Final Report: Influence of Dam Removal on Aquatic Ecosystem Contamination

Investigator: Dr. Mažeika Sullivan

Institution: The Ohio State University

Agreement: 6559

Project Period: December 1, 2013 through January 31, 2019

Project Amount: $167,455

Objective:

The overarching goal of this study was to investigate the fate and transport of contaminants in surface water, sediments, and aquatic food webs following dam removal. To accomplish this, the following objectives were addressed: (1) Characterize biotic communities (aquatic insects and fish) and quantify contaminant levels of PCBs and heavy metals (As, Cd, Hg, Pb, Se, and Tl) found in river sediments and fish before and after dam removal, both upstream and downstream. (2) Evaluate potential mechanisms, and address potential risk to wildlife and humans; assess potential for biomonitoring of ecosystem health following dam removal.

Project Description:

Widespread accumulation of contaminants in sediment of aquatic ecosystems has been known to be occurring for decades throughout the United States. Impoundments on aquatic ecosystems decrease streamflow velocity, causing sediment and sediment-bound contaminants to settle out of the water column, leading to an accumulation of sediments and contaminants behind impoundments. As the number of dams being removed throughout the United States increases, there is growing concern regarding the ecological consequences of contaminant and sediment release following dam removal. This project aims to examine the biotic and abiotic responses of stream ecosystems to dam removal along the Olentangy and Scioto Rivers following the removal of the 5th Avenue Dam (2012) and the Main Street Dam (2013) in Columbus, Ohio. Data collection was conducted from 2011 (pre-dam removal) through summer 2018. Study reaches (500 m each) were located upstream and downstream of the removed dams, as well as at control sites located upstream and downstream of intact lowhead dams (Fig. 1). The Olentangy River is a 150-km, 5th-order tributary of the 370-km, 6th-order Scioto River, in the Ohio River basin. Data collection included fluvial geomorphic variables (bathymetry and sedimentation), biological surveys (including fish, aquatic insects, and vegetation), and measures of chemical water quality and nutrients. Detailed methods can be found in Dorobek et al. (2015), Sullivan and Manning (2017), Davis et al. (2017), and Cook and Sullivan (2018). Results from this study will contribute to the emerging science of dam removal and will aid in informing future land management and stream restoration practices in Ohio and beyond.

