Fragmentation and fish passage: Can fishways mitigate discontinuities in Great Plains fish communities?

by

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Abstract

Fishways are a common tool for mitigating the effects of habitat fragmentation on fish communities, but their utility in low-gradient, sand-bed rivers of the Great Plains is not well studied. The Lincoln Street Fishway on the Arkansas River became operational in 2015 and was built specifically to pass small-bodied threatened fishes. We used a combination of surveys up- and downstream of the barrier and tagging experiments to test the ability of fishes to move into and through the fishway. Differences in fish community structure up- and downstream of the dam were more pronounced prior to the construction and operation of the fishway. In particular, Emerald Shiner *Notropis atherinoides* was absent from collections upstream of the dam before fishway construction, but commonly collected upstream in 2015 and 2016 surveys. Surveys within the fishway structure revealed 29 species, or 74% of the total species captured during our study were using the fishway. To further quantify fishway passage, we used a VIE experiment to assess if fish marked downstream of the fishway moved into or upstream of the fishway. Although we did not recapture marked fish upstream of the fishway, some marked individuals moved into the fishway. Finally, we conducted a PIT tag experiment to evaluate short distance movements within the fishway for three species of small-bodied minnow and were able to document upstream movement across a gradient of flows through the fishway. Results from our study illustrate the potential for fishways to mitigate the effects of habitat fragmentation on small-bodied fishes in sand-bed rivers.

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Preface

Chapter one is formatted for submission to *Canadian Journal of Fisheries and Aquatic Sciences* with David Bender, Jordan Hofmeier, Jessica Mounts, Ryan Waters, Vaughn Weaver, and Keith Gido as co-authors.

Chapter 1 - Can Fishways Mitigate Fragmentation Effects on Great Plains Fish Communities?

Introduction

The damming of flowing waters across the globe has affected almost half of the world's major rivers and is likely to increase in the future with continued human population expansion (Lehner et al. 2011; Olden 2016). Damming of rivers, restricts movements of fish while converting habitats from lotic to lentic waters and altering flow regimes (Poff et al. 1997; Nilsson et al. 2005; Dudgeon et al. 2006). Dams lead to a reduction in biodiversity and drive native populations toward extirpation through a combination of altering habitats and accommodating invasive species (Power et al. 1996). Historical variability of stream flows are now homogenized across the continental United States because of dams (Poff et al. 2007) and many lotic species have experienced range-wide declines. Particularly those species that have evolved strategies (e.g., migration) to contend with the natural heterogeneity in flows and resources occurring within river networks (Hoagstrom et al. 2011; McIntyre et al. 2016).

Anthropogenic alterations such as dams and water extraction that fragment river networks and prevent the upstream dispersal of fishes have resulted in reductions in populations across the Great Plains (Luttrell et al. 1999; Perkin and Gido 2011; Pennock et al. *In Press*). Dams in the Great Plains have caused changes in community structure through habitat alteration and interruption of recolonization events which, over time, result in extirpations (Winston et al. 1991; Gillette et al. 2005; Perkin and Gido 2012). The reproductive ecology of Great Plains fishes that evolved under harsh environmental stochasticity makes them particularly affected by fragmentation. For example, long-distance movement is often necessary to migrate from drying habitats during drought and serves as a means of repopulating upstream reaches during flooding

(Fausch and Bestgen 1997; Dodds et al. 2004). Several small-bodied minnows endemic to the Great Plains also have evolved a reproductive strategy whereby they release and fertilize eggs into the water column (*i.e.*, pelagic-broadcast spawning) during seasonal spates (Moore 1944; Hoagstrom and Turner 2015). As they develop, fertilized eggs passively drift downstream in suspension above the constantly shifting substrate over a period of several days (Bottrell et al. 1964). This reproductive strategy requires extensive migrations to disperse into upstream habitats and subsequently long, intact reaches of free-flowing river to allow eggs to hatch and larvae to fully develop as they drift downstream (Cross et al. 1985; Dudley and Platania 2007; Wilde and Durham 2008). The presence of dams blocks both upstream colonization of drying habitats as well as migrations back to spawning habitats by pelagic spawning minnows. Research is necessary to develop and evaluate creative solutions to mitigate the ecological consequences associated with dam construction (Fullerton et al. 2010; O'Hanley et al. 2013).

Although building fishways allowing fish to swim around dams has been in use for more than a century, there remains a large gap in our knowledge of the effectiveness of fishways in restoring connectivity for non-salmonid, small-bodied (*i.e.*, <100 mm total length) species. This is especially the case in low-gradient, sand-bed rivers found in the Great Plains (Ficke and Myrick 2007). We are only aware of two studies conducted in this region, and both assessed the use of rock-ramp style fishways. Archdeacon and Remshardt (2012) documented successful use of a rock channel-type fishway by Rio Grande Silvery Minnow *Hybognathus amarus* on the Rio Grande in central New Mexico. Ficke and Myrick (2007) evaluated community use of a rock-ramp fishway on the St. Vrain River in the front range of Colorado, but did not recapture any marked fish upstream of the fishway that had moved through the structure. Despite the sparse information on the effectiveness of fishways in the Great Plains, several studies of fishway passage by non-salmonids exist elsewhere in the world (Stuart et al. 2008; Pompeu et al. 2012; Benitez et al. 2015). Studies from river systems in Australia represent some of the most adequate documentation of community use of multiple fishway designs in low-gradient rivers (*e.g.*, Gilligan et al. 2003; Stuart et al. 2008). For example, Stuart et al. (2008) documented the successful ascension of a vertical-slot fishway by 11 species with individuals ranging in total length from 21-1030 mm. Given the potential for fishways to mitigate effects of fragmentation, there is a need to better understand the role these structures can play in regions such as the Great Plains because of the recognized importance of restoring connectivity for entire riverine communities (Benitez et al. 2015).

The objectives for this study were to: 1) compare fish community structure upstream and downstream of a dam on the Arkansas River, Kansas before and after construction of a fishway to assess if species that previously did not occur or were rare upstream of the dam are now present or in greater abundance, 2) characterize temporal and spatial patterns of species occurrence, abundance, and size structure within the fishway, 3) determine if downstream fishes are moving into the fishway, and 4) assess the movement patterns of small-bodied minnows (Family: Cyprinidae) within the fishway. By increasing our understanding of the effects fishways have on fish communities, we can inform management decisions on best practices to conserve species in areas such as the Great Plains that are affected by anthropogenic alterations. The efficacy of a fishway on a Great Plains river might differ from the same design aimed to pass salmonids on a high-gradient stream. Great Plains rivers typically consist of an alluvial sand-bed, have highly stochastic flow patterns, and are home to many small-bodied species (some endemic to the region) that have lower swimming and jumping abilities relative to large-bodied diadromous species.

Methods

Study Area-The Arkansas River begins in the Rocky Mountains of Colorado, flows through Colorado, Kansas, Oklahoma, and Arkansas before joining the Mississippi River. Upon entering Kansas, the Arkansas River channel remains predominantly dry between the Colorado border and Great Bend, KS in the central part of the state because of water diversions and groundwater extraction (Cross et al. 1985). The perennially flowing portion of the Arkansas River from Great Bend, KS to Kaw Reservoir (7 082 ha) in Oklahoma is divided into three fragments by low-head dams (Figure 1). The fragment upstream of Wichita to Great Bend is approximately 180 river kilometers (rkm), the fragment running through Wichita is isolated by two low-head dams, 9 rkm apart, and downstream of Wichita approximately 140 rkm flows freely before the river enters Kaw Reservoir, Oklahoma. The Lincoln Street Bridge in the City of Wichita was first built in 1970 and included an inflatable dam attached below the bridge to control water levels in the Arkansas River as it flowed through downtown portions of the city. The dam was built for beautification of the river as it runs through downtown Wichita (J. Hardesty, City of Wichita, personal communication). A permanent, low-head concrete structure replaced the inflatable dam in 1976. Construction began in 2010 to replace both the bridge and dam because of structural deficiencies. The new bridge and dam were built separately and include a 140 m long fishway on either side of a central boat passage (Figure 2). The dam is a run-of-the-river structure that is made up of four individually controllable panels that can be hydraulically raised and lowered to control water levels upstream and discharge within the fishway and boat passage. The fishways are both of a Dutch Pool and Orifice design (Boiten and Dommerholt 2006) that consist of 11 concrete weirs with 88 steel baffles, each with an orifice (0.2 m W x 0.3 m H) that is approximately 0.2 m up from the bottom of each baffle. The weirs consist of baffles grouped into sets of eight with orifices alternating from right to left, creating a sinuous flow pattern. There are 77 pools on each side of the fishway. The slope of individual weirs is highest towards the upstream exit of the fishway (4.1 %) and decreases towards the downstream entrance (2.5 %). The fishway at the Lincoln Street Dam was designed and built for the targeted passage of several species of conservation concern and is currently the only fishway in the state (Table 1; D. Bender, unpublished data). Several high flow events (peak discharge: 419 m^{-3} s^{-1}) occurred in the two years following completion of fishway construction causing damage to the structure. Final repairs were completed in January 2015, thus the fishway became fully operational only a few months ahead of our first sampling effort in March 2015.

