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Reductions in fish-community contamination following lowhead dam removal linked more to shifts in food-web structure than sediment pollution☆

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Recent increases in dam removals have prompted research on ecological and geomorphic river responses, yet contaminant dynamics following dam removals are poorly understood. We investigated changes in sediment concentrations and fish-community body burdens of mercury (Hg), selenium (Se), polychlorinated biphenyls (PCB), and chlorinated pesticides before and after two lowhead dam removals in the Scioto and Olentangy Rivers (Columbus, Ohio). These changes were then related to documented shifts in fish food-web structure. Seven study reaches were surveyed from 2011 to 2015, including controls, upstream and downstream of the previous dams, and upstream restored vs. unrestored. For most contaminants, fish-community body burdens declined following dam removal and converged across study reaches by the last year of the study in both rivers. Aldrin and dieldrin body burdens in the Olentangy River declined more rapidly in the upstream-restored vs. the upstream-unrestored reach, but were indistinguishable by year three post dam removal. No upstream-downstream differences were observed in body burdens in the Olentangy River, but aldrin and dieldrin body burdens were 138 and 148% higher, respectively, in downstream reaches than in upstream reaches of the Scioto River following dam removal. The strongest relationships between trophic position and body burdens were observed with PCBs and Se in the Scioto River, and with dieldrin in the Olentangy River. Food-chain length – a key measure of trophic structure – was only weakly related to aldrin body burdens, and unrelated to other contaminants. Overall, we demonstrate that lowhead dam removal may effectively reduce ecosystem contamination, largely via shifts in fish food-web dynamics versus sediment contaminant concentrations. This study presents some of the first findings documenting ecosystem contamination following dam removal and will be useful in informing future dam removals.

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1. Introduction

Dams serve many functions including provisioning hydropower, storing water, controlling floods, and providing recreational opportunities (Born et al., 1998; Graf, 1999). Lowhead, run of river dams (<7.6 m in height), are prolific in the United States (>43,000; US Army Corp of Engineers, 2013). Removal of these dams is growing in popularity, as many have become obsolete, expensive to maintain, or dysfunctional (Bednarek, 2001; Doyle et al., 2005; Harris and Evans, 2014). To date, >1000 dams have been removed in the United States alone (O'Connor et al., 2015). The ecological and geomorphic effects of large dams on rivers are well documented (Freedman et al., 2014; Poff et al., 2007; Pringle et al., 2000); increasing attention has also recently been afforded to lowhead dams (Csiki and Rhoads, 2014; Fencl et al., 2015; Mbaka and Mwaniki, 2015). Studies suggest that fish communities, in particular, experience significant shifts in diversity, community structure, and food-web architecture following lowhead-dam removal (Dorobek et al., 2015; Dorobek, 2016; Kornis et al., 2015).

Prior to dam removal, reservoirs created by impoundments behind dams have been shown to alter pH, streamflow, sediment load, and temperature (Fairchild and Velinsky, 2006; Poff and Hart, 2002; Santucci et al., 2005). As streamflow velocity, discharge, and boundary shear stress decrease behind the dam, fine suspended sediments settle out of the water column, along with contaminants

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that readily bind to sediments and the organic compounds they contain (An et al., 2016; Green et al., 2016; Syvitski et al., 2005), potentially leading to elevated contaminant levels behind dams (Gao et al., 1998; Warren et al., 2003). Contaminants of particular concern include chlorinated pesticides, polychlorinated biphenyls (PCBs), mercury (Hg), and selenium (Se). Although some of these contaminants – such as chlorinated pesticides (e.g., DDT) and PCBs – have not seen widespread use since the 1970's, they can persist in aquatic sediments (Evans and Gottgens 2007; Hinck et al., 2008; Johnson et al., 2013) by binding to benthic organic material (Warren et al., 2003).

The potential for dam removal to release contaminated sediments is a major ecological concern (Bednarek, 2001; Green et al., 2016). In the case of large dams, removal has resulted in up to 70% of the former reservoir sediment transported downstream in the initial years (Grant and Lewis, 2015; O'Connor et al., 2015; Sawaske and Freyberg, 2012), potentially transporting contaminants downstream as well (Shuman, 1995; Stanley and Doyle, 2003). As sediments are resuspended during downstream transport, contaminants may remobilize and become bioavailable to fish and other aquatic organisms. Generally, higher localized contaminant concentrations lead to elevated fish-community contaminant burdens (Madenjian et al., 2009; Odhiambo et al., 2013). However, few examples of changes in contaminant burdens in fish communities exist with regards to dam removal, in spite of documented or predicted changes in sediment dynamics (Hart et al., 2002; Poff and Hart, 2002; Stanley and Doyle, 2003).