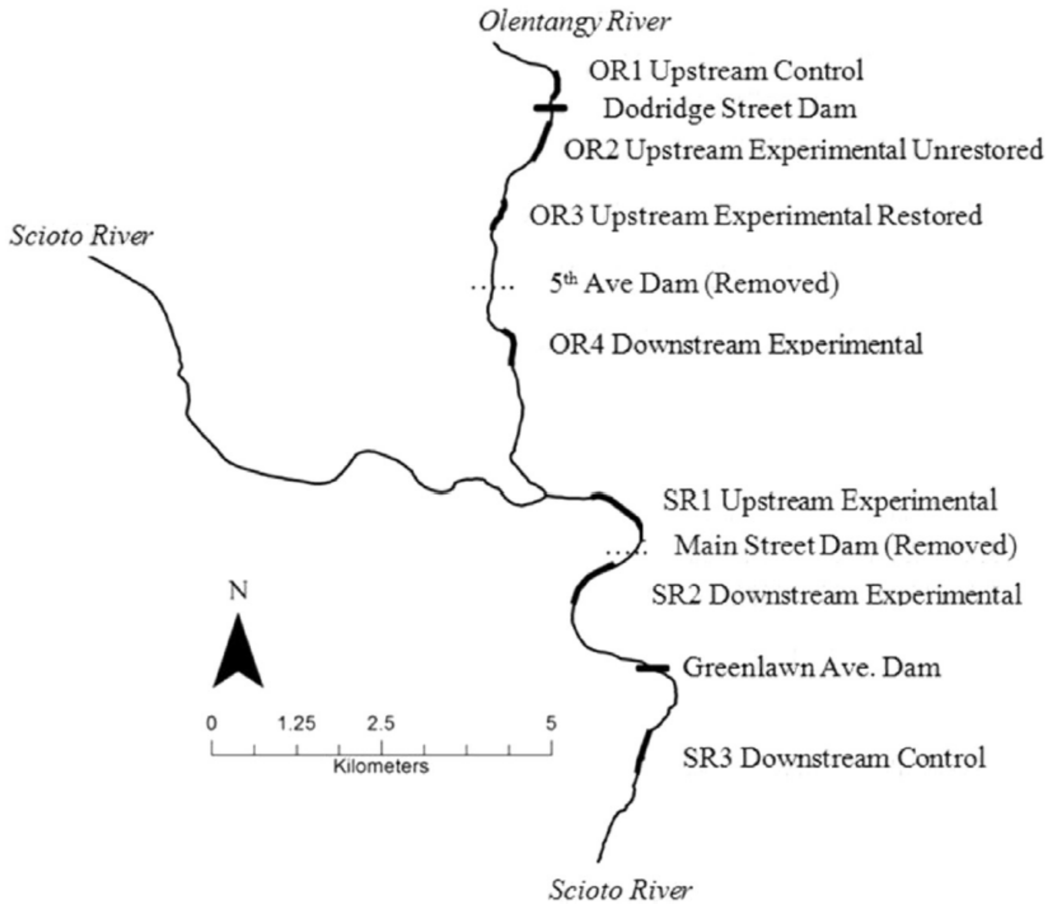

Figure 1. Study reaches on the Olentangy and Scioto Rivers in Columbus, Ohio. Reaches in the Olentangy River were located upstream and downstream of the 5th Avenue Dam, which was removed in August of 2012. Reaches in the Scioto River were located upstream and downstream of the Main Street Dam, which was removed in November 2013. From Davis et al. 2017.

Summary of Results:

Objective 1: Quantify contaminant levels

Contaminant detection rates and concentration levels were assessed in river sediment and fish tissue at multiple locations along the Olentangy and Scioto Rivers (Table 1). Mercury was the only detectable heavy metal found in river sediment, whereas fish tissue was found to have detectable levels of manganese, iron, cobalt, cooper, zinc, arsenic, selenium, molybdenum, mercury, and lead. River sediment mercury concentrations were not significantly different before or after dam removal (Fig. 2). Mercury detection in fish were low (~20 %) and were not significantly different before or after dam removal.

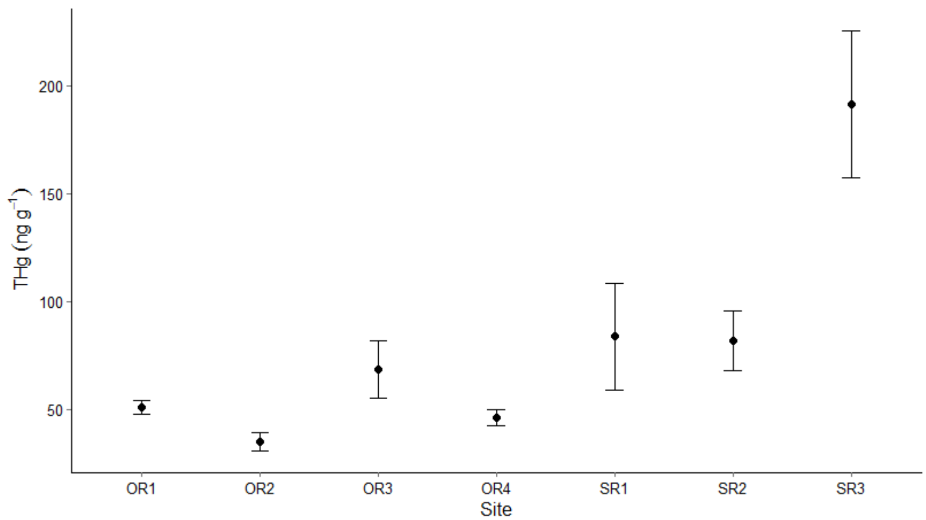

Figure 2. Total mercury (THg) concentrations were not significantly different before and after dam removal ($p > 0.05$). The downstream control (SR3) had higher THg concentrations than other study reaches. Organic carbon content, however, emerged as an important predictor of THg (R^2=0.59).

