Development of a Nebraska Culvert Aquatic Organism Passage Screening Tool

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Project Summary

Culverts channelize water relative to natural stream reaches, which can increase the velocity of water passing through them. Increased water velocities can alter stream morphology and create a possible barrier or obstacle to fish passage, which may affect localized fish abundance and diversity. In addition to changes in water velocity, a waterfall can be created on the downstream side. These changes potentially limit the ability of stream fishes to reach upstream areas.

Field surveys were conducted at privately owned culverts on gravel roads in the South Loup River watershed, NE, using backpack electrofishing to sample for fish abundance and diversity, red shiner (*Cyprinella lutrensis*) movement was assessed using a mark-recapture study over a 20 day period, plains topminnow (*Fundulus sciadicus*) from aquaculture were introduced and movement was monitored during a three day period, and FishXing models were conducted on six culverts using 10 species. Results from FishXing models were compared to field observations to determine the accuracy of modeling culvert passability by fish in prairie streams.

The single-barrel pipe culvert exhibited relatively high water velocity and downstream plunge pool depth compared to double-barrel pipe culverts and bridges, and double-barrel pipe culverts exhibited greater downstream plunge pool depth compared to bridges. Also, downstream of single-barrel pipe culverts appear to support high abundances of non-native and piscivorous fish species. Red shiner downstream proportional movement was 83% higher and movement upstream was 53% higher past

bridges compared to single-barrel pipe culverts, but a difference was not detected. Plains topminnow proportional movement downstream was 69% higher and movement upstream was 52% higher past bridges compared to single-barrel pipe culverts.

In the laboratory, the swimming and jumping performance of stream fishes were tested. A ten liter swim tunnel and an artificial waterfall were used to test ten species of fish from five families. Swimming tests were conducted at 17.5^{o} C to determine maximum swimming speed by using a constant acceleration test at 5 cm/s every 10 seconds. The swimming results varied with largemouth bass having the highest (65±1.7 cm/s) and mosquitofish having the lowest mean swimming velocity (37.5±1.2 cm/s). Jumping tests were conducted using a weir that was increased at a height of 1 cm per trial until none of the 10 individuals of a species could clear the height. Jumping results varied with green sunfish clearing the greatest height (13 cm) and bluegill which did not jump at all.

The swimming and jumping data for fish are critical to modeling potential barriers to dispersal. The data collected in this study indicate that most stream fishes would not be impeded by the assessed road crossings on the South Loup River. Predictions from the laboratory data modeled using FishXing correlated to observed field movement data and could be useful in prairie stream conservation and management by predicting fish movement through culverts. Further research is needed with larger sample sizes, more study locations, and multiple years to determine the effects of culverts on prairie stream fish abundance, diversity, and movement.

1.0 Effects of Culverts on Fish Abundance and Diversity in the South Loup River, Nebraska

1.1 Summary

Culverts channelize water relative to natural stream reaches, which can increase the velocity of water passing through them. Increased water velocities can alter stream morphology and create a possible barrier or obstacle to fish passage, which can affect localized fish abundance and diversity. Few studies have analyzed fish movement past culverts in prairie streams, and little is known about the effects of culverts on fish abundance and diversity in prairie streams. A survey was conducted at eight culverts in the South Loup River watershed, NE, using backpack electrofishing to sample for fish abundance and diversity. Four single-barrel pipe culverts, two double-barrel pipe culverts, and two bridges used as controls were analyzed in this study. Single-barrel pipe culvert exhibited high water velocity and downstream plunge pool depth compared to double-barrel pipe culverts and bridges, and double-barrel pipe culverts exhibited greater downstream plunge pool depth compared to bridges. Despite effects on stream morphology, the overall fish abundance and diversity in this system was similar among all stream crossing types. However, downstream of culverts appear to support relatively high abundances of non-native and piscivorous fish species. Further research is needed with larger sample sizes and more study locations to determine the effects of culverts on prairie stream fish abundance and diversity.

1.2 Introduction

Multiple studies have been conducted on the effect of culverts on fish movement, with most studies being conducted on salmonid species within mountainous or coastal regions (Warren and Pardew 1998; MacPherson 2012). Few studies have analyzed the effects of different types of culverts on fish abundance and diversity, and even fewer studies have analyzed the effect of culverts on prairie streams and non-salmonid species (Rosenthal 2007). Many prairie streams lack salmonid species and have different stream morphology compared to mountain stream. Therefore, analysis of culverts in mountainous regions do not compare to analysis of culverts in prairie regions.

Culverts can channelize stream flow which can increase the velocity of water moving through them compared to bridges (MacPherson 2012). Increased water velocity can cause sediment scouring downstream of the culvert creating relatively large pools directly downstream of the culverts, which can alter the natural habitat of a stream (MacPherson et al. 2012). Prairie streams could be more susceptible to the creation of large downstream pools from culverts because of the sandy/silty substrate associated with many prairie streams (Amos et al. 1997). Pools created from culverts tend to take on a lentic characteristic with relatively large littoral zones on the margin and a relatively deep pool in the center. Relatively lentic pool habitats often create a habitat for small prey fishes, which in turn can increase the abundance of piscivorous predatory fish species (Freeman 2001; Langeani et al. 2005). Piscivorous predators can congregate in pools, and possibly create a biological barrier to smaller prey fishes. Many of the piscivorous species within prairie streams are non-native sport fish that have been introduced from reservoirs or farm ponds (Cross and Moss 1987).

Culverts can also act as a barrier to fish movement from increased water velocity, decreased water depth, and by the creation of waterfalls (Burford et al. 2009; MacPherson et al. 2012). If a culvert does create a barrier or hinder movement, downstream pools can be used as staging areas for fish attempting to move upstream through the culvert. The creation of staging areas and prime habitat for small fishes by culverts can alter the natural distribution of fishes within a localized stream reach. Staging areas for small prey fish could also increase piscivorous fish. Reservoirs and lakes around the country introduce non-native sport fish that are primarily introduced for recreation (Fausch et al. 2002; Gido et al. 2005). These non-native sport fish have invaded many streams, and could be using the pools created by culverts as key habitat.

