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Effects of light on the behaviour of brown trout (*Salmo trutta*) encountering accelerating flow: Application to downstream fish passage

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ABSTRACT

Avoidance of abrupt accelerations of flow exhibited by downstream migrating fish at screens used to divert them, or at fishway entrances, can cause delay and adversely impact efficiency. The use of alternative stimuli to attract fish and mask the unwanted deterrent effects associated with velocity gradients is of interest to those working in fish passage engineering. The influence of a continuous light source on the downstream movement of brown trout (*Salmo trutta*) as they encountered accelerating velocities created by a constricted channel in an experimental flume under three discharge regimes was assessed. It was predicted that: (1) in the absence of a light source, behavioural responses typical of downstream moving salmonids would be elicited on encountering velocity gradients, and that these responses would be initiated at some threshold spatial velocity gradient relative to body length and (2) light would act as an attractant and mask the deterrent effects of a velocity gradient and thus reduce delay. Typical avoidance behaviours, e.g. rheotactic switches in orientation or retreating upstream before re-approaching a velocity gradient, were common. The spatial velocity gradient threshold at which a response was initiated when dark was similar (ca. 0.4 cm s^{-1} cm^{-1}) independent of discharge. Fish responded farther upstream at a lower spatial velocity gradient threshold (ca. 0.2 cm s^{-1} cm^{-1}) in the presence of both mechanosensory and visual cues when light. Contrary to the second prediction, downstream movement was further delayed by the addition of a light stimulus. The findings support an alternate hypothesis, that responsiveness (avoidance) can be enhanced when multimodal stimuli are presented.

1. Introduction

Anthropogenic structures that impound streams and rivers (e.g. dams and weirs) can fragment the river continuum, causing population declines and in some instances the local extinction of aquatic biota unable to effectively disperse between habitat patches (Odeh, 1999; Agostinho et al., 2005). Habitat fragmentation is a particular problem for fishes as their life cycle depends on an ability to move (from tens of metres to hundreds of kilometres) to seek refuge, food, and mates (Lucas and Baras, 2001). For upstream moving fish, passage success at anthropogenic barriers provisioned with fish passage facilities is typically determined by the ability to find the entrance and then to ascend them under high velocity, turbulent conditions (Beach, 1984; Bunt, 2001). For fish moving downstream, behaviour rather than swimming performance largely dictates movement trajectories and passage efficiency (Katopodis and Williams, in press; Williams et al., 2012). Understanding the relationship between hydrodynamic and other environmental stimuli encountered at barriers, and the behaviour of downstream moving fish in response to them, is important if efforts to mitigate for reduced habitat connectivity are to be facilitated.

Downstream passage facilities developed to facilitate migration of fish past river infrastructure have been widely employed, often in association with screening systems designed to block access to, and deflect fish away from, turbine and water intakes (Turnpenny et al., 1998; Larinier and Travade, 2002). Bypass passage efficiency, however, can be unacceptably low (e.g. <40% for postspawned American shad (*Alosa sapidissima*), Kynard and O'Leary, 1993; ≤ 50% for silver-phase European eel (*Anguilla anguilla*), brown trout (*Salmo trutta*) smolts and brown trout kelts, Calles et al., in press), and variable depending on site specific characteristics (Whitney et al., 1997; Scruton et al., 2002). The route selected by downstream migrants at river infrastructure can strongly influence survival. For example, fish passing through hydropower turbines on the Columbia River have shown approximately 7% higher rates of mortality compared with fish passing bypass systems (Muir et al., 2001). Furthermore, delay due to avoidance of conditions created at the bypass entrance, e.g. abrupt accelerations of velocity (Haro et al., 1998;

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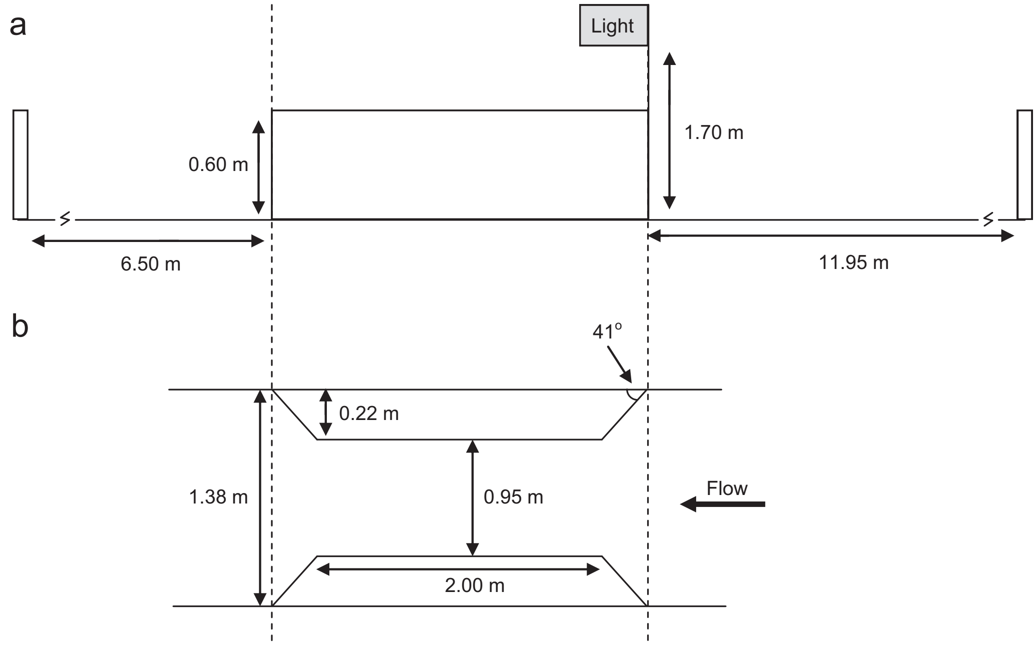