The most common chlorinated pesticides found in river sediment included DDT metabolites (69% detection rate) and chlordane metabolites (88% detection rate). A total of 186 fish, representing 15 different species were analyzed for Se and THg. A subset of 102 fish were also analyzed for chlorinated pesticides and PCBs. The most prevalent chlorinated pesticides in fish were aldrin (60% detection rate) and dieldrin (62% detection rate). PCB congeners were found in 10% of river sediment samples and 54% of fish sampled. Fish body burdens generally decreased post dam removal and converged by the end of the study period. Mean aldrin and dieldrin decreased post dam removal to 53 and 34% of the mean pre-dam removal levels in the upstream restored reach of the Olentangy River, respectively. There was some evidence that contaminants were biomagnifying, specifically for PCBs in the Scioto River and dieldrin in the Olentangy River. Food-chain length, a measure of the top trophic position of the ecosystem, most strongly predicted aldrin (R^2 = 0.33). Mean trophic position of fish was positively related to the proportion of methylmercury (MeHg) in fish (Fig. 3; R^2 = 0.24). MeHg – the biologically available form of mercury – represented 80% of total Hg on average (SD = 0.17%). Overall, fish contaminant body burdens found in this study were similar to previous observations in the broader study system, although there was variability over the course of the study.

Table 1. Detection rate (as a percentage) of analyzed heavy metals and in fish tissues and sediment in the Olentangy and Scioto Rivers, Columbus, Ohio. From Davis et al. 2017.

Test		Detection Rate (%)	
Toxic Panel		Fish	Sediment
(*n* = 186 fish, 116 sediment)			
	Manganese	100	-
	Iron	99	-
	Cobalt	12	-
	Copper	72	-
	Zinc	100	-
	Arsenic	81	-
	Selenium	100	-
	Molybdenum	19	-
	Cadmium	0	-
	Mercury (total)	22	100
	Thallium	0	-
	Lead	35	-
Chlorinated Pesticide Panel			
(*n* = 102 fish, 42 sediment)			
	BHC-alpha	2	0
	BHC-gamma (Lindane)	1	14
	BHC-beta	0	2
	BHC-delta	1	0
	Heptachlor	1	0
	Aldrin	60	0
	Chlordane-oxy	1	0
	Heptachlor epoxide	0	0
	Chlordane-trans	1	31
	Trans-nonachlor	2	26
	Chlordane-cis	0	48
	Endosulfan I	0	0
	DDE-p,p'	2	53
	Dieldrin	62	0
	Endrin	2	0
	DDD-p,p'	0	45
	Endosulfan II	4	0
	DDT-p,p'	1	4
	Endrin aldehyde	18	0
	Methoxychlor	0	0
	Endrosulfan sulfate	1	0
	Endrin ketone	0	0
Σ PCB (*n* = 103, 42 Sediment)		54	10

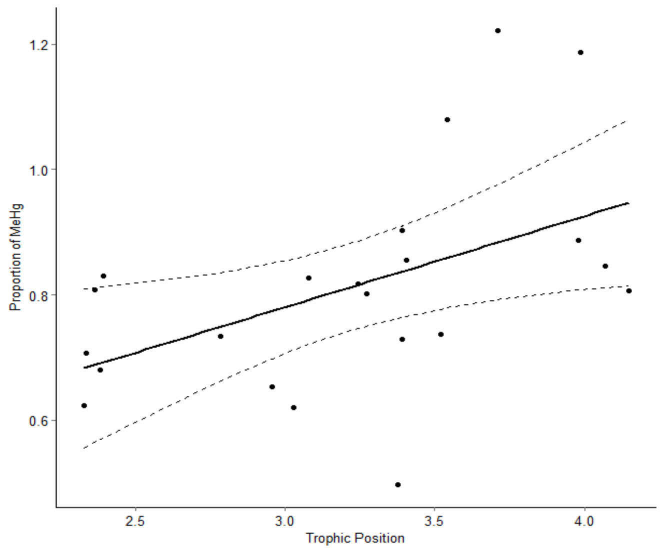

Figure 3. Trophic position was positively related to MeHg (R^2 = 0.24, F = 6.34, p = 0.002).

