Running Head: Rod vs trap salmon smolt sampling.

(Short Communication Paper)

A comparison of the behaviour and survival of angling versus trap-sampled *Salmo salar* smolts.

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ABSTRACT

An experiment was undertaken, using acoustic telemetry, to compare the survival and migratory timing of *Salmo salar* L. smolts sampled, under optimal conditions, in a traditional fixed Wolf trap against a sample of rod caught fish captured using a sensitive angling technique. No significant difference was evident in survival with 83% of both samples detected in the river outflow, 67% of the trap and 76% of the rod samples were detected in coastal waters and finally 43% of the trap and 35% of the rod samples were detected on an offshore array c. 50km from the river outlet. No significant difference was evident in the time taken for trap and rod sampled fish to reach either the river outflow, coastal or offshore waters. Angling, if undertaken sensitively, can provide an effective, resource efficient and ethically justifiable sampling tool for juvenile salmonid age classes.

KEY WORDS

Rod catch, Salmonids, Smolt, Telemetry

The understanding of fish behavior, ecology and phenology has advanced markedly in recent years through the application of rapidly evolving telemetry techniques (Hussey *et al*., 2015). The development of smaller tags, improvements in battery longevity and advancement in receiver capabilities have enabled researchers to tag younger age stages and track them for longer (Cooke *et al*., 2013). The effective sampling of younger age classes in an efficient, sensitive and ethical matter is critical to the delivery of tagging programmes (Sloman *et al*., 2019). Sampling anadromous salmonid smolts can be particularly challenging since they are physiologically delicate (e.g. prone to scale loss), can exhibit patchy distribution and tend to emigrate rapidly during periods of increased river discharge. Perhaps the most common sampling strategy for salmonid smolts involves the deployment of a trapping system to intercept the fish on their downstream migration (Kennedy & Crozier, 2010). Trapping systems, whether permanent facilities or temporary traps such as the rotary screw type, provide excellent smolt sampling platforms which are suited to population level assessments or longer term monitoring but require significant resources to procure, deploy, operate and maintain. Angling may represent a viable capture method where smaller samples are required for discrete purposes such as acoustic telemetry studies. Previous work on *Perca fluviatilis* L. and *Rutilus rutilus* L. has shown that angling can provide a sensitive capture method, comparable with other sampling tools such as electric fishing, trapping or netting (Jacobsen *et al*., 2014). The current study considered the effectiveness of angling as an expedient, low cost and highly applicable alternative sampling strategy for *Salmo salar* L. smolts. Two groups of smolts, one angled and one caught in a trap, were tagged with acoustic tags and released back to the river. The behaviour and survival was monitored through an acoustic network of receivers to test the hypothesis that angled smolts would show no difference in survival or migration timing to smolts obtained in a fixed trap, operated under optimal conditions.

The study was undertaken on the River Bush in Northern Ireland at the River Bush salmon station which is located c. 3.5 km upstream of the river outlet (55°12'N; 06°32'W) to the Atlantic ocean. As part of a long term monitoring programme downstream migrating smolts are diverted from the River Bush into a Wolf trap (Wolf, 1951) for enumeration and sampling (Kennedy & Crozier, 2010). An experiment was undertaken in April and May 2021 to compare the migration timing and survival of trapped and angled smolts from the river out to the offshore marine environment c. 50 km from the coast. To ensure comparable samples, batches of rod and trap captured fish were tagged simultaneously and in approximately equal numbers across sampling dates. On sampling days the smolt trap was emptied at 10:30 h and only fresh run fish entering the trap between 10:30-12:00 h were used for tagging to exclude any individuals that may have been retained overnight. The use of freshly trapped fish ensured limited detention time, lowered holding stress and ensured the best possible trap sample for comparison against the rod caught fish. The rod sample was captured by fly angling from the river Bush c. 100m upstream of the smolt trap at Bushmills with angling taking place between 10:30-12:00 h. The angling procedure used fly angling equipment incorporating a small barbless hook with a gape of 3-5 mm and shank length of 7-9 mm. A single experienced angler was employed across the study to ensure consistency. Upon taking the bait each fish was rapidly drawn to the bank, lifted from the water in a wet 5 mm knotless mesh landing net and unhooked directly into a holding tank. The use of barbless hooks meant that unhooking was very rapid, typically taking 1-5 s, before the fish was transferred into the holding tank. After capture, either in the trap or by angling, smolts were tagged. Prior to tagging each smolt was individually anaesthetised (c. 1-2 min) in 100 mgL^{-1} tricane (MS-222) until operculum rate became slow and the fish lost balance. The acoustic transmitter (7mm diameter, 69 kHz, delay 20-40 s, Vemco V7-2L) was inserted into the body cavity through a mid-ventral incision, anterior to the pelvic girdle. The incision was closed with one single absorbable suture (vicryl 4-0). After tagging all smolts were retained for at least 30 mins in a large 200 L lidded, flow through tank before the entire daily sample was released immediately downstream of the trap at 12:30 h on each tagging occasion. The ethical considerations of the current work were addressed and all sampling and tagging work was conducted under a UK Animals Scientific Procedures Act project licence (PPL 2869). The movement of the tagged smolts were monitored across 3 sequential arrays of acoustic receivers (VEMCO VR2W, VR2AR), located in the lower river outlet to the sea (3.5 km downstream from the tag site), off the coast adjacent to the river outlet (4.5 km from the tag site) and finally to an offshore marine array which was part of the EU SeaMonitor project (c. 50 km from the tag site). The river array had 3 receivers, the coastal array had 7 receivers deployed in 2 concentric lines (see Flávio *et al*., 2019) and the offshore Seamonitor array 122 receivers extending from Malin Head in Ireland to the Scottish coast at Islay Island (Fig. 1).

