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NOTE

# Fishway Bottleneck Relief Models: a Case Study using Radio-Tagged Pacific Lampreys

**Matthew L. Keefer** and Christopher C. Caudill**
*Department of Fish and Wildlife Sciences, College of Natural Resources, University of Idaho, 275 Perimeter Drive, Moscow, Idaho 83844-1136, USA*

**Mary L. Moser**
*National Oceanic and Atmospheric Administration Fisheries, Northwest Fisheries Science Center, 2725 Montlake Boulevard, Seattle, Washington 98112, USA*



***Abstract***
**Structural or operational changes to fishways can improve fish passage efficiency, but there is often uncertainty regarding which improvements will be most effective. We developed a "bottleneck relief" model using Kaplan–Meier methods to help managers assess where remediation efforts are likely to provide the largest increases in fishway passage. The simulation model uses a matrix of observed efficiency estimates from fishway subsections and incorporates multiple passage attempts by individual tagged fish. In a case study application to test the model, we used radiotelemetry data from 2,170 adult Pacific Lampreys *Entosphenus tridentatus* at Bonneville Dam (Columbia River, Washington–Oregon), which features multiple fishways and low lamprey passage success (mean fishway passage efficiency ~0.50; $n = 10$ years). The model was run iteratively to test potential dam passage benefits from improving efficiency in 20 individual fishway segments. The highest benefits were for improvements at top-of-fishway segments and at sites where passage routes converged. Benefits were lower for segments used by fewer fish, segments located downstream from serious bottlenecks, and segments with a limited scope for improvement (i.e., efficiency was already high). The model provides a flexible and objective method for assessing complex fish passage problems and informing remediation decision making.**

Providing effective fish passage is a central challenge for managers in regulated rivers worldwide, but many existing passage systems present partial or complete barriers to a range of migratory and resident species (Roscoe and Hinch 2010; Bunt et al. 2012; Noonan et al. 2012). Poor passage performance generally stems from mismatches between fish biology (i.e., morphology, behavior, swimming ability, and sensory physiology) and the structural, hydraulic, or operational features of passage systems (e.g., Rodríguez et al. 2006; Castro-Santos et al. 2009; Starrs et al. 2011). The recent surge in fish passage evaluations has been driven by population declines (e.g., Caudill et al. 2007; Thiem et al. 2011; Keefer et al. 2013a) and increasing awareness of the ecological importance of riverine connectivity (Ward and Stanford 1995; Nilsson et al. 2005; Cooke et al. 2012).

Fish passage studies have become more informative and quantitative through technological advances in fish monitoring techniques (e.g., Gibbons and Andrews 2004; Adams et al. 2012) and the availability of better mechanistic data on the relationships among water velocity, turbulence, structures, and species-specific traits (Haro et al. 2004; Castro-Santos 2005; Santos et al. 2012). Despite these advances, identifying the locations and causes of fish passage failure can be difficult and data intensive. In studies using tagged fish, for example, confidently associating passage failure with specific structures or operations depends on the spatial arrangement of monitoring sites plus information on the mechanism(s) affecting behavior. Such data challenges can be daunting at sites with large or complex fish passage structures (e.g., Gowans et al. 2003; Johnson et al. 2012), diverse fish assemblages (Agostinho et al. 2007; Mallen-Cooper and Brand 2007; Baumgartner et al. 2012), or large operational or environmental fluctuations.

After problem sites have been identified, managers are often confronted with the additional challenge of how to prioritize remediation efforts so that the optimal benefits are achieved (O'Hanley and Tomberlin 2005). This typically

*Corresponding author: mkeefer@uidaho.edu
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