Barriers to fish movement can either be a net positive or negative for native fish species. The species of concern in the South Loup River include the finescale dace (*Phoxinus neogaeus*), the northern redbelly dace (*Chrosomus eos*), and the plains topminnow (*Fundulus sciadicus*). Exotic species primarily include sport fish that have been introduced from lakes and reservoirs in the state, such as largemouth bass (*Micropterus salmoides*) and northern pike (*Esox lucius*). Common carp (*Cyprinus carpio*) are also an exotic species within the South Loup River. The South Loup River is a tributary to the Platte River, and thus, colonization of the invasive western mosquitofish (*Gambusia affinis*) is possible. Currently, no observations of western mosquitofish have been recorded. Culverts could create a barrier for upstream movement of exotic species, which could be positive for native fish species that compete with western mosquitofish like the plains topminnow (Schumann 2013). However, if culverts are a barrier to the upstream movement of species of concern, vital habitat for foraging and reproduction could be inaccessible.

The objective of this study was to assess the effect culverts have on fish community abundance and diversity within a portion of the South Loup River watershed. The primary hypothesis for this objective is that culverts will decrease upstream fish abundance and diversity because of the reduced/eliminated fish movement from downstream to upstream, and from the altered habitat downstream the culvert. The hypothesis was tested by comparing upstream fish abundance and diversity to downstream measures for culverts and bridges. Bridges will be used as a control for this objective because bridges have been shown to maintain streams at a more natural state and do not have the same negative effects on fish communities as culverts (Warren and Pardew 1998; Anderson et al. 2012; MacPherson et al. 2012). The secondary hypothesis that was tested was that downstream of culverts will have increased piscivorous fish abundances. The secondary hypothesis was tested by comparing the abundance of piscivorous fish downstream a culvert versus the upstream abundance of piscivorous fish. Upstream of the culvert was used as a control for this hypothesis, because this area does not have waterfalls or plunge pools which could affect fish abundance. The final hypothesis was that culverts will affect downstream morphology and water chemistry. The final hypothesis was tested by comparing upstream morphological and chemical variables with downstream morphological and chemical variables.

1.3 Methods

1.31 Study Site:

An initial inventory was conducted within the Loup River, Nebraska to determine the quantity and type of culverts within the watershed. The Loup River watershed was chosen because it is primarily groundwater spring fed, and therefore is a perennial stream. The South Loup River watershed was chosen within the Loup River watershed because of the quantity and diversity of culverts, and the ability to acquire land owner permission. Eleven sites were chosen within the South Loup River watershed. These sites were chosen based on their stream road crossing type and the likelihood that they would have water throughout the year. Site 1 and site 10 went dry in July 2013. No fish were observed at site 1 or 10, and fish were only observed downstream at site 11 in May 2013. A beaver dam at site 11 was washed away during heavy rains in late July and August 2013. However, water receded quickly after the rains, and site 11 went dry in August 2013. A pool was left by the beaver dam upstream site 11, but no fish were observed in the pool. Because of this sites 1, 10, and 11 were not used in the analysis leaving eight sites for analysis (Figure 1-1). All sites used for analysis were located on county gravel roads or private farm drives.

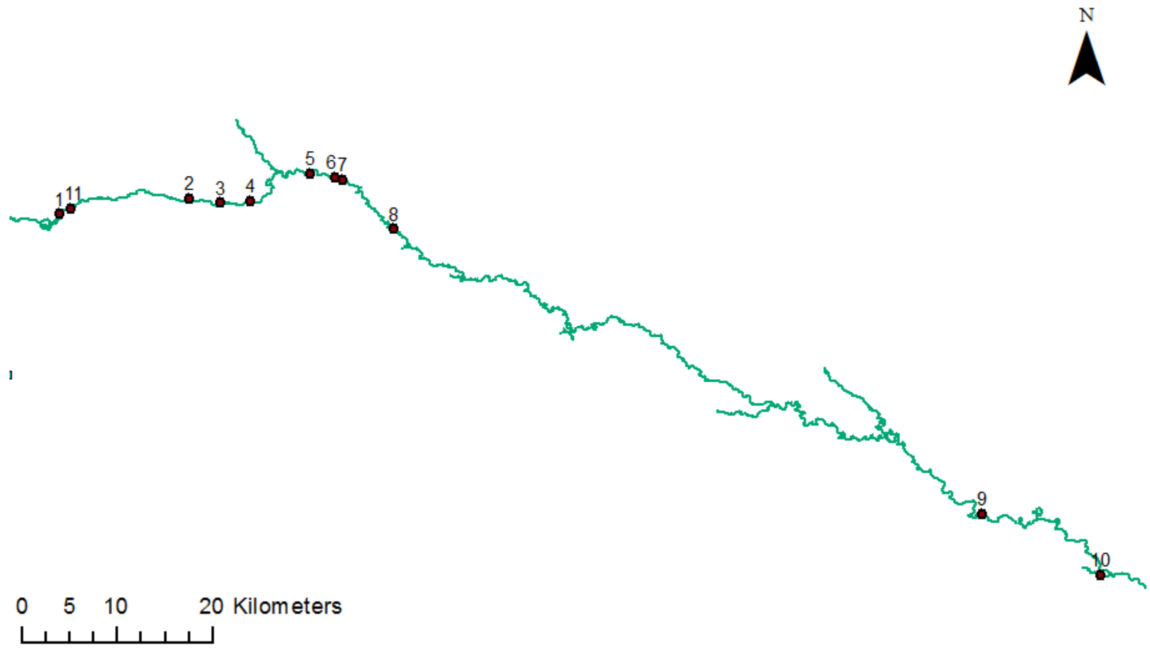

Figure 1-1: South Loup River watershed sites including all sites considered for this study.

1.32 Field Study:

A survey of the eight sites was conducted by personnel from the Nebraska Department of Roads. A topographic shapefile was created for the stream 150 meters upstream and downstream of each road crossing structure. Culvert length (cm), height (cm), width (cm), inlet and outlet elevations (m), and construction material was recorded. Stream road crossing structure slope (%) was then calculated using the culvert length, inlet and outlet elevations (Table 1-1).

