BOREAL ENVIRONMENT RESEARCH 19: 408–416 © 2014
ISSN 1239-6095 (print) ISSN 1797-2469 (online) Helsinki 28 November 2014

Effects of handling adult sea trout (*Salmo trutta*) in a fishway and tagging with external radio transmitters

Eva B. Thorstad[1)]*, Anders Foldvik[1)], Håvard Lo[2)], Thomas Bjørnå[3)] and John Haakon Stensli[2)]

[1)] *Norwegian Institute for Nature Research, P.O. Box 5685 Sluppen, NO-7485 Trondheim, Norway (*corresponding author's e-mail: eva.thorstad@nina.no)*
[2)] *Norwegian Veterinary Institute, P.O. Box 5695 Sluppen, NO-7485 Trondheim, Norway*
[3)] *Mosjøen og Omegn Næringsselskap KF, Fearnleys gt 7–9, NO-8656 Mosjøen, Norway*

Received 22 Dec. 2013, final version received 11 June 2014, accepted 11 June 2014

Thorstad, E. B., Foldvik, A., Lo, H., Bjørnå, T. & Stensli, J. H. 2014: Effects of handling adult sea trout (*Salmo trutta*) in a fishway and tagging with external radio transmitters. *Boreal Env. Res.* 19: 408–416.

Survival and behavioural effects of handling and transport related to a fishway in a natural waterfall was examined for radio-tagged sea trout (*Salmo trutta*, $n = 39$) during their upstream migration to spawning grounds. Main aims were to examine (1) if handling and transport impacted their subsequent survival, (2) whether they remained above the waterfall and resumed upstream migration, or migrated downstream again below the waterfall, and (3) if migration behaviour differed between fish tagged with small and large external transmitters. A high survival rate (at least 97% of the fish), fast upstream movement after release above the waterfall (average 6 km during the 6 first days), no recorded downstream movements during the entire study period, and wide-ranging migration before the spawning period (average 25–27 km upstream of the release sites), indicated that handling, tagging and transport of the sea trout did not greatly impact their subsequent survival and behaviour. The results did not differ between two release sites (0 and 9 km upstream from the waterfall) and did not depend on fish body size or sex. Fish with large, external radio transmitters had covered a shorter distance before spawning than fish with small transmitters. Our results indicate that the use of external transmitters may reduce the migration distance and affect the distribution of fish during the spawning period. Hence, we recommend using as small external transmitters as possible in watersheds where fish have to negotiate waterfalls and river stretches with strong currents. A low determination coefficient of the model ($r^2 = 0.22$) indicates that other factors than the external transmitters largely affect the migration distance among individuals.

Introduction

Fishways are installed to facilitate upstream migration of salmonids and other fishes in natural waterfalls, dams and other man-made installations. In some fishways, fish may be handled, dip-netted and transported for monitoring purposes (Roscoe and Hinch 2010). This may also happen if a fishway does not cover the entire barrier. Many studies focus on the functioning of fishways themselves, but there are few studies examining the effects of handling and transport

Editor in charge of this article: Outi Heikinheimo

related to fishways and fish post-passage movements to spawning grounds (Roscoe and Hinch 2010, Yoon *et al*. 2012).

Upstream-migrating individuals that are caught and released in recreational fisheries may show subsequent behavioural reactions, such as unusual migration delays, erratic movement patterns, downstream movements and a shortened migration distance, as shown in studies of the Atlantic salmon (*Salmo salar*) (Webb 1998, Tufts *et al*. 2000, Thorstad *et al*. 2003). If fish handled and transported in a fishway have similar behavioural responses, this may reduce the efficiency of a fishway. The reasons for such behavioural responses are not known, but may be stress-induced (Thorstad *et al*. 2008). The worst-case scenario is that handling-induced stress results in fish mortality (Pickering 1981).

