ANALYSIS OF BROOK TROUT SPATIAL BEHAVIOR DURING PASSAGE ATTEMPTS IN CORRUGATED CULVERTS USING NEAR-INFRARED ILLUMINATION VIDEO IMAGERY

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We used video recording and near-infrared illumination to document the spatial behavior of brook trout of various sizes attempting to pass corrugated culverts under different hydraulic conditions. Semi-automated image analysis was used to digitize fish position at high temporal resolution inside the culvert, which allowed calculation of various spatial behavior metrics, including instantaneous ground and swimming speed, path complexity, distance from side walls, velocity preference ratio (mean velocity at fish lateral position/mean cross-sectional velocity) as well as number and duration of stops in forward progression. The presentation summarizes the main results and discusses how they could be used to improve fish passage performance in culverts.

1 INTRODUCTION

In a recently developed field-based predictive model of brook trout passage in natural culverts, Goerig *et al.* [1] showed that for a given nominal mean cross-sectional velocity, probability of success was higher in corrugated pipes than in smooth pipes, particularly among smaller fish. They hypothesized, that ascending fish were able to exploit the larger low velocity areas found along the side-walls and bed undulations of corrugated pipes [2, 3].

This paper presents the preliminary results of a field study aiming at better understanding the behavior of brook trout of various sizes attempting to pass corrugated culverts under different hydraulic conditions. It analyses the flow velocity and water depth preferences of ascending fish as related to their size and to hydraulic conditions as well as their swimming behavior along the entire culvert length in order to identify possible resting periods in low velocity areas.

2 METHODS

A video camera (Gopro HD Hero) was used in a 9 m long x 2,7 m diameter steel culvert with helical corrugations. The camera was mounted in the center of the culvert above the water; field of view covered a zone of 150 x 200 cm. 147 brook trout of 70-190 mm were individually introduced in the culvert centerline, facing upstream, and recorded during 3 min. Five trials were conducted under hydraulic conditions ranging in mean flow velocity from 0,30 to 0,63 m/s and in mean water depth from 0,13 to 0,22 m.

An alternative design was used in a 35 m long x 2,2 m diameter corrugated culvert. This design consisted in 5 light-sensitive near-infrared (λ = 850 nm) illuminated surveillance video cameras (Hikvision DS-2CD2032) spanning the entire length of the pipe (Figure 1). Concurrent use of passive integrated transponder (PIT) antennas distributed along the pipe allowed identification of individual fish recorded on video images (Figure 1).

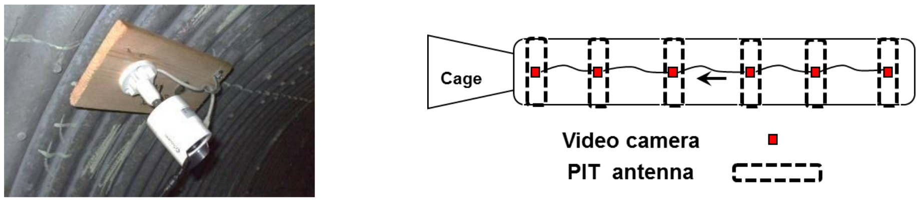

Figure 1. Left: one of the five surveillance video cameras mounted on the ceiling of the culvert and pointed downward. Right: schematic representation of the culvert equipped with the video cameras and PIT antennas (not to scale). Arrow indicates flow direction.

Three trials lasting 50-64 h each were conducted at hydraulic conditions of increasing intensity (mean flow velocity 0,72 - 1,36 m/s). For each trial, 30 trout (Fl 80-170 mm) were PIT-tagged (TIRFID HDX 12 and 23 mm) and released in a cage located at the downstream end of the culvert where the only way to leave the cage was to volitionally make an attempt to ascend the culvert.