Legacy contaminants can biomagnify (i.e., the multiplicative increase in contaminant body burdens up the food chain (Miranda et al., 2008)); and remain stored in fatty tissues of fish (Borga et al., 2012). Thus, contaminant body burdens in fish are commonly associated with fish food-web properties (Bentzen et al., 1996; Rasmussen et al., 1990). Trophic position, and in particular, food-chain length (FCL) – the maximum number of energetic transfers in a food chain – can be strongly related to biomagnification in fish, whereby individuals feeding at higher trophic positions exhibit greater contaminant body burdens than those feeding at lower trophic positions (Houde et al., 2008; Schmitt et al., 2011; van der Velden et al., 2013). Of fundamental importance to the biomagnification process, FCL can be altered by the insertion or deletion of consumers feeding at distinct trophic levels (Post et al., 2000; Sabo et al., 2010), thereby creating or removing trophic steps. Hoeinghaus et al. (2008) found that FCL varied by habitat type, with impounded river reaches having the longest food chains, which they attributed to the insertion of trophic interactions occurring below top predators. Conversely, Kautza and Sullivan (2016) observed that FCL in impounded reaches of the Scioto River system was shorter ($\bar{x} = 3.88$) than free flowing reaches ($\bar{x} = 4.19$), owing to the exclusion of top predators at the impounded sites.

Here, we measured concentrations of a suite of common environmental contaminants in sediment and fish communities before, as well as multiple years following the removal of two dams in two rivers of Columbus, Ohio. Previous research in this system has shown strong fish-community and food-web responses to the presence and subsequent removal of dams (see Dorobek, 2016; Dorobek et al., 2015 for details), along with downstream transport of fine sediment, suggesting that contaminant body burdens in fish following dam removal would reflect both changes in contaminant availability due to sediment release, as well as the shifting trophic composition of the fish community.

Within this context, we hypothesized that changes in fish-community body burdens would be related to changes in contaminant concentrations in sediment, as well as fish trophic positions through time and space. Specifically, we predicted that: (1) Contaminant concentrations in sediment would be a function of sediment grain size, organic carbon content, and streamflow velocity (which is related to flow dynamics such as boundary shear stress that influence sediment size) (Jones and de Voogt, 1999; Miller and Orbock Miller, 2007; Selin, 2009; Warren et al., 2003; Zhao et al., 2010); (2) Fish contaminant body burdens would be positively correlated with trophic position, but this relationship would be stronger before dam removal and at upstream, reservoir reaches, where greater sediment concentrations of sequestered contaminants and more predatory fish species were found; (3) Contaminant body burdens in fish would decrease in reaches where there was a loss of large predatory fish occupying high trophic levels (Dorobek, 2016); and (4) In general, contaminant body burdens in fish would be the most invariant in downstream reaches through time following dam removal, where anticipated shifts in sediment contaminant concentrations (Ashley et al., 2006; Cantwell et al., 2014) and changes in the trophic composition of fish would be minimal (Dorobek, 2016). We anticipate these findings will help inform future dam removal efforts relative to their potential impacts on contamination of resident fish communities and drivers of contaminant transfer.

2. Methods

2.1. Study reaches and experimental design

Seven, 500-m river reaches were surveyed in the Olentangy and Scioto Rivers (Fig. 1) in Columbus, Ohio using a modified Before-After-Control-Impact design (Kibler et al., 2011a; Stewart-Oaten et al., 1986). The Olentangy River is a 150-km, 5th-order tributary of the 370-km, 6th-order Scioto River, in the Ohio River basin. Study reaches were located upstream and downstream of two channel-spanning dams: the 5th Avenue Dam (2.5 m high) in the Olentangy River and the Main Street Dam (4.1 m high) in the Scioto River. The 5th Avenue Dam was removed during low-flow conditions in late summer of 2012. Approximately 1600 m^3 of sediment was removed from behind the dam and was used for the construction of riparian and wetland habitat surrounding the newly designed river channel (DLZ, 2015). The Main Street Dam was removed in November 2013. Prior to removal of the Main Street Dam, the Ohio EPA conducted an analysis of metals, pesticides, and PCBs within the sediment and found that only arsenic exceeded Residential Criteria values (Ohio EPA, 2011).

Study reaches from both rivers were assigned to various treatments (e.g., upstream/downstream, upstream restored/unrestored, before/after) to assess the impacts of dam removal and subsequent restoration efforts on contaminant body burdens in fish communities. Control reaches were designated “upstream control” and “downstream control” and represent both impounded (OR1) and free-flowing (SR3) reaches. The upstream control reach (OR1, Fig. 1) is behind an intact dam of comparable size and age to the removed 5th Avenue dam; the downstream control reach (SR3, Fig. 1) is also separated from other upstream reaches by an intact lowhead dam. All other reaches were designated as “experimental”. In the Olentangy River, a 2.6-km section of the river immediately upstream of the previous dam was restored from August 2013 through winter 2014, and included channel engineering (using heavy machinery) to create heterogeneous in-stream habitat (e.g., pools and riffles), developing and reconnecting floodplain wetlands, and planting riparian vegetation (Ohio EPA, 2011). Further upstream was left unmodified. We surveyed one upstream reach in the restored section (OR3, upstream restored; Fig. 1) and one upstream reach in the unmodified section (OR2, upstream unrestored; Fig. 1). Study reaches in the Scioto River were located upstream and downstream of the Main St. Dam in downtown Columbus. Channel restoration

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