Examination of Non-Game Fish Use of a Denil Fishway on the Cedar River, Nebraska

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Abstract - Studies on the effectiveness of fish passage structures to allow for upstream movements through dams have mostly focused on recreationally important fishes. A Denil fishway fitted with a passive integrated transponder (PIT) tag array was constructed on the Cedar River near Spalding, Nebraska, in 2015. We evaluated whether this passage structure would allow for upstream movement of five non-game species. Individuals were captured, implanted with PIT tags, and released during 2016–2018. An attempt at passage was noted if an individual passed the antenna placed at the bottom of the fish passage structure and successful passage was defined as crossing the antenna at the top of the fish passage structure. The number of attempts and successful passages by date and species were monitored. Passage attempts and successful passage occurred between April and September for all five species, but peaked in May in 2017 and 2018 and later in the year in 2016. The rates of attempts varied from 15% for *Platygobio gracilis* (Flathead Chub) to 67% for *Carpiodes carpio* (River Carpsucker). The rates of successful passage varied from 66% for *Cyprinus carpio* (Common Carp) to 100% for Flathead Chub. Results of this study indicate that non-game fish use and successfully move upstream through a Denil fish passage structure on the Cedar River in Nebraska. Similar structures might be useful to facilitate movement of non-game fishes through dams in Great Plains rivers.

Introduction. Great Plains rivers and streams are dynamic systems; these waters may periodically become intermittent, especially during the summer months or dry years (Fausch et al. 2002, Scheurer et al. 2003). Such changes in discharge and connectivity can influence the distribution and local abundances of aquatic taxa (Hedden and Gido 2020, Hughes 1999). Consequently, fish taxa have evolved to tolerate a wide range of abiotic conditions and have adopted multiple strategies that aid in their dispersal when connectivity of habitats is restored (Gido et al. 2010, Schumann et al. 2015). However, physical barriers such as dams or road crossings may further challenge movement of fish and have often been cited as one of the threats to population persistence of many Great Plains fishes (MacPherson et al. 2012, Perkin et al. 2015).

Various structures have been engineered over the past 300 years to allow fish passage upstream and downstream through or around dams (Nemenyi 1941). Fish passage structures were originally designed to allow for upstream spawning migrations of many salmonid species (Cobb 1925), and the majority of fish passage studies have focused on salmonids and other recreationally important fishes (Roscoe and Hinch 2010). However, many species in rivers and streams are small-bodied fishes and considered non-game. Many of these species migrate to spawn and to find different habitats seasonally (Lindsey and Northcote 1963, Mills 1991, Smith 1991, Tyus 1985). Movement may be important for locating critical edge habitats (Schwalme et al. 1985), preferred seasonal thermal habitats (Labbe and Fausch 2000), or appropriate channel depths and canopy cover (Wellemeyer et al. 2019). The movement of non-game fish species upstream has been hypothesized as an important mechanism for repopulating upstream reaches where dewatering and other habitat fragmentations have

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led to local extirpations (Cross et al. 1985, Fausch and Bestgen 1997, Luttrell et al. 1999, Perkin et al. 2019, Walters et al. 2014). Barriers such as dams may lead to localized extinctions if adults are not allowed to traverse upstream through fish passage structures.

The design and construction of a fish passage structure may influence fish use and passage efficiency (Noonan et al. 2012). This is true for both the target species for which the structure was designed as well as other species that may use these structures. Several studies have examined non-game fish passage through passageways associated with dams (e.g., Bunt et al. 2001, Lucas and Frear 1997, Lucas et al. 1999, Smith 1991). However, not enough data has been collected to justify choosing one fish passage structure design over others based on observed attraction and passage efficiency (Bunt et al. 2012). Some studies completed to date show a large portion of tagged non-game species entering passage structures, but low (<50%) success in passing through the fish passage structure (Lucas and Frear 1997, Lucas et al. 1999). In addition, most non-game fish species passage research has been conducted in rivers in other regions (i.e., east and west of the Great Plains), where hydrology may be less dynamic than in the Great Plains.