Table 1-1: Site information for eight road crossing structures evaluated in this study (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Site	Crossing Type	Latitude	Longitude	Slope	County	Notes
2	PC	41.4892	-100.4536	0.37%	Logan	Double waterfall
3	PC	41.4855	-100.4239	2.82%	Logan	Large plunge pool

4	DB	41.487	-100.3959	1.16%	Logan	Low clearance
5	PC	41.5132	-100.3398	1.10%	Logan	Double waterfall
6	PC	41.5093	-100.3167	-0.46%	Logan	Large plunge pool
7	DB	41.5076	-100.3098	2.90%	Logan	Large plunge pool
8	BG	41.461	-100.2618	0.49%	Logan	
9	BG	41.1928	-99.7087	0.84%	Custer	

All sampling was conducted between April and October 2013 to examine seasonal variability in abundance and diversity. Sampling was performed from downstream to upstream to reduce the disturbance of fish, physical characteristics, and chemical characteristics. Each site had an upstream and a downstream transect from each stream road crossing structure. The length of each site was 40 times the wetted width of the stream (50 m upstream from the road crossing structure), with a minimum length of 150 m and a maximum length of 300 m (Arend and Bain, 1999). The width for determining the length of the transect was taken 50 m upstream from the road crossing structure to reduce the influence of the structure on stream morphology.

1.33 Physical and Chemical Characteristics:

Physical and chemical characteristics of the stream were collected each month to determine the mean characteristics throughout the year from April through October 2013. Stream attributes collected included stream width (cm), stream velocity (cm/s), stream depth (cm), dissolved oxygen (DO) (mg/L), turbidity (NTU), pH, conductivity (µS/m). The culvert attributes collected included culvert hang height (cm), culvert water velocity (cm/s), culvert depth (cm) and downstream pool depth (cm). Stream width was measured at 1/3 and 2/3 of each transect. At every width measurement, water velocity and depth was measured every 1/4 of the width. Velocity was measured at 2/3 of the water depth using a Hach FA950 portable velocity meter. Physical stream characteristics were averaged for each sampling period, and pooled throughout the season from April through October 2013 separately upstream and downstream the stream road crossing.

DO, temperature, pH, conductivity, and turbidity were measured at each 1/3 of the transect (Arend and Bain, 1999). DO and temperature were collected using a YSI 55 DO meter, pH and conductivity were collected using a Hanna HI-98129, and turbidity was collected using a Hach DR/890 turbidity meter. Chemical characteristics were pooled throughout the season from April through October 2013 separately upstream and downstream the stream road crossing structure. Crossing water velocity was measured at 1/3 and 2/3 of the crossing depth, and for double-barrel culverts water velocity and depth were measured for both barrels. Crossing characteristics were pooled throughout the season from April through October 2013. Sediment was collected at sites two, three, four, seven, eight, and nine, representing two of each crossing type (single-barrel pipe culvert, double-barrel pipe culvert, bridge).

Two sediment samples were collected 1/3 and 2/3 the width of the stream directly upstream and downstream each crossing, and 100 meters upstream and downstream each crossing. All stream physical and chemical characteristics were collected prior to fish sampling. Ranges and means (± SE) were calculated for all stream and culvert characteristics.

To test the effect culverts have on stream characteristics a single-factor Analysis of Variance (ANOVA) between single-barrel pipe culverts, double-barrel pipe culverts, and bridges of stream velocity, stream depth, DO, pH, conductivity, turbidity on the proportion of downstream and upstream stream characteristics was conducted ($\alpha < 0.05$). Downstream culvert hang-height, downstream plunge pool depth, and the average culvert velocity was also tested using a single-factor ANOVA between single-barrel pipe culverts, double-barrel pipe culverts, and bridges ($\alpha < 0.05$). Kolmogorov-Smirnov test was used to determine normality of data, and Levene test was used to determine equality of variance. Tukey's Honest Significant Difference (HSD) was used to test post hoc pairwise comparisons of physical and chemical characteristics between single-barrel pipe culverts, double-barrel pipe culverts, and bridges ($\alpha < 0.05$). Soil was analyzed using a bouyoucos hydrometer analysis (Thien and Graveel 2003). Sediment was calculated as percentage clay, silt, and sand, and mean percentages were calculated for each crossing type (single-barrel pipe culverts, double-barrel pipe culverts, and bridges). A textural triangle was used to determine the soil type for each crossing type (Thien and Graveel 2003).

1.34 Fish Community Abundance and Diversity:

A Smith-Root LR-24 backpack electrofisher using pulsed DC was used to sample fish. Stream conductivity was tested prior to shocking, and voltage and frequency was set using the electrofisher's built in quick set up outside the study area. If quick set up was inadequate voltage was increased by 20 V, until fish were stunned. Sampling started downstream and worked upstream to minimize stream disturbance. To assess the difference between fish community abundance and diversity upstream and downstream of road crossings Catch Per Unit Effort (CPUE) was used to calculate relative fish abundance, and total diversity, the Shannon Diversity Index, and the Gini-Simpson Index were used to determine fish diversity. A single pass electrofishing method was used to sample fish, monthly from April through October of 2013. Monthly samples were pooled for each species by road crossing structure and separated by upstream and downstream designation. Relative abundance was calculated as CPUE (# fish caught / hour electrofishing) for each fish species.

A paired t-test by species was conducted for each road crossing type to determine if there was a significant difference between upstream and downstream relative abundance for all stream road crossing types ($\alpha < 0.05$). Paired t-tests by species with a Bonferroni corrections were also conducted for each road crossing type to determine if there is a significant difference between upstream and downstream relative abundance of pooled piscivorous species (channel catfish, green sunfish, largemouth bass and northern pike), pooled non-native fish species (largemouth bass, northern pike, and common carp), and pooled fish for each family that was collected (Cyprinidae, Centrarchidae, Catostomidae, Ictaluridae, Fundulidae, and Esocidae) ($\alpha <$ 0.05). Kolmogorov-Smirnov test was used to determine normality of data. Downstream to upstream proportional relative abundance was calculated for all species and for the abundance of all fishes. To test the effect culverts have on fish relative abundance a single-factor ANOVA between single-barrel pipe culverts, double-barrel pipe culverts, and bridges of upstream proportional relative abundance was conducted (α<0.05). Tukey's HSD was used to test post hoc pairwise comparisons of fish abundance between single-barrel pipe culverts, double-barrel pipe culverts, and bridges ($\alpha < 0.05$). Kolmogorov-Smirnov test was used to determine normality of data, and Levene test was used to determine equality of variance.