Community Sampling-Pre-fishway and contemporary fish community data were used to assess the influence of the fishway on upstream and downstream community structure. The City of Wichita (hereafter, the City) conducted fish community sampling of the Arkansas River as part of a water-quality monitoring program from 1991-2008 (V. Weaver, unpublished data; Weaver 1993). One site was sampled 7 rkm upstream of the Lincoln Street Dam in 1991 and 1995-2000. Two sites were sampled downstream of the dam, the first was located 300 m downstream of the dam (sampled in 1991 and 1994-2008) and the second was located 3 rkm downstream of the dam (sampled in 2002-2004 and in 2006). All sites were sampled from one to four times per year and were located within 2 rkm of contemporary sampling locations. Sampling for this study was conducted at 12 sites distributed from 0 to 5 rkm upstream and downstream of the dam and fishway at 1 km intervals. Sites were sampled once per month in 2015 and 2016 during March, May, June, July, August, and October. We sampled wadeable portions of a site using a seine (4.6 x 1.8 m, 3.2 mm mesh) and limited our time at a site, including fish processing, to no more than 1.5 h. The first three sites upstream of the dam are impounded during normal dam operations and consist of a homogenous u-shaped channel lined with rip-rap on both banks. Due to the coarse, rip-rap substrate we sampled 100 m of shoreline using a combination of backpack electrofishing (Smith-Root LR24, 100-170 V, Freq: 60, Duty Cycle: 30) and seining where possible (*i.e.*, if wadeable). If surveys occurred when the dam was lowered (*e.g.*, for maintenance upstream), we sampled using seining only as at other sites. The first site upstream of the dam started at the exit of the fishway. The first site downstream of the dam was located approximately 500 m from the dam face where the first consistently forming sand-bar reappeared; the point where the river regained its natural pattern of sand-bar formation. Collected fishes were identified to species, counted, and total length (TL) measured to the nearest mm for up to 30 individuals of each species per site.

We tested differences in species richness among communities up- and downstream of the fishway separately for both time periods with a One-Way ANOVA. Differences in size-structure upstream and downstream of the dam for the three most common species (*i.e.*, cumulative relative abundance > 90%) collected during contemporary sampling was tested with a Kruskal-Wallis ANOVA. To avoid inflating the power of statistical tests, we used mean length of each species for each visit to a site as our sample unit (Neumann and Allen 2007). We analyzed community structure upstream and downstream of the Lincoln Street Dam prior to and after fishway construction with a Bray-Curtis (B-C) dissimilarity index (Bray and Curtis 1957) using 4th root transformed abundance. Due to differences in sampling methodology, community structure was not directly compared between pre-fishway and contemporary sampling periods. We used permutational multiple analysis of variance (pMANOVA, N = 10,000 iterations; Anderson 2001) on B-C dissimilarities to test the effects of location (*i.e.*, up- or downstream) on fish community structure. We visualized differences in community structure among locations using non-metric multidimensional scaling (NMDS) ordinations. All analyses were completed using the vegan: Community Ecology Package, version 2. 4-1 (Oksanen et al. 2016) in program R, version 3.3.1 (R Core Team 2016).

Fishway Sampling-To evaluate fishway use by different species, we sampled the structure once per month during March (2016 only), May, June, July (2015 only), and August in 2015 and 2016. Custom nets (0.5 m W x 1 m H, 3.22 mm mesh) were used to block baffle openings, trapping fish in pools between baffles. Trapped fish were scooped out with a custom dip net (0.6 m W x 1.4 m H x 0.9 m D, 3.2 mm mesh). The number of pools sampled varied across sampling events (range: 112-154) due to the downstream end of the fishway filling with sediment. Species identity and abundance were recorded for each pool separately. In 2015, the first 30 individuals of each species from each side of the fishway were measured to the nearest mm TL. However, in 2016, we measured all individuals.

We analyzed species occurrence (richness) and number of individuals (abundance) within the fishway using generalized linear mixed models (GLMM). Richness and abundance were assessed as dependent variables in GLMMs with a Poisson distribution and log-link function (Zuur et al. 2009). We used weir as a fixed effect and month as a random effect. Due to a difference in which months were sampled during 2015 and 2016 each year was modeled separately. We examined residual plots for potential auto-correlation. Turnover was high across samples in space and time, and residual plots showed no evidence of auto-correlation. Thus, we assumed samples were independent. Mixed models were constructed using the lme4 Package, version 1.1.12 (Bates et al. 2015) in Program R, version 3.3.1 (R Core Team 2016). Size-structure of common species within the fishway was tested using linear regression. We tested if mean lengths of abundant species varied as a function of weir (i.e., if larger fish were more likely to occur higher up in the fishway). Mean length was calculated for each weir across all samples of the fishway, and was then regressed as a function of weir number.

Fish Movement-To assess the movement ability of small-bodied minnows within the fishway at different water levels (treatments), we released fish tagged with passive integrated transponders (PIT) into the middle of a series of pools (between baffles) of weir 7 with an antenna array installed up- and downstream of the release pool (Figure 2). Six stationary antenna (1 m x 1 m) attached to a multiplexing reading station (QuBE-IS1001, Biomark, Boise, Idaho) were spaced out such that the release pool was bracketed by antenna immediately up- and downstream, two antenna were placed at the most upstream and downstream pools, and two antenna were placed at the first pool of the next upstream weir and at the last pool of the next downstream weir. In addition to the stationary antenna, we used a mobile wand antenna attached to a reader (BP Plus portable; HPR Plus reader, Biomark, Boise, Idaho) to scan each pool of the fishway every 2 h on the side where fish were released. Following methods outlined in Pennock et al. (2016), we tagged between 45-50 individuals from two species per treatment, including Red Shiner *Cyprinella lutrensis* and Sand Shiner *Notropis stramineus* that ranged in size from 45-78 mm TL with full duplex 9 mm PIT tags (9 mm x 2.15 mm; Biomark, Boise Idaho). We also tagged a minimum of 30 individuals per treatment of Plains Minnow *Hybognathus placitus*, a threatened species targeted for passage by the fishway, with full duplex 12 mm PIT tags (12 mm x 2.15 mm) due to their larger body size (65-117 mm). Fish were tagged the day prior to release and held in aerated coolers overnight to assess survival and tag retention. Prior to release, fishes were scanned to confirm presence of a PIT tag and measured to the nearest mm TL. Fishes were held in a net in the release pool for a minimum of 5 min to acclimate to flows before being released. Experimental fish releases occurred at three different water levels within the fishway.

The City operates the dam at a standard water level, which we used as our baseline treatment. The second and third treatments involved lowering the water level in the fishway by 0.1 and 0.15 m, respectively. Fish detections on antennas were monitored for an 8 h period after release for each water level. Because of potential vandalism of equipment, 8 h was the longest we could effectively leave PIT antenna equipment running. During each treatment, we measured discharge in the boat passage and the maximum velocity for each orifice to assess how upstream water level affects flows in the boat passage and fishway. The experiment was repeated twice and water level treatments were manipulated over three consecutive days in May and June 2016. Plains Minnow were only compared among two water level treatments due to their scarcity in the system.

To determine if fishes moved from downstream into or through the fishway, we marked fish with visible implant elastomer (VIE, Northwest Marine Technology Inc., Shaw Island, WA) at three locations downstream of the fishway (*i.e.*, directly below dam/fishway, site 5, and site 4; Figure 1) in July 2015 and August 2016. All fishes were tagged at the base of the dorsal fin with a different color for each tagging location. Crews of 4-12 people spent approximately 8 h at each tagging location. Tagging events occurred one week before standard community and fishway sampling in July 2015 and August 2016. All individuals from surveys taken after the initial tagging in 2015 were checked for marks. Recaptured individuals were measured to the nearest mm TL.

