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Effects of water velocity, turbulence and obstacle length on the swimming capabilities of adult Pacific lamprey

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Abstract The swimming capabilities of adult Pacific lamprey, *Entosphenus tridentatus* Gairdner, were tested in an experimental vertical-slot fishway in response to three different fishway features: water velocity (1.2, 1.8 and 2.4 m s^{-1}), the length of the vertical slot (0.33, 0.66, 1.00 m) and during the presence/absence of a turbulence-intensifying structure that increased turbulence for each respective treatment. Passage success was lowest (52.7%) and attachment rates were highest (92.9%) during the most difficult passage conditions (high velocity, high turbulence, long slot length). Passage success was >83% for all other treatment combinations. Although passage of the vertical-slot weir was not associated with fish body size, Pacific lamprey with larger dorsal distances (distance between the two dorsal fins) were more likely to pass the vertical-slot weir. Increased attachment rates and longer attachment times during strenuous passage conditions suggest that endurance capacity may be an important factor limiting the passage of Pacific lamprey at fishway obstacles.

KEYWORDS: Columbia River, fish passage, lamprey, turbulence, velocity.

Introduction

River systems worldwide have been altered by the construction of anthropogenic barriers. One of the most frequently cited concerns for the construction of barriers is the obstruction of river corridors for migratory fish species, for which the primary solution has been the development of fish passage systems (Clay 1995; Bunt *et al.* 2012; Noonan *et al.* 2012). Providing adequate passage conditions at barriers can be challenging, particularly when accommodating morphological and behavioural diversity. Morphological differences among species are particularly important to passage design because morphology affects elements of swim speed, endurance and fatigue (Beamish 1978; Haro *et al.* 2004; Katopodis & Gervais 2012). Swimming capacities can also be positively correlated with body size (Beamish 1974; Rodríguez *et al.* 2006), and some evidence suggests that large barriers act as size-selective filters against smaller individuals (Agostinho *et al.* 2007; Keefer *et al.* 2009a). Understanding how different fish species respond to their hydraulic environment has thus been critical for predicting fish behaviour in altered flow environments (Liao 2007).

The historical design of upstream fish passage systems gave primary consideration to economically and socially valuable fishes such as salmonid species (*Oncorhynchus* spp. and *Salmo* spp). Many salmonid-specific fishways were built with slopes of ~10% and created a flow environment composed of high velocities (frequently >2 m s^{-1}) and turbulent conditions that matched the strong burst swimming capabilities observed for these taxa (Clay 1995; Castro-Santos *et al.* 2013). By contrast, the development of passage criteria for non-target species was not considered due to socio-economic values of the era and a lack of information on the swimming capabilities of these species (Katopodis & Williams 2012). Unfortunately, developing passage criteria for single taxa

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