Presence absence logistic regression models were conducted for all fish species using the parameters site (eight different sites evaluated in this study), crossing (single-barrel pipe culverts, double-barrel pipe culverts, and bridges), transect (upstream and downstream), species (all of the species caught for the specific model), month (April through October), crossing velocity, downstream plunge pool depth, hang height, crossing length, and crossing slope. Models were calculated for all fish species collectively caught throughout the study, piscivorous fish species (channel catfish, green sunfish, largemouth bass and northern pike), all non-native fish (common carp, largemouth bass, and northern pike), red shiner, sand shiner, and plains topminnow. Models conducted on individual species did not contain the parameter species. For all analyses Akaike's Information Criterion (AIC) was used determine the best fit models given the data. The top four models were displayed for all analyses. Spearman correlation was used to test for multicollinearity, and no multicollinearity was found.

The Shannon Diversity Index and the Gini-Simpson index were used to assess diversity. The Shannon Diversity Index is defined as; $H = \sum_{i=1}^{S} -(P_i * \ln P_i)$, where P_i = the fraction of the entire population made up of species *i*, and S = the numbers of species encountered. The Gini-Simpson Index is defined as; $\mathrm{D} = 1 - (\frac{\sum n(n-1)}{N(N-1)})$, where n = the total number of organisms of a particular species, and N = the total number of organisms of all species. Total diversity is the number of species caught per transect. To test the effect culverts have on fish diversity a single-factor ANOVA between single-barrel pipe culverts, double-barrel pipe culverts, and bridges of was conducted (α<0.05). Kolmogorov-Smirnov test was used to determine normality of data, and Levene test was used to determine equality of variance. Tukey's HSD was used to test post hoc pairwise comparisons of fish diversity between single-barrel pipe culverts, double-barrel pipe culverts, and bridges (α < 0.05).

1.4 Results

Crossing velocity, plunge pool depth, and culvert hang height was higher at single-barrel pipe culverts compared to double-barrel pipe culverts and bridges (Table 1-2). Temperature was greater upstream compared to downstream for all road crossings (Table 1-3). All road crossings both upstream and downstream contained soil class of sand, with all crossings containing more than 90% sand except for double-barrel pipe culverts (Table 1-4). Crossing velocity was significantly different between the different crossings using the single-factor ANOVA, and crossing velocity was significantly different between single-barrel pipe culverts and bridges, and double-barrel pipe culverts and bridges using Tukey's HSD (Table 1-5). Downstream plunge pool depth was also significantly different using the single factor ANOVA, and downstream plunge pool depth was significantly different between single-barrel pipe culverts and bridges using Tukey's HSD (Table 1-5). Temperature was the only chemical characteristic that showed a significant difference using the single-factor ANOVA, and the comparisons of bridges and single-barrel pipe culverts, and bridges and double-barrel pipe culverts were different using Tukey's HSD (Table 1-6).

Table 1-2: Mean (± SE) stream and culvert physical characteristics upstream and downstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing	Crossing Velocity (cm/s)	Plunge Pool Depth (cm)	Hang Height (cm)	Stream Velocity (cm/s)	Discharge (CMS)
Downstream					
PC	124.11(7.24)	130.92(NA)	2.56(2.17)	20.80(2.15)	0.30(0.07)
DB	46.64(29.66)	63.25(NA)	0.00(0.00)	22.41(2.75)	0.36(0.15)
BG	42.14(4.75)	0.49(0.49)	0.00(0.00)	35.77(6.89)	1.53(0.96)
Upstream					
PC	61.65(4.68)	1.64(1.64)	0.36(0.36)	22.27(1.75)	0.40(0.18)
DB	49.43(6.15)	0.00(0.00)	0.00(0.00)	23.54(1.52)	0.42(0.20)
BG	30.95(4.86)	0.00(0.00)	0.00(0.00)	34.71(6.16)	1.53(0.97)

Table 1-3: Mean (± SE) chemical characteristics upstream and downstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing	Temp (C^{o})	DO (mg/L)	Turbidity (NTU)	Conductivity (µS/m)	pH
Downstream					
PC	15.44(0.53)	8.05(0.30)	28.00(0.84)	161.71(14.01)	8.21(0.09)
DB	15.75(0.00)	8.48(0.04)	34.77(0.91)	162.93(19.21)	8.05(0.03)

BG	14.67(0.65)	8.11(0.87)	61.10(8.90)	235.11(82.61)	8.52(0.00)
			Upstream		
PC	15.73(0.53)	8.12(0.32)	27.79(3.97)	161.11(13.10)	8.21(0.06)
DB	16.08(0.06)	8.75(0.13)	36.60(5.60)	159.57(16.00)	8.13(0.03)
BG	15.48(0.52)	8.84(0.38)	60.15(2.15)	220.95(68.62)	7.98(0.09)

Table 1-4: Mean % (± SE) stream sediment composition and soil class category at all road crossing structures.

		Downstream		
Crossing	Sand	Clay	Silt	Soil Class
PC	90.71(0.21)	5.05(0.05)	4.18(0.20)	Sand
DB	89.78(1.51)	5.41(0.08)	4.81(1.44)	Sand
BG	93.96(0.46)	4.36(0.14)	1.68(0.14)	Sand
		Upstream		
PC	90.41(1.03)	4.72(0.34)	4.88(1.38)	Sand
DB	88.97(0.13)	6.04(0.37)	4.99(0.24)	Sand
BG	93.02(0.02)	5.18(0.33)	1.79(0.29)	Sand

Table 1-5: Single-factor ANOVA test results of stream and culvert physical characteristics with pairwise comparisons of single-barrel pipe culverts, double-barrel pipe culverts, and bridges. Differences were analyzed using Tukey's HSD (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Variable	df	*F*	*P*
Downstream Plunge Pool			
Between Groups	2, 5	6.44	0.04
PC vs BG			0.04
PC vs DB			0.78
DB vs BG			0.12
Crossing Velocity			
Between Groups	2, 5	13.08	0.01
PC vs BG			0.02
PC vs DB			0.02
DB vs BG			0.98
Downstream Hang Height			
Between Groups	2, 5	0.58	0.59
PC vs BG			0.67
PC vs DB			0.67
DB vs BG			1.00
Stream Width			
Between Groups	2, 5	1.19	0.38