Electronic tagging methods, also termed fish telemetry, are widely used to study fish movements and migrations (Cooke *et al*. 2004). Two of the main methods for attaching electronic tags to fish are surgical implantation in the body cavity and external attachment (Bridger and Booth 2003). Surgical implantation in the body cavity is the most commonly used method (Cooke *et al*. 2011). The disadvantages of external tagging are interference with the streamlined body shape of the fish and increase of drag, which may reduce swimming speeds; a tag can also become entangled in aquatic vegetation and other structures (Bridger and Booth 2003). Advantages are that the procedure requires less training than other tagging methods, it can be used in fishes not suitable for surgical implantation due to body shape or if tagging is performed close to spawning, external placement may be more suitable if sensors measure the external environment, and fishers easily detect the tag at recapture (Bridger and Booth 2003). Furthermore, surgical incisions may not heal easily in fish that are in periods of high activity, and sutures may open up when fish are jumping and swimming in waterfalls and strong currents (own observations in Atlantic salmon). External tags may therefore be preferred in studies of upstream-migrating salmonids and other strong swimmers in rivers with waterfalls and areas with strong currents. However, while to date effects of surgically-implanted electronic tags has been extensively studied (*see* e.g., Jepsen *et al*. 2002, Cooke *et al*. 2011 and references therein), there are relatively few studies of effects of externally attached tags.

The present study was performed in a natural waterfall where the anadromous brown trout (*Salmo trutta*), hereafter termed the sea trout, were taken from the fishway to nearby tanks for treatment in salt water to prevent spreading of the parasite *Gyrodactylus salaris* (*see* Davidsen *et al*. 2013) to areas above the waterfall. After treatment in salt water, which kills this freshwater parasite, the sea trout were released upstream of the waterfall to resume migration to spawning areas. The aims of the study were to (1) examine if handling of the sea trout in the fishways affected their subsequent survival, (2) examine whether they remained above the waterfall and resumed upstream migration or migrated downstream again below the waterfall, (3) compare two release strategies: half of the fish were released immediately above the waterfall while the other half was transported by car to a release site 9 km upstream of the waterfall, and (4) examine possible effects of the transmitter size on the subsequent survival and behaviour by tagging half of the fish in each release group with small external radio transmitters, and half of them with large external transmitters.

Material and methods

Study area

The study was performed in the Vefsna River system (precipitation area 4220 km^2) in northern Norway. The anadromous Atlantic salmon and sea trout could access the lower 29 km of the Vefsna River until a fishway was built in the 16-m high Laksforsen waterfall in the 1880s. After this, 13 fishways have been built, resulting in accessible stretches for anadromous salmonids of totally 126 km. The first fishway upstream of Laksforsen (9 km upstream) is in the 5-m high waterfall Fellingsforsen. Similar to Laksforsen, Fellingsforsen is a migration barrier for upstream-migrating Atlantic salmon and sea trout, and can only be passed through the fishway. The river system is not regulated for hydropower or other purposes, and is generally little impacted by anthropogenic activities. The human population density in the three municipalities covering the drainage area is 2.4 persons per km^2, with 60% of the population living in the town of Mosjøen at the river mouth.

The daily mean water discharge at Laksforsen varied from 59–90 m^3 s^{-1} during 17–30 August 2009 (first two weeks of the study), increase to 102–290 m^3 s^{-1} during 31 August–8 September, and was thereafter very variable (106–992 m^3 s^{-1}) during the rest of the study.

