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Habitat mosaics and path analysis can improve biological conservation of aquatic biodiversity in ecosystems with low-head dams

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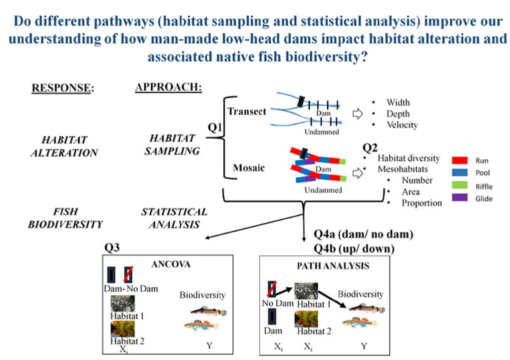
HIGHLIGHTS

- Low-head dams are ubiquitous impacts that represent a challenge for environmental management worldwide.
- Our research quantifies how low-head dams affect habitat and biodiversity in lotic ecosystems.
- Continuous sampling of habitat mosaics revealed new insights into stream fish-habitat relationships.
- Both direct and mediated effects of habitat on biodiversity should be considered when outlining management strategies.
- Here, we provide science-based guidance for environmental practitioners who must manage aquatic systems with dams.

GRAPHICAL ABSTRACT



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ABSTRACT

Conserving native biodiversity depends on restoring functional habitats in the face of human-induced disturbances. Low-head dams are a ubiquitous human impact that degrades aquatic ecosystems worldwide. To improve our understanding of how low-head dams impact habitat and associated biodiversity, our research examined complex interactions among three spheres of the total environment. i.e., how low-head dams (*anthroposphere*) affect aquatic habitat (*hydrosphere*), and native biodiversity (*biosphere*) in streams and rivers. Creation of lake-like habitats upstream of low-head dams is a well-documented major impact of dams. Alterations downstream of low head dams also have important consequences, but these downstream dam effects are more challenging to detect. In a multidisciplinary field study at five dammed and five undammed sites within the Neosho River basin, KS, we tested hypotheses about two types of habitat sampling (transect and mosaic) and two types of statistical analyses (analysis of covariance and path analysis). We used fish as our example of biodiversity alteration. Our research provided three insights that can aid environmental professionals who seek to conserve and restore fish biodiversity in aquatic ecosystems threatened by human modifications. First, a mosaic approach identified habitat alterations below low-head dams (e.g. increased proportion of riffles) that were not detected using the more commonly-used transect sampling approach. Second, the habitat mosaic approach illustrated how low-head dams reduced natural variation in stream habitat. Third, path analysis, a statistical approach that tests indirect effects, showed how dams, habitat, and fish biodiversity interact. Specifically, path analysis

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revealed that low-head dams increased the proportion of riffle habitat below dams, and, as a result, indirectly increased fish species richness. Furthermore, the pool habitat that was created above low-head dams dramatically decreased fish species richness. As we show here, mosaic habitat sampling and path analysis can help conservation practitioners improve science-based management plans for disturbed aquatic systems worldwide.

1. Introduction

Managing the adverse impacts of low-head dams on aquatic biodiversity is an urgent but complex biological conservation challenge that requires combining insights from the hydrosphere, biosphere, and anthroposphere (Cooper et al., 2017). Low-head dams (<4 m in height) are ubiquitous worldwide with as many as 2 million of these small barriers fragmenting river ecosystems in the U.S. alone (Graf, 1993). In spite of the widespread distribution of these disturbances, the ecological effects of low-head dams on riverine ecosystems remain poorly understood (Benstead et al., 1999; Poff and Hart, 2002; Fencl et al., 2015). Creation of upstream, lake-like reservoir habitats and the consequent reduction of native biodiversity are well-documented hydrological and biological impacts of low-head dams (Ward and Stanford, 1979; Watters, 1996; Santucci et al., 2005; Fencl et al., 2017). However, changes in habitat and biota downstream of low-head dams can also have important impacts on natural communities and ecosystems. These downstream dam effects are often more challenging to detect (e.g., Fencl et al., 2017). Here we evaluate how man-made low-head dams impact habitat and associated native biodiversity (Fig. 1) by comparing two approaches to quantifying habitat (mosaic and transect) and two statistical analyses [analysis of covariance (ANCOVA) and path analysis]. Additional tools for detecting low-head dam impacts on habitat and biodiversity will help conservation efforts of state and federal environmental agencies that seek to monitor, manage, repair, or prioritize the removal of low-head dams (Bellmore et al., 2016; Tullos et al., 2016).

