ASSESSMENT OF SCALE-LOSS TO ATLANTIC SALMON (*SALMO SALAR* L.) SMOLTS FROM PASSAGE THROUGH AN ARCHIMEDEAN SCREW TURBINE

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1 ABSTRACT

The potential for external damage to Atlantic salmon (*Salmo salar* L.) smolts from passage through an Archimedean screw turbine was tested with controlled field trials at two turbine speeds. Change in external condition of smolts was measured by grading photographs of individual fish for scale-loss before and after the tests. Results were compared between turbine-passed and control smolts. There were no significant differences in proportions of fish with new scale-loss between treatment and control smolts. New scale-loss of between 4 and 30% was seen in 7.46% of turbine-passed smolts, exceeding the prevalence in control smolts by 2.46%. Of these, 1.49% had minor scale-loss of 5-9%. Minor scale-loss was more prevalent for both groups at the faster turbine speed, although differences between treatment and control groups were more apparent at the slower speed.

2 INTRODUCTION

Recent years have seen the accelerated development of small hydropower potential across Europe, including the retrofitting of existing low-head historic barriers with modern turbines. One technology which is increasingly being favoured for low-head sites is the Archimedean screw turbine (AST). A major limiting consideration for new hydropower development is the effect upon economically important inland and coastal fisheries. Of particular concern are the risks posed to fish species which rely on longitudinal connectivity for migration between freshwater and marine habitats. There is a need for scientific input to allow regulators and policy makers to optimize the balance between renewable power generation and the protection of such species. Passage through hydropower turbine infrastructure can result in direct or delayed mortality resulting from mechanical damage, rapid changes in water velocity and pressure and high shear stresses [1,2,3]. ASTs operate at low rotational speeds (up to 30RPM), with no rapid or extreme changes in water pressure and velocity or high hydraulic shear stresses. Nevertheless several mechanisms for damage to fish have been identified, namely: impact by the leading edges of the turbine, grinding between moving and stationary turbine parts, or abrasion.

In Scotland, Atlantic salmon (*Salmo salar* L.) are economically important for recreational fisheries. The present study aimed to assess the potential damage to downstream migrating Atlantic salmon smolts from passage through a small, low-head AST hydropower scheme. Two approaches were used to assess damage. Firstly visual inspection of fish and post-hoc analysis of photographs were used to identify and measure external signs of damage. Secondly, and not presented here, blood chemistry measures were used in order to detect possible effects which were not readily apparent. Based on these measurements, estimations are made of the prevalence and severity of damage resulting from passage through an AST at varying speeds.

3 METHODS

3.1 Site

The experiments were carried out at Craigpot hydropower scheme on the River Don at Keig, Aberdeenshire, Scotland between 10 and 23 April 2014. The scheme uses a 4-bladed Archimedean screw turbine to convert the movement of water over the available head of 2.2 m to electricity, up to a maximum of 60 kW at its full capacity of 4 m^3s^{-1}. The length of bladed screw is 5.4 m, and the diameter is 2.9 m. The screw is mounted in a steel trough set at 22 degrees to the horizontal. The upstream leading edges of the turbine blades are fitted with rubber bumpers with 35 mm of compression to mitigate blade strike to fish. The maximum gap between the screw blades and trough is 5 mm.

3.2 Experimental protocol

These turbine passage experiments were carried out under UK Home Office License. Atlantic salmon smolts were sourced from a commercial hatchery and transported by trailer tank to the site. The experiments were executed at two turbine speeds corresponding to operation near to maximum capacity (FAST, 26RPM), and near to the lower limit of generation (SLOW, 8RPM). Prior to the trials, fish were anaesthetized and individually visually assessed for damage, photographed and marked with elastomer to distinguish between treatment and control groups, and release batches. Fish were allowed to recover in a tank supplied with fresh river water for at least 30 minutes. Two experimental groups were used to assess change in condition of fish from passage through the turbine: a turbine treatment group was released directly above the turbine and recaptured below (TREATMENT) and a recapture control group was released directly below the turbine and recaptured as a control for possible change to fish condition resulting from recapture (CONTROL). TREATMENT and CONTROL groups were released simultaneously during daytime in batches totaling 30 to 50. In order to prevent fish from escaping upstream, a fence of 10mm smooth plastic mesh was fitted across the trash rack upstream of the turbine. The turbine outflow basin was entirely enclosed by a fence leading to a recapture box. Fish were recovered from this box or netted from the outflow basin for the remainder of the day and into the night. Recaptured fish were euthanized before the assessment process was repeated.