Results

Community Sampling-Prior to fishway construction, sampling by the City between 1991 and 2008 yielded 87 976 individuals representing 46 species (Table 2). Mean richness was twice as high downstream as upstream of the dam (ANOVA: $F_{1,\,39} = 19.8$, $P < 0.001$; Figure 3A) with 22 species collected only at downstream sites. All species collected upstream were also collected downstream. Contemporary sampling after fishway construction yielded 123 898 individuals and 39 species (Table 2). Eight species were only collected downstream and 5 species only upstream. Mean species richness was significantly higher downstream than upstream of the dam (ANOVA: $F_{1,\,142} = 9.2$, $P < 0.01$); albeit only about 16% higher after fishway construction (Figure 3B).

Pre-fishway community structure was significantly different among upstream and downstream communities, which can be visualized by clear separation in ordination space (pMANOVA: *Psuedo* $F_{1,\,39} = 11.8$, $P < 0.001$, $r^2 = 0.23$; Figure 4A). Contemporary fish communities in ordination space overlapped considerably among upstream and downstream sites, but significant differences still existed after fishway construction (pMANOVA: *Psuedo* $F_{1,\,142} = 15.2$, $P < 0.001$, $r^2 = 0.10$; Figure 4B). Variable and low sampling efficacy at sites impounded by the dam (*i.e.,* 7, 8, and 9) prompted us to reanalyze community structure while excluding these sites. Significant differences still existed among sites upstream and downstream of the dam (pMANOVA: *Psuedo* $F_{1,\,106} = 7.2$, $P < 0.001$, $r^2 = 0.06$; Figure 4C). Community structure differences in contemporary samples were driven strongly by the disparity in Emerald Shiner *Notropis atherinoides* abundance between upstream and downstream sites (Table 2). Statistical results remained unchanged even when all but the two most abundant species, Red Shiner and Emerald Shiner, were excluded.

Several species were collected during contemporary sampling upstream and downstream of the dam that were not collected during pre-fishway sampling in either upstream or downstream locations (Table 2). In particular, Emerald Shiner was only collected downstream of the dam pre-fishway construction. Although, during contemporary sampling, they were consistently collected upstream of the dam (71% of surveys), their abundance was nearly 20 times higher downstream (ANOVA: $F_{1,\,114} = 23.2$, $P < 0.001$). Emerald Shiner also were significantly larger upstream (ANOVA on Ranks: $H = 52.5$, $P < 0.001$) and median lengths differed by 14 mm between upstream and downstream (Figure 5). In comparison, Red Shiner (ANOVA on Ranks: $H = 4.01$, $P = 0.05$) were marginally smaller and Sand Shiner (ANOVA on Ranks: $H = 2.631$, $P = 0.10$) did not differ significantly in size structure between sites upstream and downstream of the dam.

Fishway Sampling-Sampling of the fishway yielded 39 767 individuals and 29 species (Table 3). Four species, Red Shiner, Emerald Shiner, Sand Shiner, and Bullhead Minnow *Pimephales vigilax*, made up > 95% of all individuals sampled. Results from GLMM models showed a significant decline in richness and abundance with increasing distance upstream within the fishway ($P < 0.001$). Richness and abundance within the fishway declined over the course of the entire study (Figure 6). Sixty-six percent of all individuals collected in the fishway were caught in May 2015. The average number of individuals declined by more than 90% in both years with significantly fewer individuals towards the exit (upstream) of the fishway (Figure 6A, B). Average species richness declined by 60% moving upstream in the fishway in both 2015 and 2016 (Figure 6C, D). Size-structure regressions were not significant for Red Shiner (df = 9, $P = 0.98$), Sand Shiner (df = 4, $P = 0.81$), or Bullhead Minnow (df = 4, $P = 0.22$) although Bullhead Minnow were never collected past weir 6. Mean length of Emerald Shiner increased significantly with distance upstream in the fishway (df = 6, $P < 0.01$, adj. $r^2 = 0.82$).

Fish Movement-Survival and PIT tag retention was high for all three species over 24 h (Table 4). Detection efficiency (*i.e.,* number of fish detected divided by number released) averaged across treatments was 47% (range: 38-57%) for Red Shiner, 47% (41-53%) for Sand

Shiner, and 52% (40-63%) for Plains Minnow. All three species were able to move upstream within the fishway (Table 5). The longest distances moved in both directions by individual Red Shiners and Plains Minnow occurred during the baseline treatment. Contrary to our expectations, these two species showed decreases in distance moved in both directions as water levels were lowered. Sand Shiner displayed the greatest downstream movement at the lowest water level (-0.15 m treatment), and the greatest upstream movement during the -0.1 m treatment. Discharge in the boat passage decreased from the baseline of 1.7 $m^{-3} \cdot s^{-1}$ to 1.4 during the -0.1 m treatment to 0.8 during the -0.15 m treatment. This decrease in flow had no measured effect of lessening fishway velocities, and we observed a subtle increase in the -0.1 m and -0.15 m treatments (mean ± SE; baseline = 0.7 ± 0.04 $m \cdot s^{-1}$, -0.1 m = 0.8 ± 0.04, and -0.15 m = 0.8 ± 0.04).

During VIE marking, we marked 20 404 fishes across all three tagging locations. The five most abundant species tagged were Emerald Shiner (number of individuals = 10 117), Red Shiner (8 797), Sand Shiner (956), Channel Catfish *Ictalurus punctatus* (196), and Bullhead Minnow (187). Marked individuals of two species were recaptured in the fishway. Six Red Shiners were recaptured in the fishway with one individual captured in weir 7 (39 mm TL) and the others in weirs 4 and 5. Two Emerald Shiners were recaptured, one in weir 8 (50 mm TL) and the other in weir 4 (41 mm TL). All recaptured individuals from the fishway were marked directly downstream of the dam and fishway.

Discussion

Construction of the Lincoln Street Fishway has allowed for reduced differences between fish communities upstream and downstream of a dam that previously limited upstream colonization by fishes. Our data show that prior to construction of the fishway, species richness was lower upstream of the dam and 48% of all species collected only occurred downstream of the dam.

Moreover, contemporary sampling indicated a decreased magnitude in difference between species richness and community structure (*i.e.*, Bray-Curtis dissimilarity) upstream and downstream of the dam. This, coupled with the consistent collection of Emerald Shiner that were not present in the upstream reach prior to fishway construction suggests the structure is allowing for improved continuity. However, differences in abundance and size-structure upstream and downstream of the dam are still present for some species and may reflect difficulties in navigating the fishway and/or impounded river upstream of the dam.

The renewed and consistent occurrence of Emerald Shiner upstream of the dam suggests this species (and likely others) can successfully pass through the fishway to move upstream. Emerald Shiner, a species that was historically present throughout the Arkansas River in Kansas, had been restricted to the reach downstream of Wichita since the construction of small dams within the City (Cross and Collins 1995; Pyron 2014). This species was completely absent from sampling conducted by the City upstream of the dam in 1991-2000, but was caught regularly in our surveys. Even so, there was a dominance of larger individuals upstream of the fishway, which might be a result of flows in the fishway reducing passage by smaller individuals due to their reduced swimming ability (Bunt et al. 2012). Alternatively (but not exclusively), sexually mature individuals of some species might be more mobile. Emerald Shiner do not reach sexual maturity until 55 mm TL (Flitner 1964) and the median size of fish upstream was 61 mm (IQR = 54-67 mm). Thus, these larger mature individuals might be more able (or driven) to move upstream than their smaller conspecifics. Assessing the effects of the fishway on size-structure of other species is more ambiguous. Red Shiner and Sand Shiner displayed no difference (or marginally smaller fish upstream) in size-structure upstream and downstream of the dam. However, these species continuously occurred upstream of the dam prior to the fishway suggesting that connectivity might be less important for their persistence. Red Shiner and Sand Shiner can reach sexual maturity at 30 mm standard length (Kansas Fishes Committee 2014), and a marked 39 mm TL Red Shiner was collected in the upper portions of the fishway. The movement of this relatively small fish in the fishway suggests smaller individuals can navigate flows in the fishway.