Fig. 1. (a) Schematic profile of the experimental channel at the International Centre for Ecohydraulics Research used to observe the behavioural responses of brown trout as they moved downstream and encountered an accelerating velocity gradient. (b) Plan view of the constricted channel.

Larinier, 1998), can result in high rates of predation (Larinier and Travade, 2002), energetic expense, and may lead to greater probability of passage via alternate routes, e.g. turbines (Castro-Santos and Haro, 2003). Downstream migrant juvenile salmon (smolts) often orient to face the prevailing flow on encountering accelerating velocity gradients, and in some instances swim back upstream to avoid the abrupt near field hydrodynamic transitions (Haro et al., 1998 for Atlantic salmon smolts (*S. salar*); Kemp et al., 2005 for Pacific salmon smolts (*Oncorhynchus* spp.)). Salmonids initiate a flight response (sudden change in swimming trajectory, often with switches in rheotactic orientation) at the same spatial velocity gradient across the body under different discharge regimes (Enders et al., 2009 for Pacific salmon smolts; Russon and Kemp, 2011 for hatchery reared brown trout), indicating that once a threshold value is detected by the fish, an avoidance response is elicited.

Some stimuli may be used as attractants to mitigate for the adverse deterrent effects created at fish passes. Man has attempted to attract fish using lights, either to enhance commercial harvest (e.g. Marchesan et al., 2005), or to protect them, e.g. by drawing fish away from hydropower intakes (Schilt, 2007). When attracted, fish typically become more active (Haymes et al., 1984), form schools, and move towards the light source (Ben-Yami, 1976). Under experimental saltwater conditions, groups of seabream (*Sparus auratus*) form closer aggregations and are more attracted to a halogen light source as intensity is gradually increased (Marchesan et al., 2005). Likewise, under experimental freshwater conditions, Alewife (*A. pseudoharengus*) are attracted to mercury vapour lights, which when deployed near a water abstraction off-take, have successfully attracted Alewife, smelt (*Osmerus mordax*) and juvenile gizzard shad (*Dorosoma cepedianum*) towards a site of collection (Haymes et al., 1984). Artificial lighting is also used as an attractant on many of the Columbia River Dams, USA, in attempt to enhance passage of juvenile salmonids to bypass systems (Mueller and Simmons, 2008). Indeed salmonid smolts have been observed to be attracted towards light under some circumstances (see Nemeth and Anderson, 1992 for dim mercury light), although results have been variable (see Fields, 1957 for experimental conditions; Gessel et al., 1991 for field conditions). As light may provide an attractant to effectively mask the deterrent effects of velocity gradients at bypass entrances and screening facilities, this study investigated whether a light source could be employed to reduce the avoidant effects of a velocity gradient associated with a constricted channel for downstream moving fish. The response of brown trout on encountering accelerating velocities in the presence and absence of a light source was assessed. Two predictions were made: (1) in the absence of the light stimulus, avoidance responses typical of downstream moving salmonids will be elicited on encountering accelerating velocity gradients, these responses will occur at the same (threshold) spatial velocity gradient relative to body length, irrespective of discharge and (2) the light stimulus will act as an attractant and mask the effects of accelerating flow and thus reduce avoidance.

2. Materials and methods

2.1. Experimental flume setup

Experiments were conducted in an indoor flume facility (21.4 m long, 1.37 m wide and 0.6 m deep) at the International Centre for Ecohydraulics Research (ICER), University of Southampton, UK. A 2 m section of the channel was constricted by approximately 30% by installing Perspex inserts (Fig. 1). Discharge was controlled by two centrifugal pumps (individual capacities of 0.15 and 0.23 $m^3\ s^{-1}$). Three discharge treatments created distinct velocity gradients (see below) at the entrance to the constricted channel. Mean water depths 1 m upstream of the constriction were 0.29, 0.34 and 0.40 m for the low, medium and high flows respectively.

Fish behaviour under two conditions of illumination were tested; ambient night (dark), and ambient night with a halogen light source (500 W) positioned directly over the entrance to the constricted channel (light) (Fig. 1) to provide a distinct localised gradient of illumination (Fig. 2). Low light, overhead video cameras and four infra-red lighting units (emitting infrared light at 850 nm) allowed fish movements to be observed at low light levels.