PC vs BG			0.42
PC vs DB			0.98
DB vs BG			0.43
Stream Velocity			
Between Groups	2, 5	1.42	0.33
PC vs BG			0.31
PC vs DB			0.95
DB vs BG			0.52
Stream Depth			
Between Groups	2, 5	1.74	0.27
PC vs BG			0.25
PC vs DB			0.66
DB vs BG			0.71

Table 1-6: Single-factor ANOVA test results of stream chemical characteristics with pairwise comparisons of single-barrel pipe culverts, double-barrel pipe culverts, and bridges. Differences were analyzed using Tukey's HSD (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Variable	df	*F*	*P*
Temperature			
Between Groups	2, 5	13.73	0.01
PC vs BG			0.01
PC vs DB			0.93
DB vs BG			0.02
Dissolved Oxygen			
Between Groups	2, 5	2.69	0.16
PC vs BG			0.14
PC vs DB			0.79
DB vs BG			0.40
Turbidity			
Between Groups	2, 5	0.12	0.89
PC vs BG			0.96
PC vs DB			0.88
DB vs BG			0.98
Conductivity			
Between Groups	2, 5	1.25	0.36
PC vs BG			0.34
PC vs DB			0.84
DB vs BG			0.68
pH			
Between Groups	2, 5	1.70	0.27
PC vs BG			0.31
PC vs DB			0.97
DB vs BG			0.32

A total of 2,769 fish of 19 species were caught downstream road crossing structures, and 2,321 fish of 18 species were caught upstream road crossing structures. Fish relative abundance was higher downstream at all single-barrel pipe culverts, but double-barrel pipe culverts and bridges had variability between upstream and downstream relative abundance (Table 1-7). Relative abundance was generally higher downstream compared to upstream road crossing structures (Table 1-7 and Table 1-8). Paired t-tests comparing average upstream and downstream abundance did not indicate a significant difference between downstream and upstream abundance for any of the crossing types (single-barrel pipe culvert: *t-stat* = 2.35, df = 3, *P*=0.09; double-barrel pipe culvert: *t-stat* = 0.67, df = 1, *P* = 0.31; BG: *t*-stat = 0.37, df = 1, *P*=0.37).

Table 1-7: Total CPUE for fish at all sites upstream and downstream the stream road crossing structure, and mean CPUE (± SE) for all stream road crossing structures upstream and downstream (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

	Total CPUE (# fish / hour electrofishing)	
Crossing	Downstream	Upstream
PC 2	168	128
PC 3	182	159
PC 5	549	369
PC 6	928	497
Mean PC	457(22)	290(15)
DB 4	299	160
DB 7	531	558
Mean DB	417(32)	359(21)
BG 8	571	440(29)
BG 9	1487	1564
Mean BG	1022(42)	1001(52)

Table 1-8: Results of paired t-test determining increased abundance downstream compared to upstream relative abundance of piscivorous fish, all non-native fish, and fish families. (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

	PC			DB			BG			All Crossings		
Group	df	*t*	*P*	df	*t*	*P*	df	*t*	*P*	df	*t*	*P*
Piscivorous	15	1.80	**0.04**	9	-0.72	0.75	9	0.56	0.3	31	1.67	0.05
Non-native	11	1.83	**0.03**	5	0.93	0.20	5	-0.06	0.52	23	1.92	**0.03**
Cyprinidae	15	1.44	0.08	7	1.23	0.13	7	0.05	0.48	31	1.59	0.06
Centrarchidae	11	1.38	0.10	5	-1.68	0.92	5	0.89	0.21	23	1.16	0.13
Catostomidae	11	0.57	0.29	5	-0.92	0.80	5	1.46	0.10	23	1.28	0.11

Ictaluridae	7	0.61	0.28	3	-0.10	0.54	3	0.97	0.20	15	0.93	0.18
Fundulidae	3	-0.32	0.61	1	-1.00	0.75	1	9.15	**0.03**	7	0.07	0.47
Esocidae	3	2.11	0.06	1	1.00	0.25	-	-	-	7	2.26	**0.02**

After using a paired t-test to determine differences between upstream and downstream abundances for different variables, only piscivorous species in single-barrel pipe culverts, non-native species in single-barrel pipe culverts, and the family Fundulidae in bridges were found to be significantly different (Table 1-8). Using the single-factor ANOVA of the proportion of downstream and upstream fish abundance between all stream road crossing types a difference was not observed (F = 0.49, df = 2, 5, P = 0.64). Fish relative abundance comparisons did not display a significant difference between bridges single-barrel pipe culverts, and double-barrel pipe culverts using Tukey's HSD (single-barrel pipe culverts and bridges: P = 0.63; single-barrel pipe culverts and double-barrel pipe culverts: P = 0.99; double-barrel pipe culverts and bridges: P = 0.76). The most parsimonious logistic regression model for all fish species is crossing type, season, transect, and species; for piscivorous fish is site, season, transect, and crossing length; for non-native species is site, season, species, plunge pool depth, and crossing length; for red shiner is site, season, crossing velocity, and crossing length; for sand shiner is site and slope; and for plains topminnow is site, season, and crossing type (Table 1-9). Season is the only similar parameters in the top four models for regressions containing multiple species, and site and season are the most common parameter in the top four models for regressions containing only one species (Table 1-9).

Diversity of fish was similar upstream compared to downstream for all sites measured in the South Loup River. Both the Shannon Diversity Index and Gini-Simpson Diversity Index showed a trend of high evenness in the upstream sites and low evenness in the downstream sites (Table 1-10). There was variability between upstream and downstream diversity with some site containing higher diversity upstream, and other sites containing higher diversity downstream (Table 1-10). Using the single-factor ANOVA of the total diversity between all stream road crossing types a difference was not observed (F = 1.83, df = 2, 5, P = 0.25). Fish diversity comparisons did not display a significant difference between bridges, single-barrel pipe culverts, and double-barrel pipe culverts using Tukey's HSD (single-barrel pipe culverts and bridges: P = 0.68; single-barrel pipe culverts and double-barrel pipe culverts: P = 0.23; double-barrel pipe culverts and bridges: P = 0.67).

Table: 1-9: Four best models for determining presence of fish using logistic regressions of fish at all sites. Models with more than one species contained four parameters at most, and models with one species contained three parameters at most.