The Lincoln Street Fishway is likely to pass many species in the community. Although our study did not directly measure successful ascension (*i.e.*, a marked fish released at the entrance recaptured at the exit or upstream), we did document 29 species within the structure showing that a majority (74 %) of the species in the entire sampled riverine community used the fishway in some fashion. Recently, the importance of multi-species fishways has been expressed, and several efforts documenting community use of fishways have taken place. A vertical-slot fishway (*i.e.*, a series of baffles each with a vertical slot) passed 11 species on a lowland river in Australia (Stuart et al. 2008). Two vertical-slot fishways in Belgium passed 14 and 22 species, respectively (Benitez et al. 2015). Both of these case studies provide evidence of successful ascension of fishways by multiple species within a fish community and a range of sizes within populations. Fishes ranging in size from 20-1150 mm TL were captured in the Lincoln Street Fishway, and Longnose Gar *Lepisosteus osseus* were observed moving upstream through the high velocities (>2 m s^{-1}) of the boat passage (C. Pennock, personal observation). Thus, this fishway potentially has the capacity to restore connectivity for multiple species and for multiple life-stages.

Plains Minnow and Peppered Chub *Macrhybopsis tetranema*, two species targeted for passage at the fishway were not collected during contemporary sampling, and may be extirpated from the system (Perkin et al. 2015; Pennock et al. *In Press*). The absence of these two species likely contributed to the homogenization between upstream and downstream communities. Similar to our study, other researchers have found delayed, albeit improving, changes in community structure following the installation of fishways (Gilligan et al. 2003). Whereas the Lincoln Street Fishway has allowed for improved continuity of the Arkansas River fish community, residual habitat deficiencies might be preventing full recovery of community integrity.

Fishways restore the structural connectivity of rivers for fishes (*i.e.*, allowing for the potential for movement), but whether they restore functional connectivity (*i.e.*, fish actually moving upstream without negative physiological or fitness consequences) requires more attention (McLaughlin et al. 2013). A potential problem with fishways is that they do not fully remedy the problem and habitat deficiencies upstream may limit the restoration of functional connectivity (Brown et al. 2013). Moreover, if fishways entice fish (*e.g.*, fishway flows attract rheophilic fishes) to move into suboptimal habitat upstream of dams, this can lead to reduced fitness for populations (*i.e.*, an ecological trap; Pelicice and Agostinho 2008). Specifically, the Lincoln Street Dam still impounds the river for 3 rkm upstream creating a lentic habitat in which we found overall decreased abundance and richness relative to sites with lotic habitat. This lacustrine zone upstream of the fishway might negatively impact fishes that have successfully ascended the fishway by discouraging further upstream movement or allowing for increased predation risk by piscivorous fishes. Indeed in our study, sites in the impounded reach (*i.e.*, 7, 8, and 9) had the highest abundance of predatory fishes (*e.g.*, Largemouth Bass *Micropterus salmoides,* Green Sunfish *Lepomis cyanellus*, and Flathead Catfish *Pylodictis olivaris*). Thus, despite the fishway restoring movement corridors for adults, 3 rkm of impounded water might still be detrimental to egg or larval survival either through increased predation or allowing eggs and larvae to fall out of suspension.

Over the course of our study it was clear that both water level management and maintenance of the fishway play critical roles in allowing effective passage of fishes. Specifically, obstruction of fishway entrances by debris and sediments can impact performance by changing hydrology, or creating behavioral or physical barriers. Thus, fishways require regular inspection and maintenance to confirm optimal functionality (O'Connor et al. 2015). A possible explanation for the decrease in abundance of individuals and species richness in the Lincoln Street Fishway over the course of our study might be attributed to the lower portions of the fishway filling with sediments after high flow events in 2015. Sediments completely filled the first 20-30 m on both sides of the fishway, effectively moving the entrance of the fishway. Another aspect of the Lincoln Street Dam that might have influenced passage and community composition within the fishway is its hydraulically controllable panels which allows the City to adjust impounded water levels. Because the fishway is built alongside and is connected to the dam, flows through the fishway are linked to the impounded water level upstream (Appendix A). If the dam is lowered beyond 1.2 m, there is no flow through the fishway. Over the course of our study the dam was lowered such that the fishway stopped flowing on 11 separate occasions. During these occasions the fishway was dry for 1-76 consecutive days. The fishway was not flowing for a total of 106 days during 2015 (Jan.-Dec.) and 39 days in 2016 (Jan.-Aug.).

The Lincoln Street Fishway is a potential means to restore access to habitat for fishes that need long, connected reaches of river. In the Great Plains, pelagic-spawning minnows rely on connectivity and adequate seasonal flows to complete their life-history (Bottrell et al. 1964; Dudley and Platania 2007; Wilde and Durham 2008; Perkin and Gido 2011). There are many reaches where these fishes have been extirpated across the Great Plains, including our study reach (Perkin and Gido 2011; Perkin et al. 2015; Pennock et al. *In Press*). The Great Plains experienced record severe droughts in 2011 and 2012, and the interaction between drought and fragmentation has been implicated in the decline and eventual extirpation of populations of these pelagic-spawning species (Kelsch 1994; Perkin et al. 2015; Pennock et al. *In Press*). Thus, the Lincoln Street Fishway might have been constructed too late to recover these species. However, a single Plains Minnow was collected downstream of the dam and fishway during VIE tagging in 2015; it is uncertain if this fish was a native or was a bait bucket introduction. The most recently reported Plains Minnow from the Arkansas River was a single individual collected in 2006 (V. Weaver, unpublished data) despite intensive sampling in 2011-2013 (Perkin et al. 2015). Although our data is suggestive that pelagic-spawning species could benefit from the installation of fishways at dams inhibiting their movement, repatriation in reaches where they have been extirpated is a necessary first step towards their long term conservation.

In conclusion, the Lincoln Street Fishway has allowed restored continuity to the Arkansas River fish community. The recolonization of Emerald Shiner to the reach upstream of the dam serves as an indication that a Dutch Pool and Orifice fishway can allow movement of small-bodied minnows in a Great Plains river. This is further supported by the capture of VIE marked individuals of two species within the upper portions of the fishway, and the detected movement of PIT tagged fishes upstream during our water level experiment. Although the fishway appears to restore movement corridors, another low-head dam exists 9 rkm upstream that likely impedes fish movement. Removal of this barrier to fish movement on the Arkansas River in Kansas would reconnect as much as 180 rkm of perennial flowing river. Restoration of adequate riverine habitat and repatriation to reaches of river from which species have been extirpated is needed across the region to ensure the long-term persistence of endemic species reliant on connectivity and seasonal flow variation.

Figures and Tables

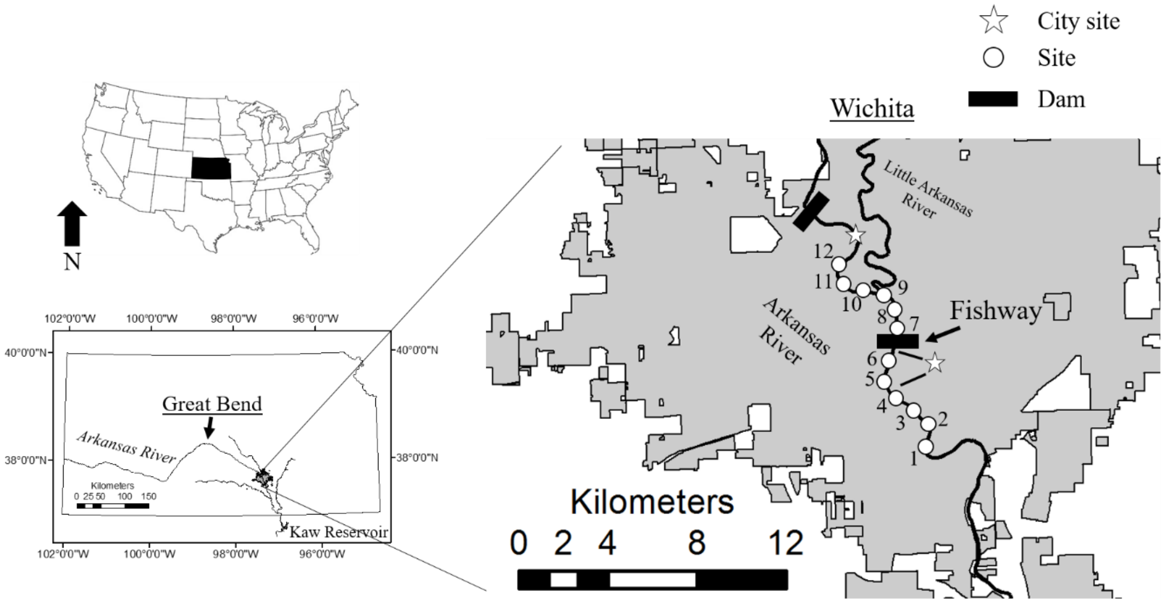

Figure 1: Study area map displaying the spatial arrangement and labeling scheme of sites (inset) sampled during 2015-2016 after construction of the Lincoln Street Dam and Fishway on the Arkansas River in Wichita, Kansas. Three sites sampled by the City of Wichita are also depicted. Within the study area the river is fragmented by two low-head dams, and flows into Kaw Reservoir upon entering Oklahoma.

