atlantic salmon in the River Tay. Scott. Fish. Res. Rep. 44, 1–32.

Webb, J.H., 1998. Catch and release: the survival and behaviour of Atlantic salmon angled and returned to the Aberdeenshire Dee, in spring and early summer. Scott. Fish. Res. Rep. 62, 1–15.

Whoriskey, F.G., Prusov, S., Crabbe, S., 2000. Evaluation of the effects of catch-and-release angling on the Atlantic salmon (*Salmo salar*) of the Ponoi River, Kola Peninsula Russian Federeation. Ecol. Freshw. Fish 9, 118–125.

Wilkie, M.P., Davidson, K., Brobbel, M.A., Kieffer, J.D., Booth, R.K., Bielak, A.T., Tufts, B.L., 1996. Physiology and survival of wild Atlantic salmon following angling in warm summer waters. Trans. Am. Fish. Soc. 125, 572–580.

Wilkie, M.P., Brobbel, M.A., Davidson, K., Forsyth, L., Tufts, B.L., 1997. Influences of temperature upon the postexercise physiology of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 54, 503–511.