Environmental professionals increasingly seek to understand and manage the effects of low-head dams (Gillette et al., 2005; Santucci et al., 2005; Slawski et al., 2008). Low-head dams have been shown to directly impact lotic ecosystems by fragmenting stream corridors (Dodd et al., 2003; Chick et al., 2006), altering the natural flow regime (Poff et al., 1997; Csiki and Rhoads, 2010; Yan et al., 2013) or blocking the dispersal of aquatic organisms (Benstead et al., 1999; Helfrich et al., 1999; Rahel, 2007). As climate change continues to degrade lotic systems (Beatty et al., 2017), dam repair and removal will be implemented globally to restore connectivity and improve fluvial health (Tonra et al., 2015). Since most dams are relatively small structures (Bellmore et al., 2016), evaluation of low-head dam impacts, as we provide here, is critical to the success of dam repair and removal efforts (Poff and Hart, 2002). A focus on habitat and landscape metrics to understand dam effects on biodiversity is essential for effective watershed management (Cheng et al., 2016).

A transect approach assesses habitat conditions at regular intervals (e.g., transects or other repeated data collection units) over a spatially extensive area (Platts et al., 1983; Fitzpatrick et al., 1998; Hauer and Lamberti, 2007). This commonly used approach to habitat sampling measures point-specific environmental characteristics (e.g., width, depth, velocity, and substrate) at systematically-placed sampling points along the stream channel (Simonson et al., 1994; Fitzpatrick et al., 1998). For example, transects can be spaced two-three times the mean stream width (Krause et al., 2013) for an extent of 13–20 transects (Simonson et al., 1994) or up to 35 stream widths (Lyons, 1992). Transects have also been used within specific habitat units (Tiemann

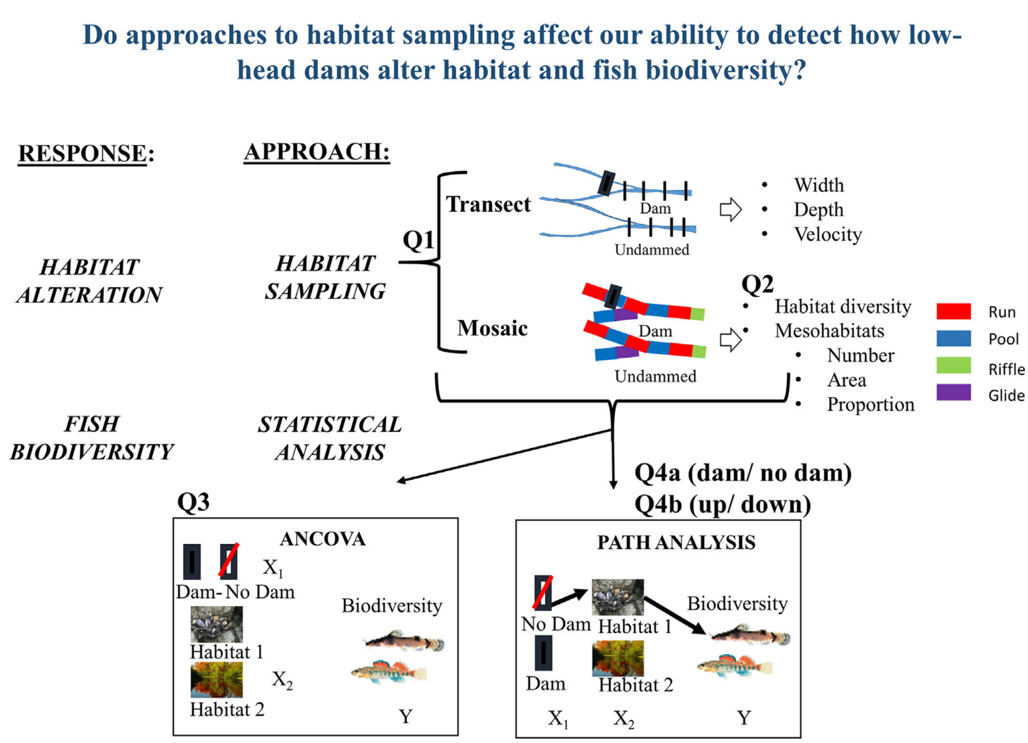

Fig. 1. Conceptual diagram illustrating how our research tests alternate approaches to habitat sampling and statistical analyses, which can alter stream habitat and fish biodiversity. Our four specific research questions are indicated.