Objective 2: Mechanisms, risk, and monitoring

Changes in food-chain length of fish were seen after dam removal, reflecting changes in community composition of fish species (Fig. 4). Prior to dam removal, fish food-chain length ranged from 2.5 to 4.3 across study reaches. Prior to dam removal, site OR3 (upstream of 5th Ave. dam) exhibited a food-chain length of 4.3. Post dam removal, food-chain length at OR3 decreased to 2.7 by 2015.

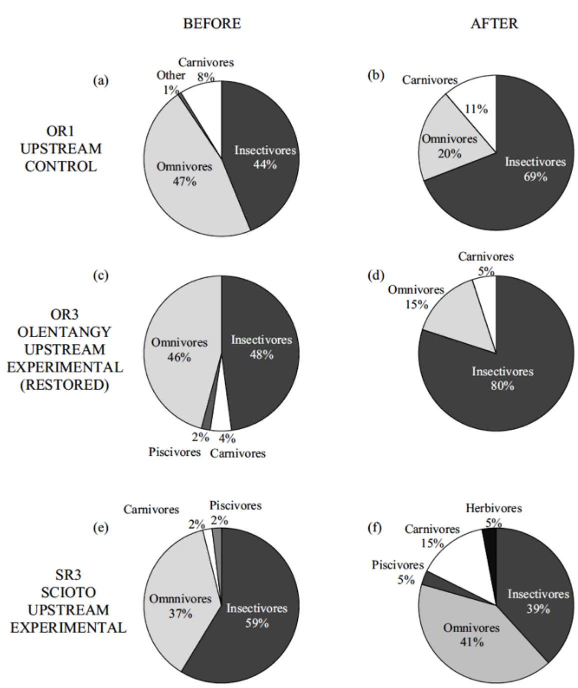

Figure 4. Proportion of fish assemblage by representative feeding guilds at the upstream Olentangy and Scioto River reaches (OR1) before, (b) OR1 after, (c) OR3 before, (d) OR3 after, (e) SR1 before, and (f) SR1 after). From Dorobek et al. (2015).

In addition to assessing fish community response to dam removal across large reaches (upstream vs downstream of previous dams), we also explored how the redevelopment of riffles following dam removal related to water-quality (DO, nutrients, water Hg), geomorphic characteristics (sediment size, streamflow velocity) and macroinvertebrate and fish assemblages. Following removal of the 5th Ave. Dam, multiple riffle habitats developed upstream of the dam removal along the Olentangy River. Riffle habitat developed in areas of the stream channel that were actively being restored, as well as in areas of passive restoration. This new riffle habitat was colonized by a number of macroinvertebrate species, with net-spinning caddisflies (Hydropsychidae), non-biting midges (Chironomidae), and mayflies (Baetidae) being the most commonly seen macroinvertebrates families. Banded Darter (*Etheostoma zonale*) and Rainbow Darter (*Etheostoma caeruleum*) were the most commonly seen fish in the newly developed riffle habitat. Fining of sediment partial size was seen downstream of the 5th Ave. Dam-removal location shortly after removal, likely due to release of previously impounded sediments. While fining of sediments occurred shortly after removal, coarsening of substrate was seen over a longer time period.

Sediment-size distribution, water depth, and streamflow velocity varied by riffle and over time. The density and diversity of macroinvertebrates and fish were also different over time, largely as a function of season. Macroinvertebrate assemblage composition was different by time but not riffle, whereas fish assemblages were similar irrespective of time or riffle. In addition to hydrogeomorphic characteristics implicated as drivers of shifts in benthic invertebrates (Fig. 5) and fish communities in these riffles, chemical water-quality parameters such as dissolved oxygen and nutrient concentrations (e.g., P and N) were also considered as potential drivers following dam removal (Fig. 6). Few studies to date have focused on fine-scale effects of dam removal, such as the redevelopment of riffle habitat units, yet this level of resolution may be important in further understanding ecosystem-level responses and potential benefits and risks related to dam removal.