For both datasets, semi-automated image analysis (custom program, Matlab 2014a) was used to digitize position of the fish's center of mass every 0,33 seconds. This allowed the calculation of various spatial behavior metrics, including instantaneous ground and swimming speed, ascent path complexity, distance from side walls, as well as number and duration of stops in forward progression. Pixel values were converted into spatial coordinates (x,y, 1 cm grid) using known landmarks in the culverts and a geometric transformation (Matlab 2014a).

Distribution of flow depth and velocity in the culvert were integrated from measured points on a 1 cm grid (Tecplot 360x 2014), in order to obtain a value of flow depth and mean velocity at each x,y coordinate. Mean flow depth and velocity for each trial were calculated by averaging all values of depth and velocity in the culvert.

3 RESULTS

3.1 Velocity and depth preference ratio

At low flow conditions, fish tended to swim against velocities larger than the mean flow velocity and to occupy water depth greater than the mean water depth (Figure 2). However, against the more challenging flow conditions, fish selected velocities lower than the mean flow velocity and shallower than the mean water depth. This was confirmed by the digitized ascent paths showing that fish were swimming near the side-walls where flow was slower and depth shallower.

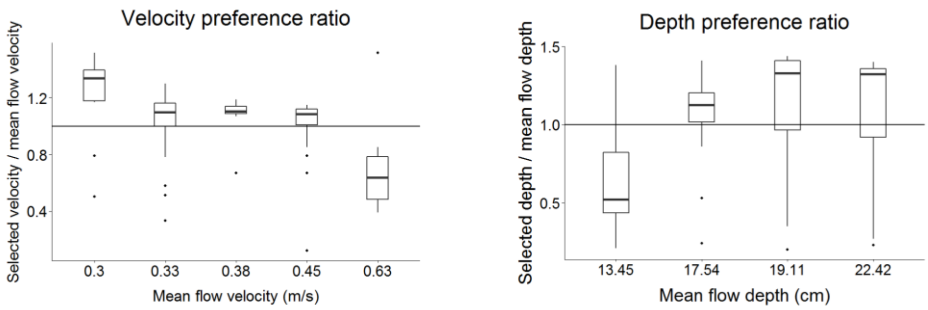

Figure 2. Velocity (left) and depth (right) preference ratios exhibited by trout during the experiment. The preference ratios were obtained by dividing the mean flow velocities and depths selected by the fish during its ascent with the mean velocity and depth in the culvert. In the box-and-whiskers, the notch represents the median, while the upper and lower hinges correspond to the first and third quartiles. The whiskers are computed as 1.5 * the interquartile range (IQR) and the dots represent outliers.

A linear model selection based on AIC minimization (R) showed that fish length had little influence on preference for both depth and velocity ratios, as shown by the Akaike weights (w) (Table 2).

Table 2. Model selection for flow velocity and flow depth preference ratios. Flow velocity is in m s^{-1}, depth is in m and fish length is in mm.

Flow velocity preference ratios				
Model	Parameters	AIC	Δ AIC	w
1	**Flow velocity + Flow Depth**	**4.39**	**0.0**	**0.48**
2	**Flow velocity**	**4.41**	**0.02**	**0.46**
3	Flow velocity +Fish length	6.2	1.81	0.03
4	Flow velocity + Flow depth+Fish length	6.33	1.94	0.03
Flow depth preference ratios				
Model	Parameters	AIC	Δ AIC	w
1	**Flow velocity + Flow Depth**	**62.98**	**0.0**	**0.73**
2	Flow velocity + Flow depth+Fish length	63.67	0.69	0.26
3	Flow velocity + Fish length	66.2	3.22	0.01
4	Flow velocity	66.29	3.31	0.01

3.2 Number and duration of resting periods

Preliminary analysis of the spatial behavior of ascending trout indicates that most fish did not swim continuously throughout the culvert. They rather exhibited frequent periods of no forward progression (Figure 3). During these periods, fish occupied low velocity areas found along the sides and bed of the pipes. Because they were mainly immobile or just maintaining position, we interpret these periods as resting periods where fish spend less energy. Thus, forward progression was made during only a small proportion of the time spent in the culvert.