A Denil fish passage structure became functional on the Cedar River near Spalding, Nebraska (NE), USA in 2015. The structure primarily was built to support the passage of *Ictalurus punctatus* Rafinesque (Channel Catfish). During 2016–2018, we examined the use of the Denil structure by five non-game fish species, two cyprinids and three catostomids. Specifically, we calculated the number of upstream passage attempts and passage success over time for *Cyprinus carpio* Linnaeus (Common Carp), *Platygobio gracilis* Richardson (Flathead Chub), *Carpiodes cyprinus* Lesueur (Quillback Carpsucker), *Carpiodes carpio* Rafinesque (River Carpsucker), and *Moxostoma macrolepidotum* Lesueur (Shorthead Redhorse).

Materials and Methods. The Cedar River (hydrologic unit code 10210010; stream length ~200 km; catchment area = 3,186 km^2) is a third-order perennial warmwater stream that flows generally southeast through the eastern Sandhills region of Nebraska before merging with the Loup River near Fullerton, NE, USA (Hilgert 1982). Baseflows of this alluvial river are largely supported by groundwater, but overland precipitation provides groundwater recharge and contributes to seasonal peak flows (Hilgert 1982, Dave and Mittelstet 2017). Mean annual precipitation in the basin is ~68 cm, mostly in the form of snow (U.S. Climate Data 2020). Lake Ericson (27.3 ha) and Spalding Lake (13.6 ha) are two impounded waters on the main-stem of the Cedar River, and both are used for hydroelectric production. Historical collections have indicated that at least 19 fish species were found in the Cedar River (Nebraska Game and Parks Commission (NGPC), Lincoln, NE, 2014 unpubl. data).

The Denil fish passage structure at Spalding Dam is comprised of three chutes and three pools (see Schainost 2018 for specific details). Each chute is 9.04 m long with a rise of 1.74 m and a slope of 13.5%. Eleven baffled slots are positioned at a 45° incline in each chute and spaced ~0.6 m apart. The elevation difference between the reservoir and the river downstream of the dam is approximately 3.66 m, depending on reservoir water levels (Schainost 2018).

In April 2016, a passive integrated transponder (PIT) tag detection system (IS1001 Biomark®, Boise, ID) was installed in the Denil fishway at Spalding Dam. One antenna was placed at the furthest upstream pool and one antenna at the furthest downstream pool. The antenna current limit was 11.0 Ap-p, firmware enforced, and had an operating frequency of 134.2 kHz. Antennae were operational from April to October.

Fish were collected from the Cedar River below Spalding Dam and the Denil fish passage structure between May 2 and June 6 each year from 2016 through 2018 using mini hoop nets (5 hoops, 508 mm diameter, 19 mm mesh), a Smith-Root SR-16S boat electrofishing unit with two netters (pulsed direct current at 200–250 volts, 8–10 amps), and a

Smith-Root LR-24 backpack electrofishing unit with two netters (pulsed direct current at 150–200 volts, 60 Hz). Collection and tagging of fish occurred in May 2016 and April 2017 and 2018. Individual fish were measured for total length (TL, mm), and all individuals of the five species >100 mm TL were implanted in the dorsal musculature with a single PIT tag (12.5 mm x 134.2 kHz, HPT 12 format, Biomark®). All fish were released near the site of capture and downstream of the Denil fish passage structure.

Times, dates, and individual fish identification numbers were downloaded from the IS1001 Biomark® system on a monthly basis. An attempt at an upstream passage was counted if the individual was detected by the antenna placed at the bottom of the fish passage structure, and successful passage was defined as being detected by the antenna at the top of the fish structure. We examined the total number of attempts and successful passages by date to determine peaks for each species and each year. The proportion of individuals attempting to pass was calculated for each species as the number of individuals that were detected by the downstream antenna divided by the total number of tagged fish for that species. If an individual made multiple attempts, only the first attempt was considered in the calculation. Passage success was calculated for each species as the total number of individuals that were detected by the upstream antenna divided by the total number of attempts for that species. If an individual made multiple attempts and multiple successful passages, then each of these occurrences were included in the calculation. The number of individuals that attempted passes and the number of successes were summed across all years for each species.