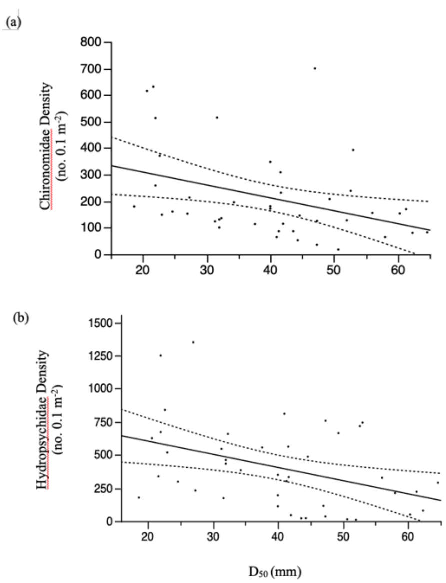

Figure 5. Relationships between D50 and densities (no. 0.1 m^{-2}) of (a) Chironomidae (y = 406.8-4.87x; R^2 = 0.14, p = 0.015) and b Hydropsychidae (y = 802.9-9.95x, R^2= 0.16, p = 0.008). Dashed lines represent confidence curves at α = 0.05. From Cook and Sullivan (2018).

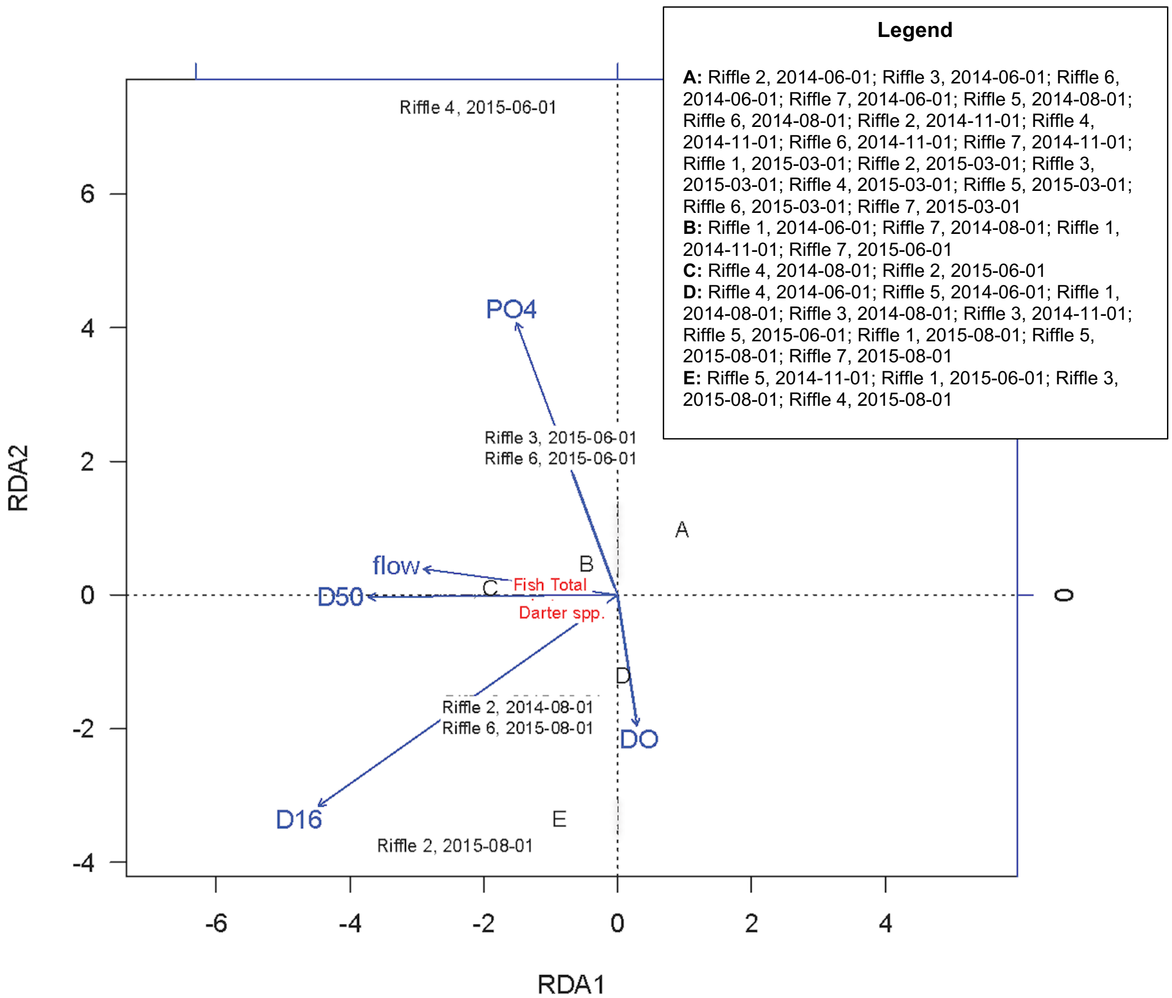

Figure 6. Redundancy analysis (RDA) of fish density (Fish Total), and darter species richness (Darter spp) at each study riffle across all the time steps. Blue arrows indicate how environmental variables were ordinated. Overall, there were 42 riffle/date combinations but only 9 unique scores. Where possible, riffles and time steps (e.g., Riffle 3, 2015-06-01) are included in the plot. For locations where labels would overlap and be illegible, letters A, B, C, D, and E represent the respective riffles and time steps as listed in the legend. From Cook and Sullivan (2018).

Working across the year, we also found that seasonality was important in predicting macroinvertebrate density and diversity following dam removal (see Sullivan and Manning 2017 for details). In particular, seasonal conditions may interact with dam removal to influence biotic communities, sediment transport, and potential the distribution and uptake of contaminants. Thus, routine monitoring protocols should take into account seasonal variability in ecosystem processes and potential responses.

Risk to humans and wildlife, overall, appears to decline following lowhead dam removal in these two river systems. However, owing to the fact that contaminants can cross aquatic-terrestrial boundaries (see Sullivan and Rodewald 2012, Environmental Toxicology and Chemistry 31: 1-9), a key risk factor for wildlife and humans lies in aquatic-to-terrestrial transport mechanisms. Largely, these pathways include trophic linkages. For instance, benthic larval insects emerge from the water as winged adults, and