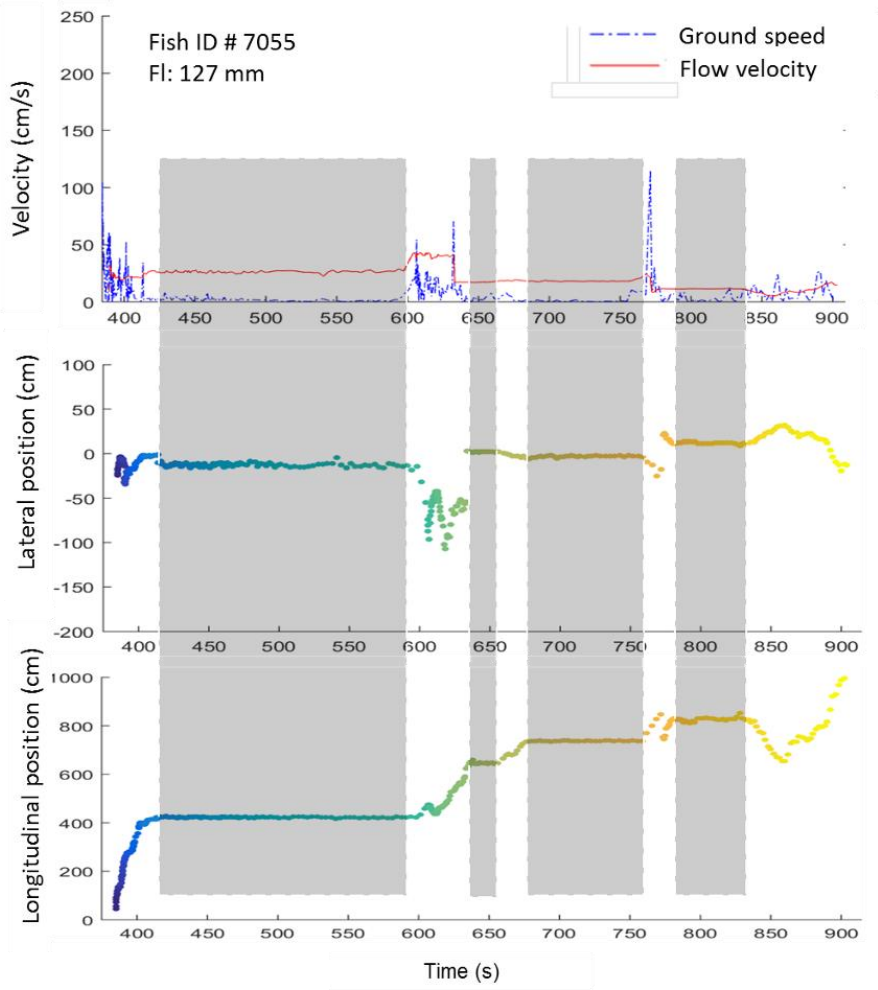

Figure 3. Example of the forward progression, lateral position, and longitudinal position of a trout in relation to the nose flow velocity experienced by the fish while ascending the culvert. Gray portions of the figure correspond to resting periods.

4 DISCUSSION

The results presented in this paper have several potential implications for the prediction of fish passage success. It is common practice for managers to assess passability of culverts based on mean flow velocity. Our study shows that this simple metric introduces bias, and may over- or underestimate what fish actually encounter, depending on the conditions. Indeed, when fish faced low intensity flows, they tended to swim near the center of the culvert where water depth was deeper despite velocities being larger than the mean flow velocity. However, when flow velocity at this location became more challenging, fish moved closer to side-walls, despite shallower depths, because flow velocities were slower at this location.

Second, the results indicate that ascending trout rarely exhibited continuous swimming behavior inside a culvert. Instead, they made episodic forward progressions separated by resting periods alongside walls or in flow separation zones located in the lee of corrugated bed undulations. This result suggests that predictive passage success models based on time-to-fatigue relationships should be adapted to account for this spatial behavior.

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