Fish capture, handling and tagging

Sea trout were captured when entering a 25-m^2-large concrete chamber in the middle of the fishway in Laksforsen. A house with fish holding tanks has been built over this concrete chamber. The fish were transferred to the holding tanks using dip nets, where they were kept until salt water treatment and radio tagging. On 11 August 2009, 39 sea trout (total body length average 67 cm, range 53–83 cm, SD 5.9; Table 1) were tagged with external radio transmitters attached at the dorsal fin with steel wires through the muscle below the fin (as described by Økland *et al*. 2001). The fish were randomly taken out of the holding tank one by one using a dip net, and every second fish was tagged with a small transmitter and every second with a large one. Before tagging, the fish were anaesthetised for approximately 3 min (100 g finquel/metacaine per l water, Western Chemical Inc., USA, buffered with 100 g sodium bicarbonate). During tagging, the fish were kept in a tube with the head in water. After tagging, the fish were kept in the holding tank until release. The water temperature was 12–14 °C during capture, handling and tagging.

The radio transmitters were flat, and two models were used (model F2110: 21 × 42 × 11 mm, 12 g in air, referred to as ‘small transmitters’; model F2120: 21 × 52 × 11 mm, 15 g in air, referred to as ‘large transmitters’, Advanced Telemetry Systems, ATS, USA). The signals were in the frequency range 142.013–142.493 MHz. Individuals were recognised based on different transmitter frequencies. Guaranteed lifetimes of transmitters were 91 (model F2110) and 195 (model F2120) days, while their battery capacities were 182 and 390 days, respectively. To ensure full functionality, a transmitter lifetime guaranteed by the manufacturer is half the guaranteed battery lifetime.

The radio-tagged sea trout were treated in salt water (PSU of 33 for 45 minutes), transported in a tank with oxygenated salt water (PSU of 20 for minimum 30 minutes) by car and released into the river on 17 August 2009. Half of the fish (n = 20) were released immediately upstream of Laksforsen waterfall, whereas half of them (n = 19) were released 9 km further upstream, i.e. immediately upstream of Fellingsforsen (Table 1). Fish were randomly taken out of the holding tank and divided into two groups, one for each release site, but with the premise that there should be an equal number of fish with small and large transmitters at each release site.

Fish were located by means of manual tracking from a car and on foot on the following dates: 17, 18, 19, 20, 21, 23 and 25 August, 1, 4 and 16 September and 8 October (receiver model R2100 and a 4-element Yagi antenna, ATS). All

Table 1. Overview of radio tagged sea trout in the Vefsna River, northern Norway.

Groups	Number of fish tagged	Total body length (cm) [average (min–max, SD)]	Number of females	Number of males
Laksforsen (immediately above catch site)				
Small transmitters	10	66 (60–71, 4.1)	6	4
Large transmitters	10	68 (58–75, 5.6)	10	0
Total	20	67 (58–75, 4.8)	16	4
Fellingsforsen (9 km upstream catch site)				
Small transmitters	9	64 (53–71, 5.4)	7	2
Large transmitters	10	71 (60–83, 6.8)	5	5
Total	19	67 (53–83, 6.9)	12	7

river stretches were not covered during all tracking surveys, because some parts of the watershed are difficult to access because they run through remote mountain areas away from roads. Arrival of snow during the last tracking made some areas even less accessible. Fish locations were plotted on a 1:50 000 map.

An automatic listening station (data logger model DCCII connected to a receiver model R2100 and a 9-element Yagi antenna, ATS) was installed 7.2 km downstream of the release site at Laksforsen to locate sea trout that possibly migrated downstream. The listening station was in operation from before release of the fish until 27 September 2009, when it was dismantled due to a flood.

The results were analysed using the software ArcMap 9.3.1 (Esri, USA) and R 2.10.1 (R Development Core Team 2009). For each fish, distance from release site was plotted against date. Distributions were compared between the fish released at Laksforsen and those released at Fellingsforsen. The furthest distance recorded from the release site and the fastest migration speed (meter per day) between tracking surveys were identified for each fish. For fish found only early in the season, the greatest distance from the release site may not reflect well how far it moved before the spawning period in the autumn. Hence, all analyses were made two times; first with all tagged fish included, and then with fish not found after 4 September ($n = 9$) excluded. A linear model was used to analyse which variables affected maximum migration distance and maximum migration speed. Release site, sex, body length, transmitter size and interactions among the variables were included in the full model. Model selection was performed using backward selection until no variable could be removed without causing a significant decrease ($p < 0.05$) in model fits (Crawley 2007). Possible differences in the proportion of sea trout with small and large transmitters passing Fellingsforsen were tested using Fisher's exact test.