can transport bioaccumulated contaminants to terrestrial consumers including bats, birds, spiders, and other insectivores. We collected some initial data relative to riparian aerial insectivores and Hg, but more research will be necessary. Humans, and many wildlife species (e.g., otters, osprey, etc.), commonly feed on fish. Although our results suggest that at least via fish, lowhead dam removal may decrease this risk, research directly addressing how dams effect the aquatic-to-terrestrial transport of contaminants will be required.

One key recommendation relative to biomonitoring and risk assessment is that our results suggest that monitoring water and sediment are likely insufficient to capture ecosystem responses to contamination. Instead, we found that fish assemblage and trophic responses, coupled with body burdens, were critical in capturing shifts in river contaminant levels following dam removal. Fish and other consumers, through their daily movements (e.g. foraging, finding habitat, etc.) can assimilate and reflect contaminant levels in ways that grab samples of physical features (e.g., sediment) typically do not, and food-web dynamics mediate the pathways of these contaminants to wildlife and humans.

Conclusions:

Overall, we found that dam removal may effectively reduce ecosystem contamination, largely via shifts in fish food-web dynamics versus sediment (and likely water) concentrations. We observed strong shifts in both invertebrate and fish assemblage composition and trophic structure following dam removal, with variable responses upstream and downstream of prior dams. Considering the interaction between the redistribution of contaminated sediment and changes in fish communities following dam removal will need to be taken into account while planning for dam removals in order to minimize ecosystem and human health risks. We provide a conceptual overview of our major findings in Fig. 7.