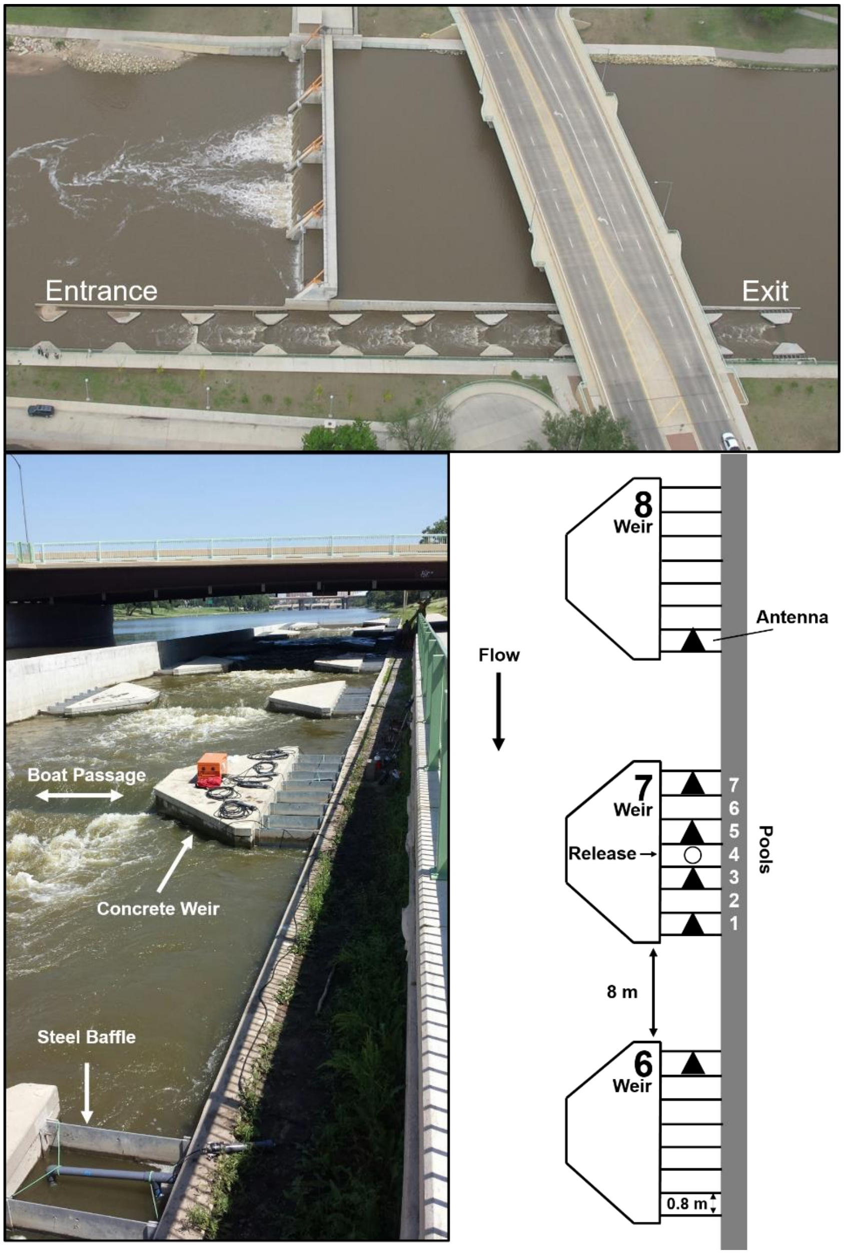

Figure 2: Areal and lateral views of the Lincoln Street Dam and Fishway on the Arkansas River in Wichita, Kansas. Dutch Pool and Orifice fishways are located on either side of a central boat passage and the downstream entrance and upstream exit labeled in the top photograph. Stationary antenna were placed within the fishway during experiments that manipulated water levels upstream of the dam to assess the movement response of fishes. Weirs are numbered from the entrance (downstream) to the exit (upstream) of the fishway. Photo credits: top) R. Schultheis, KDWPT; bottom) C. Pennock.

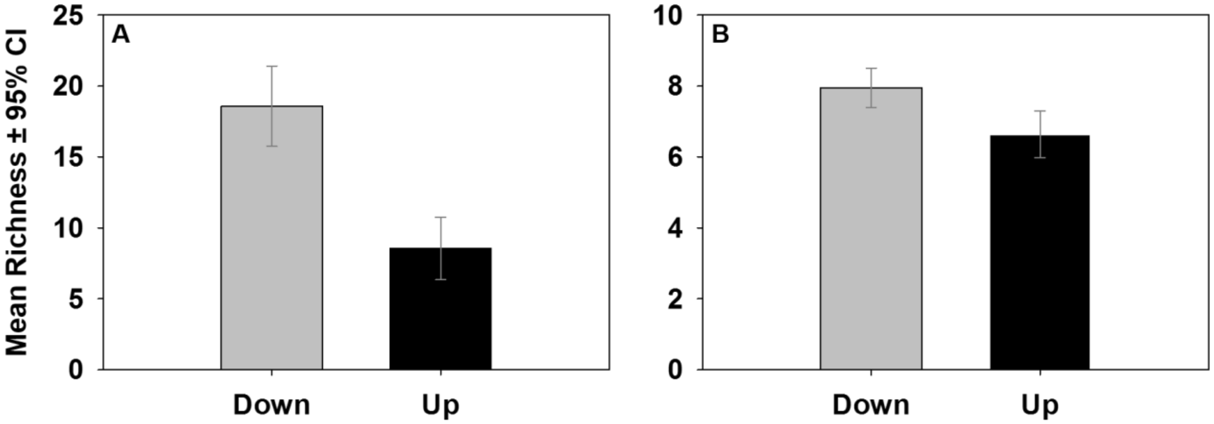

Figure 3: Comparison of mean (± SD) fish species richness upstream and downstream of the Lincoln Street Dam based on sampling by A) the City of Wichita prior to construction of the fishway (*P* < 0.001) and B) during contemporary sampling (*P* < 0.010) from this study.