Results

All the tagged sea trout were recorded after release, and none migrated downstream from the release site. During the two last tracking surveys on 16 September and 8 October, 30 of the tagged sea trout were found (77%). Five of these were already lost after 1 September. These five fish migrated fast 4–25 km upstream before they disappeared, and were not found in downstream river stretches, so they likely migrated to areas difficult to access in the upper part of the watershed. No downstream movement of any tagged fish were recorded during the study period.

All sea trout migrated upstream from the release site, except two fish remaining close to the release site above Laksforsen and one above Fellingsforsen. There are spawning sites in these areas, so despite not moving upstream they could have participated in spawning. Based on upstream movements between tracking surveys, at least 97% of the tagged trout were certainly alive in the weeks after release, whereas we could not verify whether one of the individuals which remained above Laksforsen was alive or not.

Sea trout released at Laksforsen migrated up to 27 km upstream from the release site (average 13 km, SD = 8.2), whereas those released at Fellingsforsen migrated up to 25 km from the release site (average 13 km, SD = 7.9). There was no difference between these two groups in migration distance after release (Fig. 1).

The upstream migration was initiated immediately after release. During the first six days after release, the fish moved on average 5.9 km upstream from the release site (maximum 24.8 km, SD = 5.5).

Release site, sex and body length did not affect individual maximum migration distance, and hence could all be removed from the full model (all $p \geq 0.53$) (Fig. 1). Transmitter size was the only significant variable affecting migration distance ($F_{1,37} = 10.76, p < 0.001$). However, the low value of the coefficient of determination ($r^2 = 0.22$) indicates that also other factors than those included in the model to a large extent influenced migration distance of the fish (Fig. 1 and Table 2). According to power analysis (R package *stats*, power calculation for one-way ANOVA) and the mean square residual as an estimate of within-group variance, power of the model analysis was sufficient (0.88). When fish not recorded after 4 September were excluded, none of the variables were significant, and

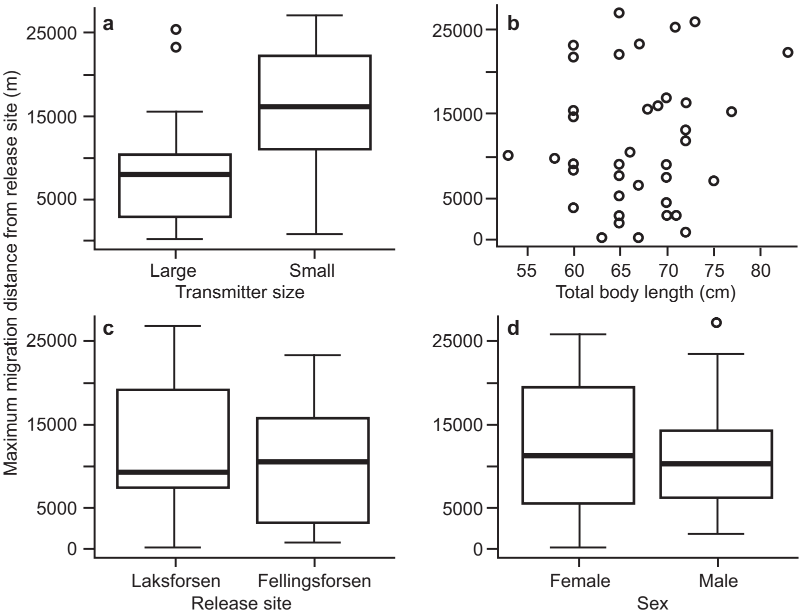

Fig. 1. Maximum migration distance upstream from the release site during the study for fish tagged with (**a**) large and small transmitters, (**b**) related to body size, (**c**) fish released at Laksforsen and Fellingsforsen, and (**d**) males and females. Box plots show the median and interquartile range, whiskers represent the minimum and maximum values, or 1.5 times the interquartile range if this is closer to the median (if so, smaller or larger values are shown as points). Data from all fish are included.