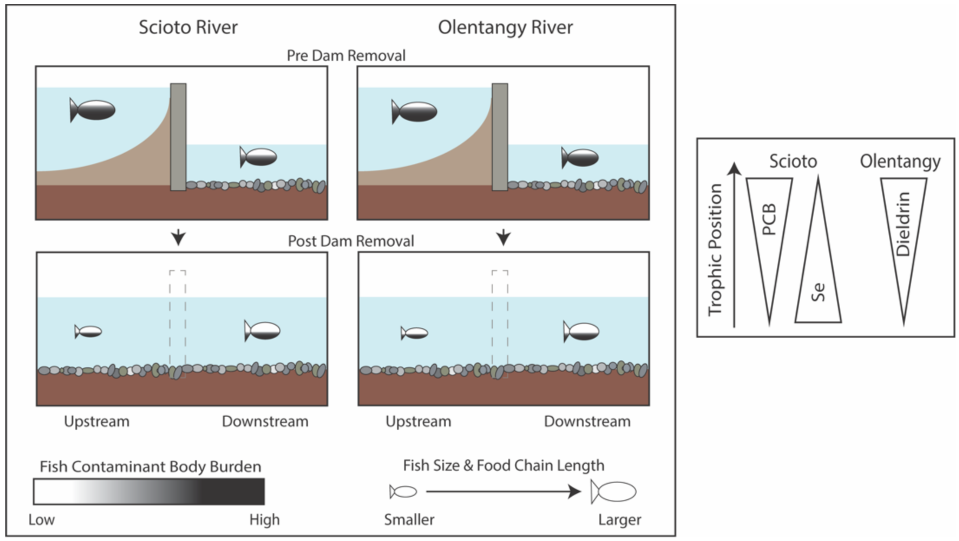

Figure 7. Data from lowhead dam removals in the Scioto and Olentangy Rivers of Columbus, Ohio, suggest that dam removal may effectively reduce ecosystem contamination, largely via shifts in fish food-web dynamics versus sediment concentrations.

It is important to note that we have considered contaminant responses to dam removal over a relative short period after the dams had been removed (< 5 yrs). Further understanding the ecosystem responses to dam removal will require data collection and monitoring over longer time scales, as initial ecosystem responses to dam removal – as observed here – might not be expected to be the same in dynamic systems such as rivers.

Deliverables (outputs/outcomes):

Data from this project were used in 6 student MS theses that have contributed to 5 peer-reviewed publications and 13 professional presentations to date. Presentation of results occurred at local conferences and a professional societies such as annual meetings of the Ohio Biodiversity Conservation Partnership, Society for Freshwater Science, American Fisheries Society, and Ecological Society of America.

Initial data and findings will be used to develop a more comprehensive proposal to the National Science Foundation studying the linked geomorphic-ecological consequences of dam removal and river restoration. Funding for the present work also came from the Ohio Division of Wildlife through the Ohio Biodiversity Conservation Partnership, USGS, and the National Science Foundation (NSF DEB-1341215).

Data will be available upon request as well as through the Stream and River (STRIVE) Laboratory at the School of Environment and Natural Resources, The Ohio State University.

Journal Articles and Theses:

Comes, E. 2016. Short-term geomorphic responses to lowhead dam removal in two mid-sized urban rivers. MSc Thesis. The Ohio State University, Columbus, Ohio.

Cook, D.R. and S.M.P. Sullivan. 2018. Associations between riffle development and aquatic biota following lowhead dam removal. Environmental Monitoring and Assessment. 190: 1-14.

Corra, J. Relationships between aerial insectivorous birds, urbanization, water quality, and climate. MSc Thesis. The Ohio State University, Columbus, Ohio.

Davis, R.P. 2016. Monitoring fish-community contaminant body burdens following lowhead dam removal in an urban river system. MSc Thesis. The Ohio State University, Columbus, Ohio.

Davis, R.P., Sullivan, S.M.P., and K.C. Stefanik. 2017. Reductions in fish-community contamination following lowhead dam removal linked more to shifts in food-web structure than sediment pollution. Environmental Pollution. 231: 671-680.

Dorobek, A.C., Sullivan, S.M.P., and A. Kautza. 2015. Short-term consequences of lowhead dam removal for fish assemblages in an urban river system. *River Systems*. 21/2–3: 125-139.

Dorobek, A.C. 2016. Short-term consequences of lowhead-dam removal for fish community dynamics in an urban river system. MSc Thesis. The Ohio State University, Columbus, Ohio.

Masheter, A. Short-term effects of lowhead dam removal on emergent aquatic insect communities in the Olentangy River, Ohio. MSc Thesis. The Ohio State University, Columbus, Ohio.

Sullivan, S.M.P., and D.W.P. Manning. Dam removal disturbance leads to seasonally distinct taxonomic and functional shifts in macroinvertebrate communities. *PeerJ.* **5**:e3189; DOI 10.7717/peerj.3189.