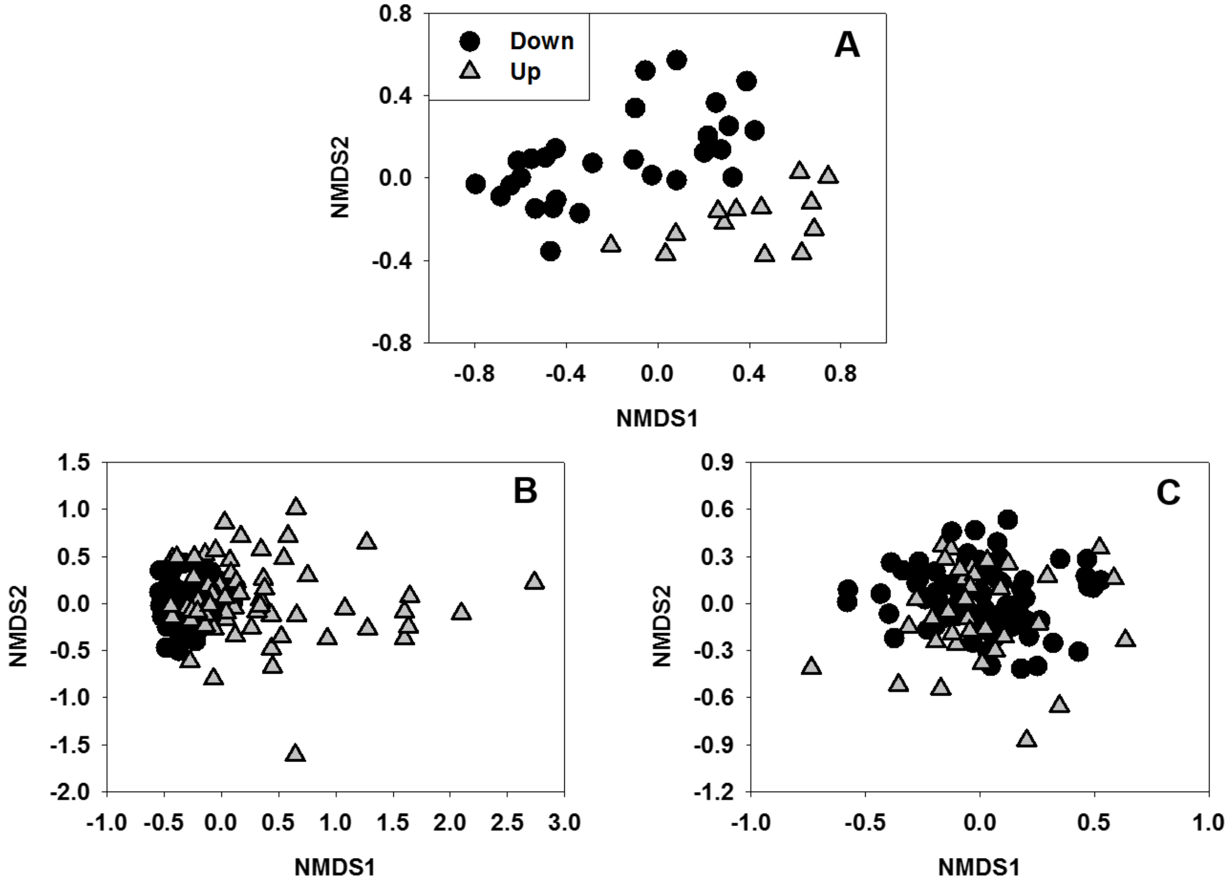

Figure 4: A) Non-metric multidimensional scaling ordination (stress = 0.14) of fish communities sampled downstream (Down) and upstream (Up) of the dam prior to the fishway being built. Results from a pMANOVA testing community structure between downstream and upstream was significant (*Psuedo* $F_{1,39} = 11.8$, $P < 0.001$, $r^2 = 0.23$). B) Non-metric multidimensional scaling ordination (stress = 0.18) of fish communities from contemporary sampling that occurred after a fishway was built on the Arkansas River at the Lincoln Street Dam in Wichita, Kansas. Community structure was significantly different (*Psuedo* $F_{1,142} = 15.2$, $P < 0.001$, $r^2 = 0.10$) between downstream and upstream communities. Communities are statistically significantly different regardless of whether all sites are considered (B) or if the lentic sites (7, 8, and 9), where sampling effort varied compared to lotic sites, are excluded (C; stress = 0.24).

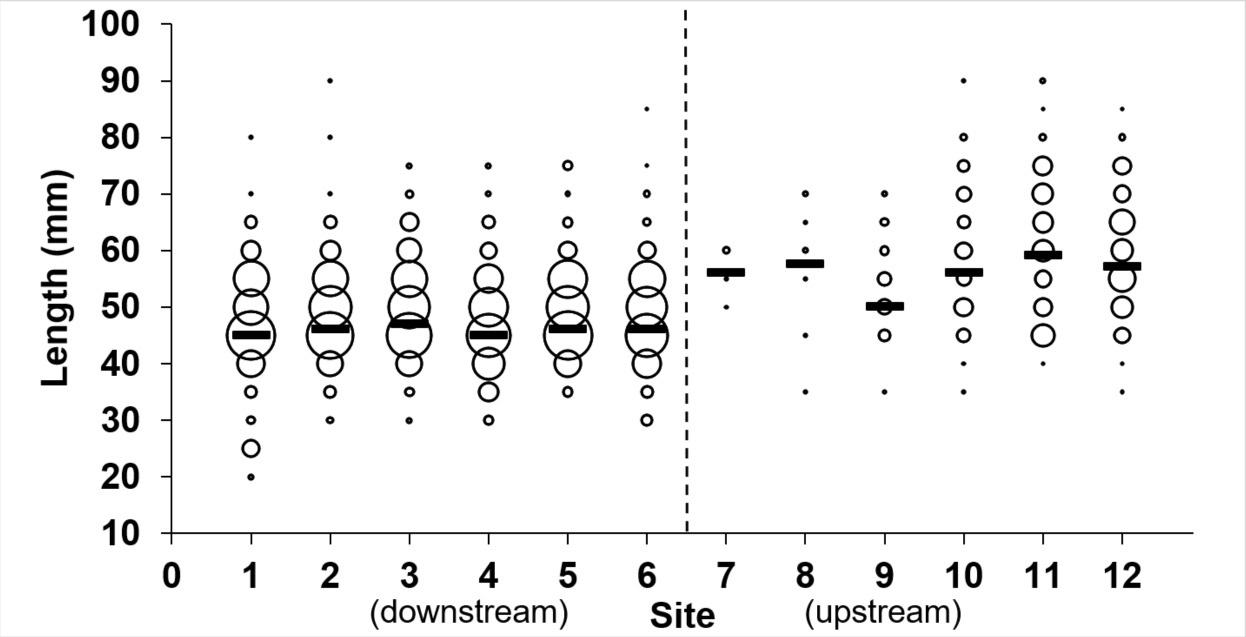

Figure 5: Length-frequencies of Emerald Shiner collected from 12 sampling sites. Dam location relative to site locations is represented by the dashed line. The area of a circles is proportional to the relative catch of 5 mm size classes ranging from 20-90 mm TL across all sites. Horizontal bars represent the median length at each site. The number of individuals was significantly higher downstream (*P* < 0.001, mean = 314 fish) compared to upstream (mean = 37 fish). Median length was significantly higher upstream (*P* < 0.001, median =61 mm) compared to downstream (median = 47 mm).

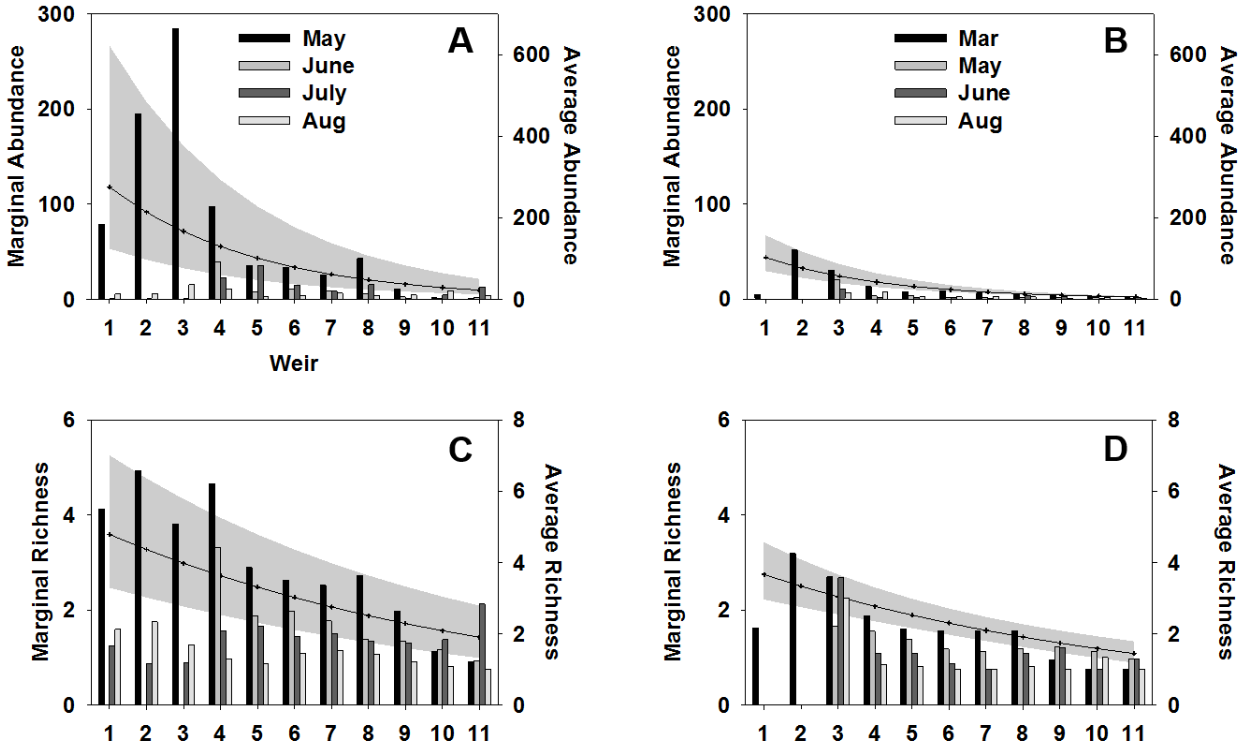

Figure 6: Number of individuals (abundance) declined significantly with increasing distance upstream (weir) within the fishway in both 2015 (A) and 2016 (B). Species occurrence (richness) showed a similar trend in 2015 (C) and 2016 (D) as abundance. Lines and confidence regions represent marginal estimates with 95% confidence intervals from generalized linear models with a Poisson distribution using weir number as a fixed effect and month as a random effect. All relationships were significant (*P* < 0.001).

