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Effectiveness of horizontally and vertically oriented wedge-wire screens to guide downstream moving juvenile chub (*Squalius cephalus*)

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ABSTRACT

Physical screens are commonly installed to prevent downstream moving fish from entering dangerous areas (e.g. intakes to hydropower turbines, irrigation canals, and fish farms), and divert them to preferred alternative routes (e.g. bypass systems). In northern temperate regions, assessments of the functioning of screens have largely focused on diadromous species (e.g. salmon and eel), while ignoring those with other life history characteristics. Recent developments in physical screens include the usage of horizontally aligned bars as opposed to traditional vertical ones, but a direct comparison in terms of guidance remains untested. To address this and aid in the development of successful screens for the wider fish community, this study compared the efficacy of wedge-wire screens with horizontally and vertically oriented bars to block and divert downstream moving groups of five chub (*Squalius cephalus*) to a bypass channel installed in a recirculating flume under two discharge regimes. Hydrodynamics differed between horizontal and vertical screens under both flows; the vertical configuration created a higher velocity gradient towards the bypass. Total guidance (the number of bypass entries as a percentage of the number of approaches) was generally low (mean = 17.3% for all treatments), the highest being recorded for the horizontal screen under low discharge (25.3%). Rejections and holding station events, both proxies for fish exhibiting avoidance of the hydrodynamic conditions created by the screen, were lowest under this treatment. Horizontal performed better than vertical screens in guiding fish to the bypass under low but not high discharge. The results confirm that screen functioning is dependent on hydrodynamic conditions as well as the fish's behavioural response.

1. Introduction

Widespread engineering of European rivers and high densities of infrastructure (e.g. dams and weirs) reflect a long historic legacy of water resource development and management (Demirbas 2007; Paish 2002). It is estimated that there are more than 55,000 large (> 15 m high) dams present worldwide (I.C.O.L.D., 2017), and over half the large rivers in Europe are affected by them (Nilsson et al., 2005). Many thousands of smaller structures, such as weirs and sluices, further exacerbate the impacts (EA, 2010; Lucas and Baras, 2001), which include the disruption of flow regimes (first order) that alters channel morphology and physical and chemical processes (second order), and leads to ecological shifts (third order), including changes in community composition and species abundance (Kemp, 2016; Petts, 1980). Depending on the type of impounding structure, fish movements can be completely blocked or impeded, while those that enter intakes may be lost (e.g. to irrigation and water supply systems), or risk injury and mortality if they pass through turbines (Kemp, 2016; Larinier and Travade 2002). As longitudinal movements are essential to the completion of their life cycles (Lucas and Baras, 2001), habitat fragmentation as a result of river impoundment threatens the sustainability of many fish populations (Liermann et al., 2012).

Often driven by legislation, environmental impact mitigation technologies are developed to protect fish at impounding river infrastructure (Kemp, 2016). For example, fishways are installed at barriers to fish movements to help fish negotiate them, while physical and mechanical screens are designed to block fish that would otherwise enter intakes (O'Keeffe and Turnpenny, 2005; Taft, 2000) and guide them to safer alternative routes, such as bypass channels (Katopodis and Williams, 2012). However, previously published research tends to focus more on fish passage than on screens, with a few notable exceptions (e.g. Gessel et al., 1991; Skalski et al., 1996 for Pacific

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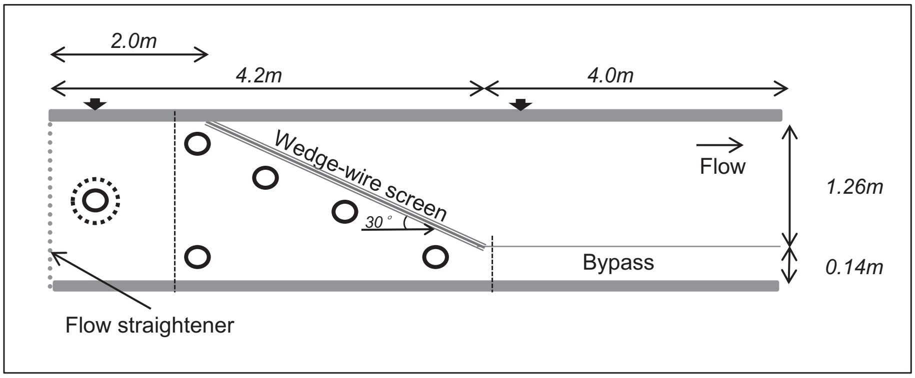

Fig. 1. Plan of the experimental section used to investigate the response of groups of five chub (*Squalius cephalus*) to conditions encountered at a wedge-wire screen oriented either in a horizontal or vertical configuration within a large recirculating flume at the University of Southampton. The wedge-wire screen was placed against the true left side of the flume, leading to the bypass entrance. Closed circles represent positions of overhead cameras. The dashed circle represents the location of fish release. Thick black arrows denote locations of 60 W bright white fluorescent tube lights that were suspended perpendicular above the flume. Fish behaviour was recorded in the observation zone that extended between the dashed lines.

salmonid [*Oncorhynchus* spp.] smolts in North America; Russon et al., 2010; Calles et al., 2013 for eel [*Anguilla anguilla*] in Europe). Furthermore, those studies that evaluate the effectiveness of screens often do so for diadromous species that are of economic and conservation concern (e.g. salmonids and eel), while benefits for the wider fish community are infrequently considered (Williams et al., 2012).