Results. A total of 172, 295, and 376 individual fish were tagged during 2016, 2017, and 2018 respectively (Table 1). River Carpsucker (42%) and Shorthead Redhorse (31%) comprised the majority of the five species tagged (Table 1). Mean TL was greatest for Common Carp ($\bar{x}$ = 490 mm, SE = 10, n = 84) and smallest for Flathead Chub ($\bar{x}$ = 155 mm, SE = 9, n = 9; Table 1). Flathead Chub were rare in 2016 and 2017 (<4% of total numbers of individuals tagged), and no individuals were caught in 2018. The initiation of tagged fish movement began in late April in 2017 and 2018 but not until late May in 2016. The number of successful passages frequently peaked in May for all five species (Table 2). The date of the last successful passage was consistently latest for Quillback (July 9–July 18) and most variable for Common Carp (June 15–September 13).

The percentage of tagged individuals that attempted passage varied from 15–67% (Table 3). Of the tagged fish that made attempts, the average number of attempted passages per individual ranged from 1–2; Common Carp, Flathead Chub, and Quillback had the highest number of attempts per individual (Table 3).

Table 1. Total number by year and overall mean total length (TL; mm) of five non-game fish species tagged with passive integrated transponder (PIT) tags within a Denil fishway at Spalding Dam on the Cedar River, Nebraska. Numbers in parentheses represent one standard error.

	Number				
Species	2016	2017	2018	Total	Mean TL
Common Carp	21	47	16	84	490 (10)
Flathead Chub	6	14	0	20	155 (9)
Quillback	40	39	29	108	290 (7)
River Carpsucker	38	130	196	364	296 (4)
Shorthead Redhorse	67	65	135	267	280 (4)
Total	172	295	376	843	

The rates of successful passage were relatively high and varied between 66 and 100% (Table 3). Of the tagged fish that successfully passed, the average number of successful passages per individual varied between 1 and 2. The highest number of successful attempts per individual were noted for Flathead Chub (Table 3).

Discussion. In this study, the timing of upstream movement and passage success was monitored across three years for five non-game fish species common to Great Plains rivers. To our knowledge, this is the first documented use and evaluation of a Denil fish passage structure on a river in the Sandhills of Nebraska. Passage through the Denil structure for all five non-game species generally peaked in May, similar to findings by Pennock et al. (2018); the later dates noted in 2016 were most likely due to initiation of tagging later in the year. This spring timeframe for migration and spawning activity coincides with those typically reported for other catostomids and cyprinids (Durham and Wilde 2005, Durham and Wilde 2009, Rodriguez-Ruiz and Granado-Lorencio 1992, Taylor and Miller 1990). Further research is needed to understand how water temperatures and discharge may attract fish to the structures and allow or disallow successful passage, particularly during spawning migration.

Frequencies of upstream passage attempts varied widely between species. These differences may be related to whether the structure provided the appropriate water flow or whether water temperatures were conducive to upstream migration for these species. For example, Quillback may make long upstream spawning migrations after water temperatures

Table 2. Dates of first, peak, and last successful upstream passage during 2016–2018 for five non-game fish species tagged with passive integrated transponder (PIT) tags at the Spalding Dam Denil fishway on the Cedar River, Nebraska. Numbers in parenthesis indicate the number of fish that made a successful passage on the peak passage date.