release site, sex and body length were removed from the full model (all $p \geq 0.26$) leaving transmitter size as the sole explanatory variable in the best model ($F_{1,27} = 3.44, p = 0.07$). For maximum migration speed between tracking surveys, none of the explanatory variables had any significant effect, and all could be removed from the full model (all $p \geq 0.25$) (Fig. 2).

Nine of the 20 fish released at Laksforsen (45%) passed the waterfall Fellingsforsen. Based on inspection of individual migration patterns, Fellingsforsen appeared to slightly delay the upstream migration, because at least five individuals were recorded in the pool below the waterfall for some days up to a week before passing. In addition, at least 6 individuals were recorded in the pool below without ever passing. The proportion of sea trout with small and large transmitters passing Fellingsforsen did not differ at $p = 0.05$. (7 of 19 sea trout with small transmitters passed the waterfall, whereas only 2 of 20 sea trout with large transmitters did so; Fisher's exact test, $p = 0.065$, power of the test 0.6).

Four sea trout were recaptured 1–2 years after tagging. One fish with a large transmitter was recaptured in the Vefsna River in July 2010, one with a small transmitter in the sea near the river mouth in the summer of 2010 (date not given), one with a small transmitter in the sea near the river mouth in April 2011, and one with a small transmitter in the Vefsna River in July 2011. There was no difference in recapture rates between the fish with small and large transmitters (Fisher's exact test, $p = 0.34$).

Discussion

The results of this study indicate that sea trout survived capture, handling and transport in the fishway, with at least 97% of the fish surviving. Upstream movements of one individual were not recorded, hence we were unable to verify whether it was alive. It remained in a spawning area at the release site, so whether it spawned here, died, or lost the transmitter is not known.

Table 2. Parameters of the best linear model describing variation in the maximum distance covered by the tagged fish in the Vefsna River, northern Norway ($r^2 = 0.22$, $F = 10.76$, $p = 0.002$).

Parameter	Estimate (SE)	*t*	*p*
Intercept	8289 (1598)	5.186	< 0.001
Transmitter: small	7510 (2290)	3.280	0.002

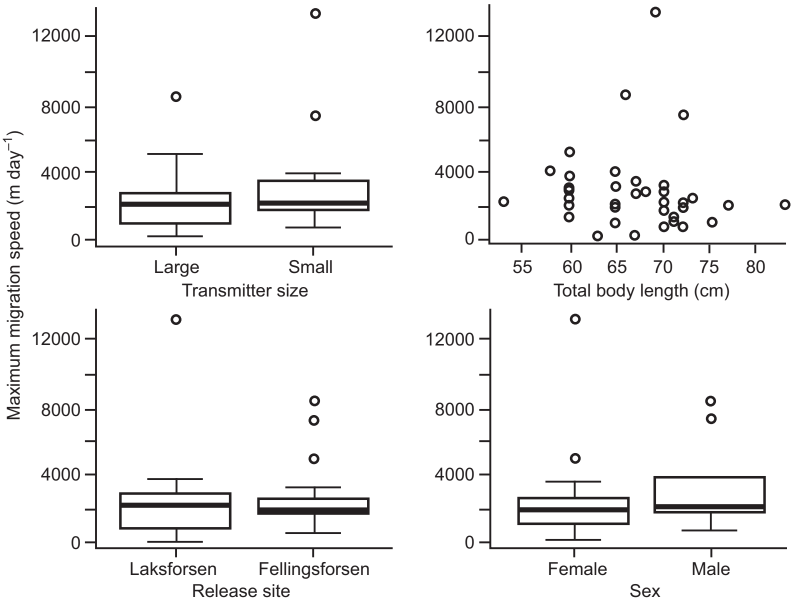

Fig. 2. Maximum migration speed between tracking surveys for fish tagged with large and small transmitters (upper left), fish released at Laksforsen and Fellingsforsen (lower left), males and females (lower right) and related to body size (upper right). Box plots show the median and interquartile range, with whiskers representing 1.5 times the interquartile range and smaller or larger values shown as individual points. Data from all fish are included.