Table 1: Species of conservation interest that are targets for passage at the Lincoln Street Fishway on the Arkansas River in Wichita, Kansas.

Common Name	Scientific Name	Conservation Status	Maximum Total Length[a]
Arkansas Darter	*Etheostoma cragini*	Threatened in Kansas	64 mm
Plains Minnow	*Hybognathus placitus*	Threatened in Kansas	130 mm
Silver Chub	*Macrhybopsis storeriana*	Endangered in Kansas	150 mm[b]
Peppered Chub	*Macrhybopsis tetranema*	Endangered in Kansas	76 mm
Arkansas River Shiner	*Notropis girardi*	Federally Threatened; extirpated from Kansas (Haslouer et al. 2005)	80 mm

[a] Kansas Fishes Committee (2014)

[b] Silver Chub maximum total length is 230 mm elsewhere in its range, but 150 mm is typical in Kansas (Mandrak 2014).

Table 2: Number of individuals collected during sampling up- and downstream of the Lincoln Street Dam and pre- and post-fishway construction on the Arkansas River in Wichita, Kansas. Sampling pre-fishway used a combination of tote barge electrofishing and seining and post-fishway sampling only used seining. Species of conservation concern (i.e., threatened or endangered) within Kansas are denoted with a T or E.

		Time Period and Location			
Common Name	Scientific Name	Pre Down	Pre Up	Post Down	Post Up
Black Bullhead	*Ameiurus melas*	2			
Freshwater Drum	*Aplodinotus grunniens*	192		36	2
Central Stoneroller	*Campostoma anomalum*	2			1
Goldfish	*Carassius auratus*	4	2	1	1
River Carpsucker	*Carpiodes carpio*	2319	61	51	62
Quillback	*Carpiodes cyprinus*	281	4	4	6
Grass Carp	*Ctenopharyngodon idella*	1			1
Common Carp	*Cyprinus carpio*	866	58	11	18
Red Shiner	*Cyprinella lutrensis*	28889	12666	46632	31888
Gizzard Shad	*Dorosoma cepedianum*	3553	15	59	55
Arkansas Darter (T)	*Etheostoma cragini*				1
Northern Plains Killifish	*Fundulus kansae*	67	76	171	103
Western Mosquitofish	*Gambusia affinis*	318	1385	11	29
Plains Minnow (T)	*Hybognathus placitus*	41			
Smallmouth Buffalo	*Ictiobus bubalus*	108		5	2
Bigmouth Buffalo	*Ictiobus cyprinellus*	3			1
Black Buffalo	*Ictiobus niger*	67		5	
Channel Catfish	*Ictalurus punctatus*	1879	128	1792	1683
Brook Silverside	*Labidesthes sicculus*	20			
Green Sunfish	*Lepomis cyanellus*	238	18	1	94
Orangespotted Sunfish	*Lepomis humilis*	647	50	22	39
Bluegill	*Lepomis macrochirus*	270	6	22	25
Longear Sunfish	*Lepomis megalotis*	348	7	9	52
Longnose Gar	*Lepisosteus osseus*	41		17	6
Shortnose Gar	*Lepisosteus platostomus*	7		1	
Silver Chub (E)	*Macrhybopsis storeriana*	87		8	
Peppered Chub (E)	*Macrhybopsis tetranema*	118			
Largemouth Bass	*Micropterus salmoides*	80	11	4	14
White Perch	*Morone americana*	14			
White Bass	*Morone chrysops*	44		2	
Palmetto Bass (Wiper)	*Morone chrysops x saxatilis*	54		4	
Striped Bass	*Morone saxatilis*	1			
Golden Redhorse	*Moxostoma erythrurum*	2			
Pealip Redhorse	*Moxostoma pisolabrum*	185	2	4	1

Golden Shiner	*Notemigonus crysoleucas*	13	2		2
Emerald Shiner	*Notropis atherinoides*	17548		20616	1046
Ghost Shiner	*Notropis buchanani*			2	
Carmine Shiner	*Notropis percobromus*			1	
Sand Shiner	*Notropis stramineus*	7023	5587	11712	5229
Ozark Logperch	*Percina caprodes*	12			
Channel Darter	*Percina copelandi*	1			
Slenderhead Darter	*Percina phoxocephala*	112	1	20	11
Suckermouth Minnow	*Phenacobius mirabilis*	441	30	247	112
Bluntnose Minnow	*Pimephales notatus*	2			
Fathead Minnow	*Pimephales promelas*	112	31	15	11
Bullhead Minnow	*Pimephales vigilax*	1466	196	736	1158
White Crappie	*Pomoxis annularis*	28		4	2
Black Crappie	*Pomoxis nigromaculatus*			1	
Flathead Catfish	*Pylodictis olivaris*	112	20	4	13
Walleye	*Sander Vitreus*	2			
Total Number of Individuals		*67620*	*20356*	*82230*	*41668*

Table 3: Species and the number of individuals collected from the fishway over the course of the entire study.

		2015				2016			
Common Name	Scientific Name	May	Jun	Jul	Aug	Mar	May	Jun	Aug
Black Bullhead	*Ameiurus melas*	4							
Freshwater Drum	*Aplodinotus grunniens*	1		7	3		5		
Goldfish	*Carassius auratus*	1		1	2		1		2
River Carpsucker	*Carpiodes carpio*	14				1	6	5	
Quillback	*Carpiodes cyprinus*	5							
Common Carp	*Cyprinus carpio*		1	2	2	1	3		
Red Shiner	*Cyprinella lutrensis*	15647	2023	749	1928	1081	871	281	511
Gizzard Shad	*Dorosoma cepedianum*	32	4	1	45		1		
Arkansas Darter (T)	*Etheostoma cragini*						1		
Western Mosquitofish	*Gambusia affinis*			1	1				
Channel Catfish	*Ictalurus punctatus*	128	98	74	17	9	276	119	8
Green Sunfish	*Lepomis cyanellus*	10	1			1	1		
Orangespotted Sunfish	*Lepomis humilis*	64	14	3		1		1	
Bluegill	*Lepomis macrochirus*	76	3	8	2	1			
Longear Sunfish	*Lepomis megalotis*	54	1	1	3	3		4	1
Longnose Gar	*Lepisosteus osseus*			1			1		
Largemouth Bass	*Micropterus salmoides*	1		1					1
White Perch	*Morone americana*	9							
Emerald Shiner	*Notropis atherinoides*	6427	83	2427	4	1820	1	1	36
Ghost Shiner	*Notropis buchanani*	1	3						
Sand Shiner	*Notropis stramineus*	3618	256	1	62	121	1	37	
Ozark Logperch	*Percina caprodes*					6			
Slenderhead Darter	*Percina phoxocephala*					11			1
Suckermouth Minnow	*Phenacobius mirabilis*	11				47			
Fathead Minnow	*Pimephales promelas*	3				4			
Bullhead Minnow	*Pimephales vigilax*	211	41	3	4	197	11	29	26
White Crappie	*Pomoxis annularis*	7			6			2	1
Black Crappie	*Pomoxis nigromaculatus*	2							
Flathead Catfish	*Pylodictis olivaris*				1		1	3	
Total Number of Individuals		*26326*	*2528*	*3280*	*2080*	*3304*	*1180*	*482*	*587*

Table 4: Number of fish released, percent tag retention, and percent survival of fish tagged with passive integrated transponder tags over 24 h. Fish were released in May and June.