Evaluation of the efficiency of screens to guide fish to bypass channels ('guidance efficiency') yields variable results, reflecting differences in local site-specific characteristics (e.g. hydrodynamics) and variation in behaviour exhibited among species and life-stage. Nevertheless, it is clear that when upstream velocities adjacent to the screen are high relative to swimming capabilities, fish may be injured through excessive mechanical abrasion if they make contact, or suffocate if they become impinged and unable to escape from the screen face (Swanson et al., 1998, 2005; White et al., 2007). For fish that exhibit strong thigmotactic behaviour, such as downstream moving European eel, this is particularly problematic because they tend to show an avoidance response only after contacting the screen (Russon et al., 2010), thus increasing the probability of injury, impingement, and mortality. Several species also exhibit avoidance behaviour to the hydrodynamic conditions created at the bypass entrance, as observed for American shad (*Alosa sapidissima*) (Kynard and Buerkett 1997) and Atlantic salmon (*Salmo salar*) (Larinier and Travade 1999), delaying downstream passage. Improving the functioning of screens requires detailed knowledge of the behaviour of the species under consideration.

To improve the performance of screens there is a need to revisit guidance on their design and operation. Current design criteria focuses primarily on placement of screens and the need to provide a suitably high sweeping flow parallel to the face to enhance fish guidance towards a bypass, while minimising perpendicular escape velocities to reduce probability of impingement (EA, 2009). As a result, it is advised that screens should be placed at an angle of 45° or less to the oncoming flow (Courret and Larinier, 2008; Raynal et al., 2013), while critical escape velocities vary depending on the target species of interest (e.g. $0.25\,m\,s^{-1}$ for coarse fish, EA, 2009). Further, the hydrodynamic conditions adjacent to screens are influenced by a range of factors, including their shape and bar spacing (e.g. Katopodis et al., 2005; Tsikata et al., 2014). It is recommended that at screens and bypass entrances abrupt hydraulic transitions, such as rapid accelerations of velocity and increasing turbulence, should be minimised because these may induce undesirable avoidance behaviour and delay fish passage (Russon and Kemp, 2011; Vowles and Kemp, 2012).

Recently, the influence of bar orientation on screen effectiveness has received attention, as there is some suggestion that horizontal alignment, rather than the traditional vertical configuration, is beneficial because it improves passive "self-cleaning" of debris (Ebel, 2008; Ebel et al., 2015) and enables escape of impinged fish through facilitating movements in the horizontal plane (Horsfield and Turnpenny, 2011). Whilst horizontal screens have currently been installed in Europe, an empirical comparison between bar orientations has not been made in the context of fish guidance.

This study aimed to compare the effectiveness of wedge-wire screens, with bars oriented either horizontally or vertically, to guide downstream moving fish to a bypass entrance. To address the bias towards diadromous species, juvenile chub (*Squalius cephalus*), a potamodromous cyprinid, was selected here as the representative model. They are widely distributed in Europe and an important species for recreational angling. As chub are gregarious, especially during the juvenile stage (Kottelat and Freyhof, 2007), the study used groups of five fish in an effort to induce natural behaviours under the experimental conditions presented. Trials were conducted under two discharge regimes ('High' and 'Low'), creating distinct flow fields at the screen and entrance to the bypass. The objectives of the study were to quantify: (1) the guidance of the screen configurations under different settings; and (2) fish behaviour in response to the hydrodynamic conditions encountered.

2. Materials and methods

2.1. Experimental setup

Experiments were conducted in a large recirculating flume (21.4 m long, 1.4 m wide and 0.6 m deep) at the International Centre for Ecohydraulics Research (ICER), University of Southampton, UK. A centrally located 8.2 m long section was isolated upstream from the rest of the channel by a flow straightener (10 cm wide polycarbonate honeycomb-structured screen) and downstream by a square mesh (0.5 cm × 0.5 cm) panel, both of which prevented fish from escaping the experimental area (Fig. 1). The flume was illuminated with fluorescent lighting installed 2.5 m above the channel floor. Five cameras mounted 1.6 m above the floor recorded fish movements in an observation zone that spanned from 50 cm upstream of the screen to the bypass entrance (Fig. 1). Black screens were installed on both sides of the flume to prevent visual disturbance to the fish.

Under treatment conditions a 2.5 m long wedge-wire screen was placed, perpendicular to the channel floor, at an angle of 30° to the oncoming flow and spanned a distance of 2.0–4.2 m downstream of the flow straightener between the flume wall and bypass entrance (Figs. 1 and 2). The screen consisted of five 50 cm × 50 cm stainless steel wedge-wire panels (3 mm bar width and 6 mm bar spacing) which were rotated to alternate between a horizontal and vertical alignment. The width of the bypass was 10% of that of the flume channel and was longitudinally separated by a Perspex screen (4 m long, 50 cm high and 1 cm thick).

Trials were conducted under two discharge regimes, defined as low ($L = 0.09\,m^3\,s^{-1}$) and high ($H = 0.15\,m^3\,s^{-1}$), controlled by adjusting the centrifugal pumps and an overshot weir at the downstream end of the flume. Discharge levels are lower than the natural environment in which chub occurs, which includes streams and rivers with discharge up to $50\,m^3\,s^{-1}$ (Kottelat and Freyhof, 2007). Chosen discharge levels