No sea trout moved downstream, and they were distributed over a large area of the watershed during the spawning period. Hence, downstream movements, or fallback, like demonstrated for other salmonids after passing fishways at hydropower dams, or after other capture and handling procedures (Bernard *et al*. 1999, Mäkinen *et al*. 2000, Schmetterling 2003, Boggs *et al*. 2004), did not occur.

High survival and quick commencement of the upstream migration after handling and transport were recorded despite additional stress induced by saltwater treatment and radio tagging. This indicates that sea trout may tolerate such handling well. There were no differences in survival and behaviour between fish released immediately above the fishway and those transported over a 9-km distance. However, since sea trout released at the two different sites did not differ in migration distance from the release site, the result was that sea trout released at the upstream site was distributed higher up in the watershed than those released at the downstream site. Hence, if the aim is to have handled and transported fish distributed over large parts of the watershed, release at different sites may be the most successful strategy.

The relatively low water temperature at handling (12–14 °C) may have contributed to the high survival in the present study. The survival of Atlantic salmon after catch and release angling seems highly temperature dependent, with negligible mortality at low water temperatures if the fish is handled well and not deeply hooked, but with an increased mortality at temperatures above 17–18 °C (Dempson *et al*. 2002, Thorstad *et al*. 2003).

The sea trout resumed migration quickly after release, with a mean migration distance of 6 km during the first six days after release. These results contrast the delay and downstream migration frequently recorded for Atlantic salmon after catch and release angling, gill net capture or electrofishing and transport (Mäkinen *et al*. 2000, Johnsen and Hvidsten 2002, Thorstad *et al*. 2003). These differences may indicate a species difference between Atlantic salmon and sea trout in stress tolerance, and/or it might be that the stress load and potential injuries differ between the capture and handling in the fishway and gill net capture, catch and release angling, and electrofishing and transport. Sea trout is not as well studied as Atlantic salmon. However, a study of Aarestrup and Jepsen (1998) indicate that sea trout may be tolerant to capture, handling and radio tagging, as 14 sea trout captured in a trap immediately above the tidal limit migrated further upstream in the river, and 12 of them ascended further upstream within 4 hours after tagging. A similar result was found in a study where 19 wild sea trout were captured in bag nets in the fjord outside a river, kept in a net pen in the fjord for up to 2.5 months, and subsequently radio tagged and released (Finstad *et al*. 2005). Eighteen of these (95%) entered the river quickly after release and were recorded alive in spawning areas during the spawning period six weeks later.

The results in this study indicate that tagging with an external transmitter may reduce the migration distance of upstream-migrating sea trout, and hence affect where in the river they spawn. Sex, body length and release site had no effect on the maximum migration distance from the release site, but the migration distance was shorter for fish tagged with a large transmitter than for those tagged with a small transmitter. Since we did not have an untagged control group, we do not know it the migration distance of the fish with a small transmitter was reduced as compared with that of untagged fish. There was no effect of transmitter size on the maximum migration speed between tracking surveys. Still, we cannot exclude that the external transmitters affected maximum migration speeds, since the time interval between tracking surveys influenced the precision of migration speed recordings. Although sample sizes in this study were relatively low, power analysis revealed that the results and conclusions regarding the effect of transmitter size on the migration distance are valid. There was a larger number of females than males included in the study, which may reduce the likelihood of detecting sex differences in migration behaviour. However, the study design was balanced with respect to proportion of males and females tagged with small and large transmitters, respectively, so a potential sex difference should not confound the results regarding transmitter size. A low determination coefficient of the model ($r^2 = 0.22$) points to a relatively large proportion of the variation in migration distance among individuals not explained by the parameters in the model. The proportion of sea trout with small transmitters passing Fellingsforsen seemed to be greater than that of fish with large transmitters, but the difference was not statistically significant. The transmitters may have affected the ability to pass the fishway at the waterfall, but this needs to be further explored with larger sample sizes.