Model	AIC	Δ AIC	R^2
All Fish			
Crossing, Season, Transect, Species	1528.85	0.00	0.34
Crossing, Season, Transect, Species, Crossing Velocity	1529.81	0.96	0.34
Crossing, Season, Transect, Species, Plunge Pool Depth	1529.96	1.12	0.34
Site, Crossing, Season, Transect, Species	1530.22	1.37	0.34
Piscivorous Fish			
Site, Season, Transect, Crossing Length	118.44	0.00	0.36
Site, Season, Species, Crossing Length	118.44	0.00	0.36
Site, Season, Crossing Length	118.60	0.16	0.35
Site, Season, Hang Height, Crossing Length	119.57	1.13	0.35
All Non-native Fish			
Site, Season, Species, Plunge Pool Depth, Crossing Length	265.43	0.00	0.41
Site, Season, Transect, Species	265.53	0.10	0.40
Site, Season, Transect, Species, Crossing Length	265.58	0.15	0.40
Site, Season, Species, Plunge Pool Depth	266.96	1.53	0.39
Red Shiner			
Site, Season, Crossing Velocity, Crossing Length	10.00	0.00	1.00
Site, Season, Crossing Velocity, Hang Height, Crossing Length	12.00	2.00	1.00
Site, Season	12.90	2.90	0.82
Site, Season, Crossing Length	13.55	3.55	0.86
Sand Shiner			
Site, Slope	40.01	0.00	0.85
Site, Crossing Velocity, Slope	41.08	1.07	0.86
Site, Crossing Velocity, Hang Height, Crossing Length, Slope	42.03	2.02	0.87
Site, Crossing, Crossing Velocity, Slope	42.13	2.13	0.87
Plains Topminnow			
Site, Crossing, Season	100.36	0.00	0.34
Site, Season, Crossing Length	100.67	0.31	0.30
Season, Crossing Length	101.13	0.77	0.32
Site, Season, Plunge Pool Depth, Crossing Length	101.19	0.83	0.34

Table 1-10: Fish diversity for all sites upstream and downstream the stream road crossing structure (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing	Shannon Diversity Index	Gini-Simpson Diversity Index	Total Diversity
Downstream			
PC 2	1.61	0.73	10
PC 3	1.26	0.60	11
PC 5	0.62	0.28	11
PC 6	0.54	0.25	12
DB 4	1.17	0.54	12
DB 7	0.53	0.24	9
BG 8	0.75	0.38	12
BG 9	1.08	0.54	16
Upstream			
PC 2	1.67	0.76	10
PC 3	1.09	0.47	9
PC 5	0.55	0.26	7
PC 6	0.67	0.32	9
DB 4	1.02	0.42	11
DB 7	0.56	0.24	9
BG 8	0.69	0.33	12
BG 9	0.85	0.52	13

1.5 Discussion

The results of this study indicate that single-barrel pipe culverts can increase water velocity by channelizing water and the increased water velocity can create downstream plunge pool. However, these changes to the stream do not appear to alter fish community abundance and diversity immediately upstream compared to downstream of single-barrel pipe culverts or double-barrel pipe culverts within prairie streams. Temperature is also different between bridges and single-barrel pipe culverts and double-barrel pipe culverts. However, this phenomenon could be explained by the fact that the bridges are farther downstream from the headwaters compared to culverts (Figure 1-1, Table 1-1). The bridge transects are also longer than the culvert transects, and the downstream transect was always sampled before the upstream transect. Therefore, the downstream transect was sampled earlier in the day when the temperature was lower.

Single-barrel pipe culverts appear to generally have higher relative abundance of fishes downstream compared to upstream, but differences were not significant. Burford et al. (2009) found that cutthroat and brook trout displayed differences between downstream and upstream abundances at individual single-barrel pipe and box culverts. However, this study was only conducted on salmonid species within a mountainous region and a pooling of single-barrel pipe culverts or box culverts was not conducted to determine a general difference between culverts and natural reaches or bridges. Vander Pluym et al. (2008) concluded that culverts do not affect fish abundance and diversity within a non-salmonid, primarily forested, coastal stream system. The results from this study are comparable to Vander Pluym et al. (2008), therefore, the effects of culverts in prairie streams appears to be most similar to non-mountainous and non-salmonid based stream systems.

Prairie stream culverts possess many of the same physical characteristics as culverts found in other regions. Culverts analyzed in this study had a range of velocity from 12.15 cm/s to 166.50 cm/s. Other regions have similar ranges of velocity (Belford and Gould 1989; Warren and Pardew 1998), and very few studies have been conducted on culverts that have higher velocities than in this study (Toepfer et al. 1999; MacPherson 2012). The culverts analyzed in this study had slopes ranging from -0.46% to 2.90% (Table 1-1). Even in mountainous regions, most studies have presented similar slopes as this study (Belford and Gould 1989). The major difference observed between prairie streams and other regions is the dominance of sand in the substrate (Table 1-4). Studies conducted in mountainous regions have substrates dominated by gravel, cobble, and bedrock (Warren and Pardew 1998; MacPherson 2012). Amos et al. (1997) showed that less dense substrates like sand and silt are more erodible than dense substrates like clay and bedrock. The dominance of sand substrate in prairie streams make sediment scouring more prominent than in environments with clay, cobble, and/or bedrock.