Species	Treatment	Number Released	Percent Retention	Percent Survival
Red Shiner	Baseline	92	100	93
	0.1 m lower	96	100	100
	0.15 m lower	93	99	100
Sand Shiner	Baseline	94	100	97
	0.1 m lower	91	100	97
	0.15 m lower	99	100	97
Plains Minnow	Baseline	65	100	98
	0.1 m lower	30	100	100

Table 5: Mean distances (m; mean ± SD) moved by detected fish in the fishway in downstream and upstream directions during an experiment that manipulated the water levels in the fishway. Numbers in parenthesis represent the maximum distance moved by any individual in a given direction during each treatment.

Water Level Treatment	Red Shiner		Sand Shiner		Plains Minnow	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Baseline	2.90 ± 3.14 (16)	2.85 ± 2.71 (13)	2.06 ± 1.06 (5)	1.11 ± 0.33 (2)	4.56 ± 5.86 (24)	3.65 ± 5.51 (26)
-0.10	2.91 ± 2.66 (13)	1 (1)	3.09 ± 2.38 (13)	8.5 ± 10.6 (16)	1.78 ± 0.67 (3)	1.56 ± 1.33 (5)
-0.15	1.91 ± 1.28 (7)	2.29 ± 1.36 (5)	2.39 ± 2.35 (18)	1.5 ± 0.71 (2)	---	---
Grand Mean	2.50 ± 2.39	2.50 ± 2.23	2.53 ± 2.13	2.31 ± 4.13	3.82 ± 5.16	3.11 ± 4.86

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Appendix A-Fishway Characteristics

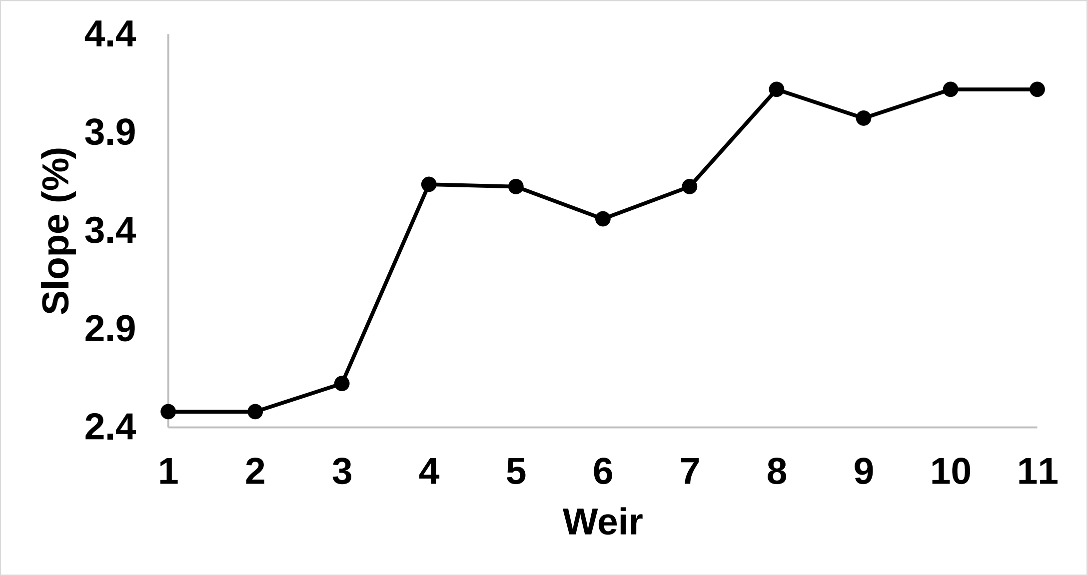

Figure A.1: Slope of concrete weirs in the Lincoln Street Fishway on the Arkansas River in Wichita, Kansas.

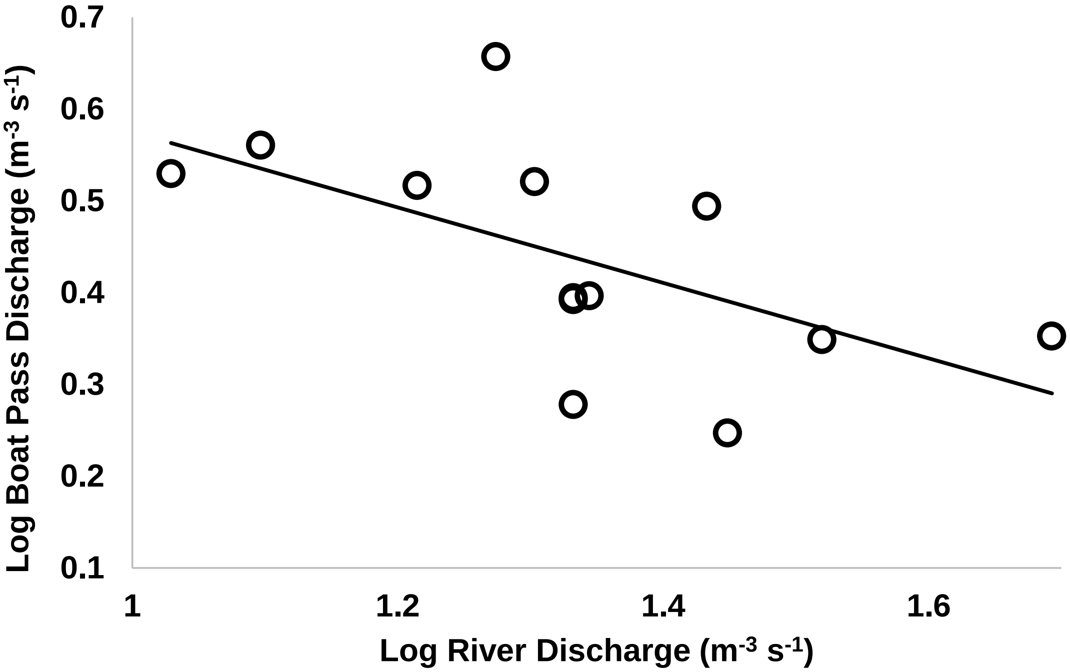

Figure A.2: Regression of discharge in the Lincoln Street Boat Passage as a function of river discharge. River discharge was taken from the nearest USGS gage which is ~3 km downstream.

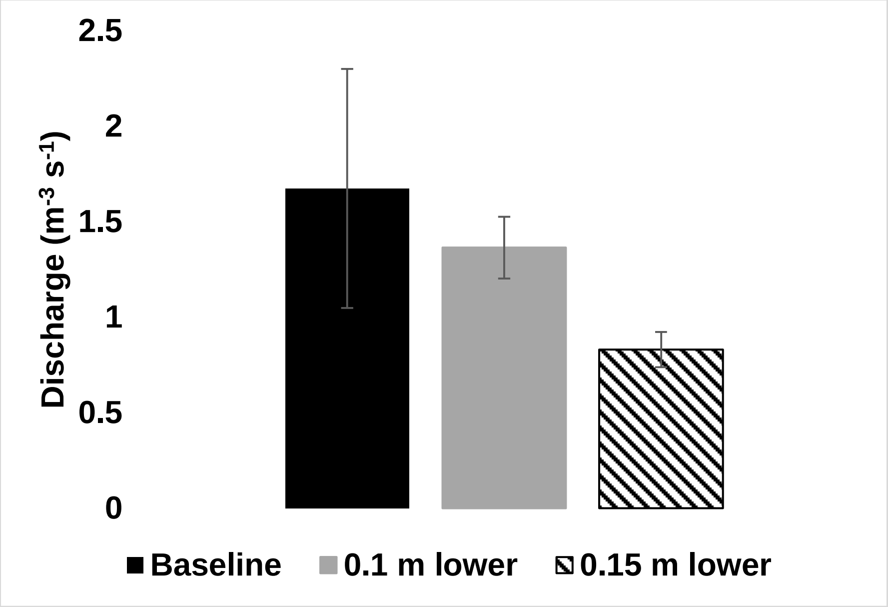

Figure A.3: Discharge in the Lincoln Street Boat Passage (mean ± SD) measured at three water level treatments during two replicated fish movement experiments in the Lincoln Street Fishway on the Arkansas River in Wichita, Kansas.