Considering available river stretches in this watershed, the relatively short migration distance of the tagged sea trout may support the conclusion that the migration distance could have been reduced due to tagging. Sea trout within a watershed may belong to different populations (Jonsson & Jonsson 2011), and therefore tend to return to their site of origin. We do not have information on population structure of the sea trout in this watershed, and whether the tagged sea trout may have belonged to populations in the area where they resided during spawning, or to populations further upstream. If the tagged sea trout were successfully returning to a home site in the river, we would expect a similar distribution in the river at spawning for fish released at the two different sites, since individuals were randomly selected for the two groups. This would mean that the sea trout released at the upstream release site would on average have migrated a distance that was 9 km shorter than the fish released at the downstream site until spawning, since the release sites were 9 km apart. The fact that migration distance did not differ between fish released at the two different sites indicates either that the tagged sea trout did not have a strong homing instinct to certain sites in the river but perhaps stopped when they approached suitable spawning areas, or that they might have had a homing instinct, but due to handling and tagging did not have the urge to complete migration all the way to the home site.

Similar transmitters to those used in the present study (both the small and large ones) did not affect swimming capacity of similarly sized Atlantic salmon in endurance tests in a swim speed chamber in the laboratory (Thorstad *et al*. 2000). This, together with the results in the present study, may imply that these external transmitters do not influence the swimming capacity greatly during normal swimming, but that they may potentially reduce the ability to pass waterfalls and shorten the migration distance in rivers with waterfalls and areas with strong currents. Hence, we might speculate that the large external transmitters may affect burst activity more than sustainable swim speeds, but this remains to be tested. A laboratory study of rainbow trout (*Oncorhynchus mykiss*) has shown shorter fatigue times for externally radio-tagged fish as compared with those of other tagged groups and controls (Mellas and Haynes 1985). It has also been shown that external radio transmitter may increase tail beat frequency and opercular beat rate in rainbow trout (Lewis and Muntz 1984). The mass difference between the small and large transmitters used in the present study was small (3 g in air). We therefore suggest that the main reason for the different effects on the fish migration between these transmitters is not the mass but the difference in size with larger transmitter creating more drag.

Based on the results in the present study, we recommend using as small external transmitters as possible in watersheds with areas that are potentially challenging to negotiate. The disadvantage with using smaller transmitters is a shorter battery life. We were also worried that they might be more difficult to track manually in a large river due to a weaker signal. However, in practical terms there was not a large difference in how easy these small and large transmitters were to locate during manual tracking.

In conclusion, the high survival rate, fast upstream movement after release and a wide-ranging migration before the spawning period, indicated that the handling of sea trout in the fishway, tagging and transport did not greatly impact their subsequent survival and behaviour. The results did not differ between two release sites, and did not depend on body size or sex. Fish with large external radio transmitters had a shorter migration distance before spawning than fish with small transmitters. Due to experiences with surgical incisions opening up and not healing well in another watershed where the fish had to negotiate several waterfalls (own unpublished results), surgical implantation might not necessarily be an appropriate alternative. Recaptures of four fish (10% of the tagged fish) 1–2 years after tagging indicated that an external transmitter may withstand long attachment.