Species	Successful Passage	Year 2016	Year 2017	Year 2018
Cyprinus carpio (Common Carp)	First	June 15	May 2	April 28
	Peak	June 15 (1)	May 5 (4)	May 7 (4)
	Last	June 15	September 13	July 10
Platygobio gracilis (Flathead Chub)	First	NA	May 6	July 22
	Peak	NA	May 13 (2)	July 22 (1)
	Last	NA	May 13	July 22
Carpiodes cyprinus (Quillback Carpsucker)	First	July 9	May 5	May 1
	Peak	July 9 (1)	May 6 (4)	May 21 (4)
	Last	July 9	July 10	July 18
Carpiodes carpio (River Carpsucker)	First	June 28	April 22	May 1
	Peak	August 2 (2)	May 5 (23)	May 23 (51)
	Last	August 3	August 1	July 20
Moxostoma macrolepidotum (Shorthead Redhorse)	First	May 30	April 22	May 1
	Peak	August 3 (2)	May 14 (4)	May 21 (13)
	Last	August 3	July 28	July 26

Table 3. Attempted passages, approaches and successful passages during 2016–2018 of five non-game fish species tagged with passive integrated transponder (PIT) tags at the Spalding Dam Denil fishway on the Cedar River, Nebraska. Numbers in parentheses represent one standard error.

Species	Tagged fish that attempted passage		Average approaches per individual	Rate of successful passage	Average successful passages per individual
	(n)	(%)[1]	n (±SE)	(%)[2]	n (±SE)
Cyprinus carpio (Common Carp)	40	48	2 (±0.2)	66	1 (±0.1)
Platygobio gracilis (Flathead Chub)	3	15	2 (±0.3)	100	2 (±0.3)
Carpiodes cyprinus (Quillback Carpsucker)	38	35	2 (±0.2)	82	1 (±0.1)
Carpiodes carpio (River Carpsucker)	243	67	1 (±0.8)	83	1 (±0.0)
Moxostoma macrolepidotum (Shorthead Redhorse)	122	46	1 (±0.8)	79	1 (±0.1)

[1]The rate of individuals attempting to pass upstream was calculated for each species as the number of individuals who passed through the downstream antennae divided by the total number of tagged fish for that species. If an individual made multiple attempts, only the first attempt was considered in the calculation.
[2]The rate of passage success was calculated for each species as the total number of individuals who passed through the upstream antenna divided by the total number of attempts for that species. If an individual made multiple attempts and multiple successful passages, then each of these occurrences were included in the calculation.

exceed 5°C and when discharges are relatively high (Parker and Franzin 1991). Bunt et al. (2012) found that rates of passage attempts by different cyprinid species through a low-head weir varied with discharge rate. Research is needed to understand which species may make multiple upstream movements within a given season and what environmental factors may influence their movements.

A high proportion of the fish that attempted to pass upstream in our study did so successfully. Overall, frequencies of successful passage through the Denil structure were higher in our study than other migratory fish (Lucas and Frear 1997, Bunt et al. 2012, Noonan et al. 2012). Higher passage success may be related to the selection of relatively larger non-game species available in Cedar River; previous research has shown that large bodied non-game species are more likely to withstand higher discharges than small-bodied individuals (Ficke et al. 2011, Prenosil et al. 2015). However, it could also be possible that small fish are able to navigate higher discharge rates by using boundary layer effects (Bunt et al. 1999). The design of fish passage structures on Great Plains rivers in the future should consider swimming capabilities of non-game species as well as temperature and flow cues that initiate fish movement (Dodds et al. 2004).

Fish passage structures are often constructed to support passage of recreationally important fish or species of greatest conservation need (Roscoe and Hinch 2010). Existing structures could allow for passage of other species (e.g., Noonan et al. 2012, Roscoe and Hinch 2010, Slatick and Basham 1985), but most are not specifically designed for non-game fish (Mallen-Cooper and Brand 2007, Warren and Pardew 1998, Roscoe and Hinch 2010). Fish passage structures may also be designed to support or prevent the upstream movement of non-native species such as Common Carp (McLaughlin et al. 2013). Managers can use the results of this study and others on the timing of movement through the Denil fishway to operate fish passage structures that promote upstream movement of these native non-game species. Additionally, managers have been urged to promote selective fragmentation of and look for opportunities to reduce fish passage capabilities of non-desired species within a system while not compromising movement of desired species (Rahel and McLaughlin 2020). Ultimately, improved knowledge of how various fish species use a variety of fish passage designs can lead to additional ability to manage aquatic resources.

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