Near-term fish movement prediction in rivers and reservoirs: 25 years supporting federal and nonfederal water operations and engineering design projects

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Abstract

Predicting an individual with volitional control of its own movement is exceptionally challenging in static environments and all the more challenging when the environment itself is also changing. Nonetheless, federal and nonfederal entities frequently confront scenarios where the successful outcome of a management action or engineering design depends largely on the decisions that animals make. In rivers, fish often must be managed with care where one cannot simply exclude, or repulse, them from undesirable locations; volitional guidance is commonly needed. Guiding an individual under its own will to a specific location within a river or reservoir (e.g., hydropower dam forebay) is challenging and knowing in advance the likely outcome is even more so. The emerging field of cognitive movement ecology pursues techniques and tools for understanding past and predicting future animal movement decisions. While terrestrial, avian, and aquatic applications share a lot in common, rivers are a unique environment in which to interpret animal movement. Animals in rivers such as fish move within a media that itself is moving. Research into fish movement behavior dates back more than a century. For the past 25 years, the U.S. Army Corps of Engineers, Research and Development Center (ERDC), has been working on a management tool that can hindcast and predict near-term future fish response to infrastructure designs and management actions. The model, a Eulerian-Lagrangian-agent Method (ELAM), has had some unique successes in the field of animal prediction, accurately predicting near-future, out-of-sample fish movement and passage/entrainment at infrastructure.

Broadly, the ELAM is an approach for analyzing and predicting the movement and spatial distribution patterns of individual animals responding to environmental conditions. Using environmental information available from 3-D or 2-D hydrodynamic and/or water quality models, the ELAM approach allows biologists, engineers, scientists and managers to explore observed animal movement patterns in a way that provides a mechanistic biological explanation (hypothesis) of the patterns, which can be further studied (e.g., validated) with experimental means. The ELAM provides a systematic, tractable means for forecasting the movement behavior response of a population, composed of individuals, to alternative water operations and engineering design strategies.

In the 20 years that the ELAM has been operational, the model has influenced tens of millions of dollars' worth of infrastructure design, saving taxpayers millions of dollars in some instances where design flaws were discovered in the early stages of project planning. Near-term ecological forecasting focuses on meeting the needs of daily to decadal environmental decision-making under high uncertainty and adaptive management by rapidly testing hypotheses through comparison of quantitative predictions to new observational data under different scenarios, one

of the strongest tests of scientific theory (Dietze et al. 2018). The ELAM was originally designed and applied for near-term fish prediction in water operations and infrastructure design at Lower Granite Dam on the Snake River in Washington state (Goodwin 2004), then applied to both federal and nonfederal dams (Goodwin et al. 2007; Goodwin et al. 2005; Goodwin et al. 2006; Politano et al. 2013; Weber et al. 2006), and then lastly basin-wide (Goodwin et al. 2014).

There are multiple areas of continuing work. One area is understanding, mathematically, why the model performs well in some applications and not so well in others. Another area where the ELAM has been extended is in tidal settings (Goodwin et al. in revision). Developments suggest the potential exists to realize a single calibration, or nearly so, for describing juvenile Pacific salmon at numerous sites along the U.S. west coast, from dam forebay to tidal river settings. Emerging theoretical work suggests the potential exists also to invert the behavior rules for describing downstream migrants in order to reproduce the patterns of upstream-moving fishes; these research findings are entering the documentation phase. Recent ELAM research also includes predicting fish response to nonphysical barriers such as bubbles. Lastly, steps are underway to realize real-time fish prediction with *in situ* sensing.

The past 10 years has included spinning-up new users, including the German Government and researchers in the United Kingdom, Canada, and Greece. While fish movement depends on the species, work unifying past data into a common framework – and advanced by a growing user community – facilitates value-added benefits to existing data, the ability to understand fish behavior more quickly, and the ability to better incorporate animal behavior into the fast-paced nature of water operations and engineering design projects.

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