Piscivorous fish were observed at all sites. However, there was a difference between the abundance of piscivorous fish downstream of single-barrel pipe culverts and not downstream double-barrel pipe culverts and bridges (Table 1-8). Non-native fish were also in more abundant downstream compared to upstream at single-barrel pipe culverts. Piscivorous fish and non-native fish overlapped as two out of the three non-native fish species were also piscivorous (largemouth bass and northern pike) (Table 1-8). Gido et al. (2004) suggested that prairie streams could have a resistance to invasion from non-native fish species due to the variability of prairie environments. The relatively lentic pool environment that culverts in prairie streams create appear to produce stable habitats for non-native species and piscivorous species. Increased crossing velocity and plunge pool depth may be associated to the increased abundances of non-native and piscivorous fishes at culverts because both variables were shown to be different at single-barrel pipe culverts compared to double-barrel pipe culverts and bridges. Litvan et al. (2008), observed a difference in percentage of scour pools at grade control structures compared to sites without grade control structures in an Iowa prairie stream. Litvan et al. (2008) also observed high abundances of largemouth bass at pools downstream of grade control structures. This study observed a similar trend, with largemouth bass and northern pike abundances being higher at sites with downstream plunge pools. However, according to the regression models for non-native fish, the individual sites and the time of season accounted for the variability in non-native fish presence (Table 1-9). The results of regression modeling indicate that crossing length and downstream plunge pool depth are other variables affecting the presence of non-native fishes. Increased velocities from culverts can create large plunge pools that are stable environments, and therefore, could be contributing to the presence of non-native species in low abundances, but more parameters appear to be accounting for the variability in the presence of non-native fish species. Similar studies investigating the affects culverts have on fish abundances did not assess the affect culverts could have on non-native species (Vander Pluym et al. 2008; Burford et al. 2009; MacPherson et al. 2012). Future research examining the effects of culverts on fish should also investigate the effects culverts could have on non-native species.

Like other studies, water velocity and plunge pool depth appear to be effected by culverts (Table 1-5) (Warren and Pardew 1998; MacPherson et al. 2012). These effects do not appear to affect the fish community significantly in the South Loup River. Prairie stream culverts channelize the water, and may produce culvert velocities and hang heights that could affect fish movement (Table 1-2), and therefore, could affect fish abundance and diversity upstream. However, spring high flows appear to provide ample water depth to allow for colonization of fishes upstream of culverts, as evidenced by the abundance and diversity of fish upstream site two, three, five, and six (Table 1-7 and Table 1-10). Briggs and Galarowicz (2013) investigated the parameters effecting fish movement through road crossing structures, and determined that culvert length is the major variable accounting for the variability in the movement of creek chub in Central Michigan. Briggs and Galarowicz (2013) concluded that from their results culverts could affect fish movement because of behavioral limitations along with physical limitations. This study indicates that the major variable affecting fish presence at road crossing structures, other than site specific and seasonal variability which were not investigated in Briggs and Galarowicz (2013), is crossing length (Table 1-9). Fish presence at crossings could be determined by behavioral characteristics along with physical variables in prairie streams. In other words, prairie stream fish might be deterred to move through culverts because they are long, dark, high flowing crossing structure other than the physical limitations of the fish. However, these behavioral movement limitations did not appear to significantly affect fish abundances.

There was a trend of less species being caught but with lower abundance in the headwaters and more species being caught with higher abundance of a few species farther downstream. However, site nine appears to be the point when the trend begins to reverse. This is partly because more species were caught at site nine, but there was also a relatively high abundance of individuals within the same species. Species diversity did not appear to be affected by culverts, and instead appeared to be driven by the river continuum (Vannote et al. 1980).

In conclusion, single-barrel pipe culverts affect stream velocity and downstream plunge pool depth. Increased stream velocity and downstream plunge pool depth appears to affect the abundance of piscivorous and non-native fish species, however, does not appear to affect total fish abundance. Behavioral variables could also be affecting the abundance of piscivorous and non-native fish species. More research is needed to determine the effects of culverts on fish abundance and diversity. This study had a relatively low sample size and was limited to one river system. Future research should focus on increasing the sample size and expand the range outside the South Loup River watershed. Lastly, this study did not use randomization because it was limited to the South Loup River watershed and had a finite number of culverts. However, if the range is increased to multiple watersheds a randomized sample would be possible.

2.0 Prairie Stream Fish Jumping and Swimming Ability

2.1 Summary

Stream fragmentation can be detrimental to lotic fish species by preventing movements important for spawning and predator avoidance. The swimming and

jumping ability of ten Nebraska stream fish was evaluated to be used for fish movement models and determine restrictions to fish movement. All tested fish were between 30 and 100 millimeters total length due to limitations of the swim tunnel. An artificial waterfall with an adjustable weir was used to test jumping performance and a ten liter swim tunnel was used to test swimming performance. Jumping ability ranged from 0 centimeters for bluegill to 13 centimeters for green sunfish while swimming ability ranged from 37.5 cm/s for mosquitofish to 65.0 cm/s for largemouth bass. Differences in swimming and jumping ability demonstrate how movement through road crossing structures can be taxa specific and therefore impact the conservation of rare species and management of exotic species.

2.2 Introduction

Luttrell et al. (1999) noted that historically the streams in the Great Plains were shallow and meandering. Anthropogenic activities have altered the landscape and changed characteristics of these streams (Matthews 1988; Dodds et al. 2004). Sampson and Knopf (1994) found that up to ninety-eight percent of the plains have been altered by humans, most often through conversion to agriculture. Dams and road crossings such as culverts have been widely used to manage resources and connect human interests. Dams and culverts can fragment a stream system and prevent fish and other organisms from moving freely in the stream (Matthews 1988; Warren and Pardew 1998; Dodds et al. 2004; Guenther and Spacie 2006). These impacts can reduce biodiversity because many stream fish require large scale movements to maintain life history requirements including overwintering, spawning and predator avoidance. When an upstream population is extirpated, the downstream population must recolonize the upper reach of the stream (Dodds et al. 2004). A culvert or dam can prevent this from happening however, culverts and other barriers are not the only problem native stream fish face.

Non-native fish have entered most of the Great Plains streams and have caused losses of diversity and abundance through a number of mechanisms (Tyus and Saunders 2000). Invasive species can prey on native species and their young causing a decline in abundance (Tyus and Saunders 2000) and can increase competition for resources, spread diseases and disrupt other ecosystem functions.

Removing all road crossings in a stream is not feasible, but knowing which structures limit passage of a given species can be used for targeted management. To predict which structures limit passage, the swimming and jumping ability of fish species must be researched. Many studies have been done on the swimming and jumping ability of salmon and trout but, until recently few have been done on prairie stream fish. When testing swimming ability, multiple types of tests can be performed including measures of sustained, maximum, prolonged and sprint swimming ability (Beamish 1978; Ficke et al. 2011). Leavy and Bonner (2009) tested the maximum swimming ability of 37 species in nine families. Swimming abilities among species were highly variable ranging from the largespring gambusia, *Gambusia geiseri*, which had a mean absolute speed of 15.7 ± 1.36 cm/s to the emerald shiner that had a maximum mean absolute speed of 81.4 ± 5.46 cm/s (Leavy and Bonner 2009). In addition to velocity, some stream barriers require jumps to move past. Waterfalls and beaver dams are natural examples and human-made barriers include dams and weirs.