3.3 Measurement of scale-loss

Scale-loss on each side of the body was assessed *post-hoc* from the photographs taken during the fish assessment. Photos were graded in random order without reference to experimental treatment data, according to the following grading system, and by comparison with reference diagrams designed to be typical of the grade. Grade 1: 0-1%; negligible scale-loss, scattered and isolated across the fish's body; Grade 2: 2-4%; low scale-loss, scattered across the body but with multiple groups of scale-loss several scales across; Grade 3: 5-9%; moderate scale loss, mostly small patches scattered across the body but with at least one larger patch, the height and width of which approximates the width of the wrist of the tail; Grade 4: 10-30%; extensive scale-loss comprising multiple patches, with at least one patch with both dimensions exceeding the width of the wrist of the tail.

Pictures of recaptured fish were then matched with those taken of the same individual before release using batch mark, length, mass, and distinctive identifiers (e.g. opercular spots and distinct fin shapes). Fish that could not be identified and matched in this way were excluded from the analysis.

To test whether treatment had an effect on scale-loss, the numbers of fish with differences in scoring category from before release to after recapture (score-change) was compared between treatment and control groups. In order to detect new scale-loss to either side of the fish, the higher value of score-change from either side was used as the response tested. Score-change was tested at two thresholds of severity: first for any positive change (i.e. a move from any scoring category to a higher one, labelled condition α) and second for any change greater than one scoring category (condition β). To detect overall changes to both sides of the fish, the summed score-changes were tested for any positive change greater than one (i.e. a move from any scoring category to more than one higher, or a move by one on both sides of the fish, labelled condition γ).

Statistical analyses were carried out using R. Fisher's exact test was used for comparisons between treatment and control groups of the frequencies of changes to scale-loss scores between release and recapture. Generalized linear mixed effect logistic regression was used to check for potential influences on scale-loss by other measured covariates which could not be controlled as part of the experimental design. Release batch was included as a random effect, and the fixed effects tested were treatment, turbine speed, fish length, condition factor, method of capture, lag between release and recapture, and average scale-loss score before release. The contribution of fixed effects to the model fit were tested by likelihood ratio tests between the model with and without each covariate, with a significance threshold of $p<0.05$.

4 RESULTS

There were no significant differences between TREATMENT and CONTROL groups in the proportions of fish with any of the three score-change conditions, for the trials as a whole, nor within the FAST and SLOW turbine speed tests (Fisher's exact test, $p>0.1$) (Table 1). Overall, 7.46% of TREATMENT fish had a score-change at condition β (Figure 1), which represents the most severe new scale-loss to one side of a fish, and equates to new scale-loss ranging from 4-30%. Five percent of the CONTROL group was affected at the same condition, leaving an estimated 2.46% of smolts affected due to turbine passage. Of this percentage, 1.49% comprised a minor change of 5-9% scale-loss, with the remaining 0.97% having changed by 9-30%. At condition α, which represents any new scale-loss to one side, 2.8% of treatment fish were affected over and above the control group proportion of 37.5%, (Figure 1). The proportion of control fish affected by condition γ, which accounts for any change to both sides, actually exceeded the treatment estimate of 11.9% by 8.1%.

Condition α was correlated with average score before release (generalized linear mixed logistic regression, estimate = -2.7, $p<0.05$), and lag between release and recapture (generalized linear mixed logistic regression, estimate = 0.335, $p<0.05$). Condition γ was correlated only with the lag between release and recapture (generalized linear mixed logistic regression, estimate = 0.2883, $p<0.05$). It was not computationally possible to determine correlations with covariates by logistic regression for condition β as only 5 out of the 86 fish with all covariates measured had changes in score greater than 1.

Table 1. Results of Fisher's exact tests for differences in frequencies of fish with changes in score between TREATMENT and CONTROL groups, for all the trials and the trials subsetted by turbine speed category. Total sample sizes are given in column N, with TREATMENT group sample size in brackets.