Acknowledgements

The Norwegian Directorate for Nature Management (DN) and the Norwegian Institute for Nature Research (NINA) funded the project. We would like to thank Leif Bekkevold, Torstein Bjørnå, Christian Johnsen, Margrethe Jønsson, Arnt Eirik Teodorsen and Martin Øybakken for assistance during capture, handling and tracking of the fish.

References

Aarestrup K. & Jepsen N. 1998. Spawning migration of sea trout (*Salmo trutta* (L)) in a Danish river. *Hydrobiologia* 372: 275–281.

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.

Boggs C.T., Keefer M.L., Peery C.A., Bjornn T.C. & Stuehrenberg L.C. 2004. Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake River dams. *Trans. Am. Fish. Soc*. 133: 932–949.

Bridger C.J. & Booth R.J. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behaviour. *Rev. Fish. Sci*. 11: 13–34.

Cooke S.J., Hinch S.G., Wikelski M., Andrews R.D., Kuchel L.J., Wolcott T.G. & Butler P.J. 2004. Biotelemetry: a mechanistic approach to ecology. *TREE* 19: 334–343.

Cooke S.J., Woodley C.M., Eppard M.B., Brown R.S. & Nielsen J.L. 2011. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effect studies. *Rev. Fish Biol. Fish*. 21: 127–151.

Crawley M.J. 2007. *The R book*. Wiley Publishing, Chichester.

Davidsen J.G., Thorstad E.B., Baktoft H., Aune S., Økland F. & Rikardsen A. 2013. Can sea trout *Salmo trutta* compromise succesful eradication of *Gyrodactylus salaris* by hiding from rotenone (CFT-Legumin) treatments? *J. Fish Biol*. 82: 1411–1418.

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.

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.

Jepsen N., Thorstad E.B., Baras E. & Koed A. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? *Hydrobiologia* 483: 239–248.

Johnsen B.O. & Hvidsten N.A. 2002. Use of radio telemetry and electrofishing to assess spawning by transplanted Atlantic salmon. *Hydrobiologia* 483: 13–21.

Jonsson B. & Jonsson N. 2011. *Ecology of Atlantic salmon and brown trout — habitat as a template for life histories*. Springer, New York.

Lewis A.E. & Muntz W.R.A. 1984. The effects of external ultrasonic tagging on the swimming performance of rainbow trout, *Salmo gairdneri* Richardson. *J. Fish Biol*. 25: 577–585.

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.

Mellas E.J. & Haynes J.M. 1985. Swimming performance and behavior of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. *Can. J. Fish. Aquat. Sci.* 42: 488–493.

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.

Pickering A.D. 1981. *Stress and fish*. Academic Press Inc., London.

R Development Core Team 2009. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Roscoe D.W. & Hinch S.G. 2010. Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions. *Fish Fish.* 11: 12–33.

Schmetterling D.A. 2003. Reconnecting a fragmented river: Movements of westslope cutthroat trout and bull trout after transport upstream Milltown Dam, Montana. *N. Am. J. Fish. Man.* 23: 721–731.

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 hook and release on Atlantic salmon in the River Alta, northern Norway. *Fish. Res.* 60: 293–307.

Thorstad E.B., Økland F., Aarestrup K. & Heggberget T.G. 2008. Factors affecting the within-river spawning migration of Atlantic salmon, with emphasis on human impacts. *Rev. Fish Biol. Fish.* 18: 345–371.

Tufts B.L., Davidson K. & Bielak A.T. 2000. Biological implications of ‘‘catch and release’’ angling of Atlantic salmon. In: Whoriskey F.G. & Whelan K.E. (eds.), *Managing wild Atlantic salmon*, Atlantic Salmon Federation, St. Andrews, New Brunswick, pp. 195–225.

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.

Yoon J.D., Kim J.H., Joo G.J. & Jang M.H. 2012. Post-passage movement of the fluvial fish *Zacco temminckii* following upstream transportation by a fishway operation in dam. *Aquat. Ecol.* 46: 421–430.