In total 59 smolts were tagged between 26th April – 4th May 2021 with 29 captured by angling and 30 captured in the Wolf trap (Table 1a). A general linear mixed model using the Residual Maximum Likelihood procedure (REML; VSN, 2020), where the random effect was tagging date, was fitted to assess if there was a significant effect of capture method on the biological metrics of length, weight and condition factor. There were no significant differences observed between the rod and trap method of capture for length ($F_{(1, 55.2)} = 0{\cdot}54$, $P = 0{\cdot}465$), weight ($F_{(1, 55.1)} = 0{\cdot}97$, $P = 0{\cdot}328$) or condition factor ($F_{(1, 57)} = 0{\cdot}61$, $P = 0{\cdot}437$).

The time to migration was modelled using the Cox proportional hazard model (Collett, 2015). Separate models were applied to investigate the migration to the estuary, migration from the estuary to the coast and migration from the coast to offshore. The smolts lost between arrays were not included in the analyses as the time at which those particular fish were lost could not be determined. The models were developed using a forward selection procedure assessing the variates, length (cm), weight (g), condition factor (Fultons' Index) and the method of capture (Trap vs Rod) for significant association with time to migration. The forward selection procedure was based on analysis of deviance and calculation of the consequential log likelihood value to determine the goodness of fit for each variable. Only those variables which attained a minimum level of 5% significance were included in the final fitted model. The analysis was carried out in R (R Core Team, 2021) using the survival (Therneau, 2021) and survminer (Kassambara *et al*., 2021) packages.

A total of 25 trapped and 24 angled fish, accounting for 83% of each sample respectively, were detected in the outflow of the river 3.5 km downstream of the tagging site (Table 1b). The mean time that elapsed between release and detection in the river outflow was 103·8 h (23·2 h 95% CI) for the trap sample and 125·9 h (30·6 h 95% CI) for the angled sample (Table 1b). Length (χ_1^2 statistic = 4·25; P < 0·05) was the only significant association with migration time to river outflow such that longer smolts had a greater likelihood of successful migration to the river outlet.

In total 20 (67%) trap fish and 22 (76%) angled fish were subsequently detected on the coastal array and the time taken from the river outlet until detection on the coastal array was 3·5 h (1·4 h 95% CI) for the trap sample and 3·9 h (1·9 h 95% CI) for the angled sample (Table 1b). There were no significant variables associated with the time taken to migrate from the estuary to the coastal array. The null model was the optimal model.

The offshore marine array detected 13 (43%) trap fish and 10 (35%) angled fish. The mean time taken from the coastal array to the offshore array was 46·0 h (9·0 h 95% CI) for the trap sample and 40·4 h (4·5 h 95% CI) for the angled fish. There was a significant association between condition factor (χ_1^2 statistic = 8·40; P = 0·004) and the time taken to migrate from the coastal to offshore array. Fish with higher condition factor were associated with shorter periods of time between detection on the coastal array and detection on the offshore array.

The results of the three separate time to event scenarios modelled from the river Bush indicate that angled fish provided an excellent sample for tagging and did not differ from trap sampled fish in either survival or migration timing as method of capture was not significantly associated with any of the time to event scenarios investigated. This finding suggests that angling could be used in telemetry studies as a reliable sampling method. Previous telemetry work has indicated that rod caught adult *S. salar* can also exhibit good survival rates > 90% when water temperatures are < 18^{o}C (Dempson *et al.*, 2002; Havn *et al.*, 2015). Despite high potential survival rates, adult *S. salar* often exhibit delayed migration following catch and release angling, with mean sojourns frequently exceeding 30 days before upstream movements recommenced (Thorstad *et al.*, 2007). In the present study rod caught *S. salar* smolts showed no significant difference in their migration timing to trap caught fish. The negligible impact on migration in rod caught smolts may be a consequence of their small size and a sensitive capture technique. The capture process from the smolt taking the bait until retention in the holding tank was fast, typically taking < 10 s, which prevented a prolonged, physiologically exhausting struggle and left fish more capable of quick recovery. Adult *S. salar* by contrast take much longer to land on angling gear and can incur significant energetic and physiological debt (Kieffer *et al*., 2002) perhaps leading to exhaustion and the requirement of an extended recovery phase before migration can recommence.

Gargan *et al*., (2015) showed that angling gear type was a critical determinant of post release survival in rod caught adult *S. salar* and that lure caught fish had much lower subsequent survival levels (55%) than fish captured on fly fishing gear (98%). Fly fishing gear is often associated with cleaner hooking, lower physiological injury and less bleeding (Gargan *et al*., 2015; Lennox *et al*, 2017). The current work employed tiny barbless hooks which aided unhooking and facilitated rapid, removal of the hook with minimal damage. The use of small, barbless hooks meant that some fish were lost during angling but the procedure ensured those smolts that were landed provided an undamaged, unexhausted and highly active sample for subsequent tagging.

The current study indicates that, conducted sensitively, angling can represent an effective, safe, non-disruptive and ethically justifiable method to sample juvenile salmonids for research purposes. Angling as a fish sampling tool offers a range of advantages as it is cheap, rapidly deployed and applicable across a wide range of aquatic environments. For salmon smolts particularly, angling with delicate gear, small artificial flies and barbless hooks can offer a utilitarian means to effectively capture fish from lakes or rivers. Angling is also applicable over deep waters which may be challenging for other methods such as electric fishing, and an angler working alongside a fish tagging team can rapidly sample extensive areas of channel in search of actively migrating shoals. Although angling cannot provide the consistent temporal sampling afforded by fixed traps it does offer significant logistical advantages whenever a discrete sample is required for research purposes.

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