		α: any positive change	γ: summed side changes>1	β: change to either side>1
Group	*N*	*p*	*p*	*p*
ALL	107 (67)	0.84	0.28	0.71
FAST	89 (59)	0.82	0.13	1
SLOW	18 (8)	0.56	0.44	0.44

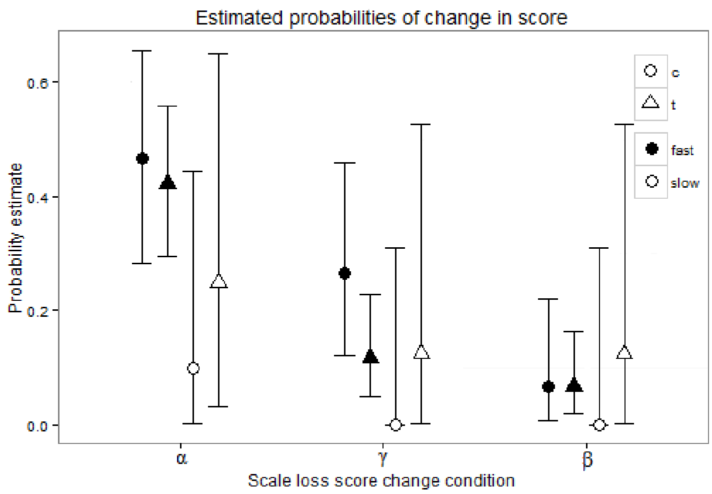

Figure 1. Estimated probabilities of changes in scale-loss scoring category. Solid symbols represent the estimates for the FAST speed. Hollow symbols represent the estimates for the SLOW speed. Circles represent the CONTROL group and triangles represent the TREATMENT group. 95% Confidence intervals for the estimates are derived from a binomial distribution and are shown with black lines. Score-change conditions are: α = any positive change in scale-loss score; γ = any positive change greater than 1, when the scores for each side of the fish are summed; β = any positive change greater than 1 for either side of the fish.

5 DISCUSSION

The comparisons of score-change between TREATMENT and CONTROL groups reveal no significant increase in scale-loss due to turbine passage. This is in agreement with available evidence supporting the perspective of low risk from ASTs to fish. Spah [4] passed a range of species through an AST and found that 4.4% suffered limited and recoverable scale-loss. Merckx and Vries [5] found no damage, again to a range of fish species. In tests with hatchery-reared brown trout (*S. trutta*), Kibel [6] reported scale-loss of under 10% in 3-4% of experimentally passed fish, and found similar rates of 4.4% for naturally migrating Atlantic salmon smolts, almost entirely below the assessed recapture net damage rate of 3%. Bracken & Lucas [7] found a damage rate of 1.5% for downstream migrating larval and juvenile lampreys (*Lampetra sp.)*through an AST. The data from this study provide an estimate of 1.49% prevalence of 5-9% new scale-loss, and a further 0.97% with 10-30% scale-loss beyond the estimated prevalence of new scale-loss to control fish. Thus although the data does not support a treatment effect, it does not rule out the possibility of turbine-induced scale-loss at a low prevalence. Injured fish with extensive scale-loss may have a reduced osmoregulatory ability [8] and decreased performance and survival during smolt migration. The maximum descaling tolerated by smolts in freshwater is in the region of 20-30% [9]. Although the proportions of affected fish appear to be consistently low, the long term significance at a population level remains a question to be resolved.

Change in scale-loss was not significantly affected by turbine speed, but for condition α at the SLOW speed the estimates for TREATMENT and CONTROL were notably lower, and the difference between these estimates was greater. It may be that low severity scale-loss from contact with the recapture system was more prevalent at the higher water velocities during the FAST trials, when velocity in the outflow exceeded $1ms^{-1}$ in the centre of the channel, as compared to around $0.5ms^{-1}$ at the slow speed. Based on average fork length (182 mm), sustained swimming speeds for these fish is expected to be around 0.8 ms^{-1}, and it is conceivable that fish entering the outflow basin would be more likely to come into contact with - and sustain damage from - the recapture system at the fast speed. Score-change conditions were correlated with the lag between release and recapture, which suggests a time-dependent damage effect from the recapture structure.

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