Sullivan, S.M.P., Manning, D.W.P., and R.P. Davis. 2018. Do the ecological impacts of dam removal extend across the aquatic-terrestrial boundary? Ecosphere 9: Article e02180.

Vent (Cook), D.R. 2015. Associations between riffles and aquatic biota following lowhead dam removal: implications for river fish conservation. MSc Thesis. The Ohio State University, Columbus, Ohio.

Presentations (from most recent to oldest):

Sullivan, S.M.P. and D.W.P. Manning. Society for Freshwater Science. Special Session on Stressors in Linked Aquatic-Terrestrial Ecosystems – Raleigh, NC. June 2017. "Effects of Dam Removal Extend to Terrestrial Food Webs: Evidence from Common Riparian Consumers".

Corra, J.W., and S.M.P. Sullivan. Aerial insectivorous birds: conservation across the land-water interface. Oral. Society for Freshwater Science Annual Meeting, May 2018. Detroit, MI.

Corra, J.W., and S.M.P. Sullivan. Aerial insectivorous birds: conservation across the aquatic-terrestrial boundary. Poster. Ohio Biodiversity Conservation Partnership Annual Meeting, Nov. 2017. Columbus, OH.

Corra, J.W. and S.M.P. Sullivan. Linking water quality and Tree Swallow populations across an urban-forested landscape gradient. Poster. Society for Freshwater Science Annual Meeting, June 2017. Raleigh, NC.

Sullivan, S.M.P. Ohio Biodiversity Conservation Partnership Annual Meeting, Columbus, OH. November 2016. Keynote Address: “Multiple Stressors and Multiple Challenges: Evidence-based Conservation of Stream-Riparian Ecosystems”.

Manning, D.W.P. and S.M.P. Sullivan. Benthic macroinvertebrate community responses to multiple stressors associated with dam removal. Oral. Society for Freshwater Science Annual Meeting, May 2016. Sacramento, CA.

Dorobek, A.C. and S.M.P. Sullivan. Shifts in fish-centered food webs following dam removal in an urban river system. Oral. Society for Freshwater Science Annual Meeting, May 2016. Sacramento, CA.

Dorobek, A.C. and S.M.P. Sullivan. Shifts in Fish Food Webs Following Lowhead Dam Removal in an Urban River System. Poster. Ohio Biodiversity Conservation Partnership (OBCP) – Terrestrial Wildlife Ecology Laboratory Meeting (TWEL), Nov. 2015, OSU 4-H Center, Columbus, OH.

Davis, R., and S.M.P. Sullivan. Assessing the short-term effects of lowhead dam removal on contaminant movement through fish food webs in an urbanized river system. Oral. American Fisheries Society 145th Annual Meeting, August 2015, Portland, OR.

Dorobek, A.C., and S.M.P. Sullivan. Lowhead dam removal in an urban river system leads to shifts in fish assemblages in the short term. Oral. American Fisheries Society 145th Annual Meeting, August 2015, Portland, OR.

Dorobek, A.C. and S.M.P. Sullivan. Fish community dynamics in the short-term following lowhead dam removal in an urban river system. Oral. Ohio Biodiversity Conservation Partnership Annual Meeting, Feb. 2015, OSU 4-H Center, Columbus, OH.

Dorobek, A.C., Kautza, A., and S.M.P. Sullivan. Short-term consequences of lowhead dam removal for river fish assemblages in an urban landscape. Oral. Joint Aquatic Sciences Meeting, May 2014. Portland, OR.

Dorobek, A.C., A. Kautza, and S.M.P. Sullivan. Consequences of lowhead dam removal for river fish assemblages in an urban landscape: initial evidence. Poster. Ohio Biodiversity Conservation Partnership Annual Meeting, Feb. 2014, OSU 4-H Center, Columbus, OH.

Relevant Websites:

https://u.osu.edu/strive/field-photos/dam-removal/

Accounting of Project Final Costs:

A final fiscal report has been provided by OSU Office of Sponsored Programs. Traci Aquara (aquara.1@osu.edu, 614-688-1765) is the Sponsored Program Officer on this agreement.