The objectives of this study were to 1) determine the maximum swimming velocity of ten fish species found in central Nebraska to evaluate water velocity as a barrier for fish passage and 2) evaluate the jumping ability of ten fish species in central Nebraska to determine waterfall height that would be a barrier to fish passage.

2.3 Methods

2.31 Fish collection: Plains topminnow, *Fundulus sciadicus*, northern plains killifish, *Fundulus kansae*, western mosquitofish, *Gambusia affinis*, sand shiner, *Notropis stramineus*, red shiner, *Cyprinella lutrensis*, channel catfish, *Ictalurus punctatus*, black bullhead, *Ameiurus melas*, bluegill, *Lepomis macrochirus*, green sunfish, *Lepomis cyanellus* and largemouth bass, *Micropterus salmoides* were tested for maximum swimming and jumping performance. All fish tested were between 30 and 100 millimeters total length because of the limits associated with the swim tunnel. Fish were collected using seines, trap nets and dip nets. Two sets of topminnows were tested to evaluate if there was a difference between individuals captured in lotic and lentic systems. Lotic plains topminnow were collected from the Rock Creek hatchery and Lentic plains topminnow were collected from a rearing pond at Sac Wilcox WMA (Schumann et al. 2012). Bullhead, bass and bluegill were collected from the Valentine fish hatchery in Nebraska. Channel catfish were collected from the North Platte fish hatchery in Nebraska. Sand shiners, red shiners and killifish were collected from the Platte River near Kearney, NE. Mosquitofish were collected from a small tributary to the Platte River at Blue Hole WMA south of Elm Creek, NE. Green sunfish were collected from a pond at Sandy Channel WMA south of Elm Creek, NE. Once the fish were collected, they were placed in a 378 liter aerated tank for transport back to the lab. Once back to the lab the fish were placed in a 1,900 liter holding tank. The water in the holding tank was kept at 17.5^{o} Celsius. While in the holding tank fish were fed a mixture of frozen blood worms, frozen brine shrimp daily. Largemouth bass were also fed small bluegill. A water pump was placed in the holding tank to provide a light current of 5-10 cm/sec (Ficke et al. 2011). The fish were kept on the local photo period (40.6994^{o} N).

2.32 Swimming assessment: To test the swimming ability of each species, a ten liter swim tunnel was built (Figure 2-1). Water from the holding tank was used to fill the swim tunnel. A single fish was randomly selected from available fish and placed in the swim chamber. Once the fish was placed in the chamber it was allowed 5 minutes to acclimate to the flow direction and recover from handling. An acclimation speed of 0.5 body length per second was used (Ficke et al. 2011). After recovery time was reached, a constant acceleration test was used to find the maximum swimming speed of each individual. The velocity was increased at a rate of 5 cm/sec every 10 seconds (Leavy and

Bonner 2009). This increase was continued until the fish fatigued and was pinned against the back screen for four seconds (Leavy and Bonner 2009). The velocity at that point and the length of the fish was then recorded. Thirty individuals of each species were tested. Each individual was used once to avoid effects caused by the trial (Farlinger and Beamish 1978). If an individual did not swim it was removed and a new fish replaced it.

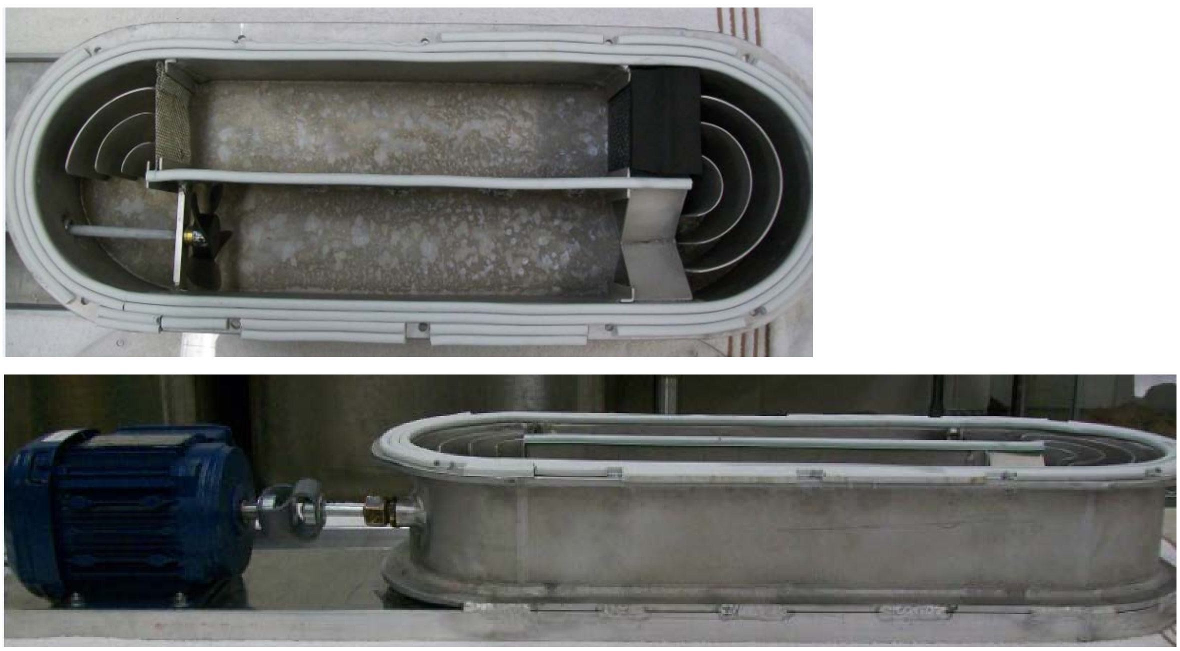

Figure 2-1: Ten liter swim tunnel used to test fish swimming speed

2.33 Jumping ability assessment: To test jumping ability an artificial waterfall was created based on Kondratieff and Myrick (2005)(Figure 2-2). The apparatus was 60 cm wide by 120 cm long by 120 cm tall. A weir was placed in the middle creating two chambers, an upper and a lower chamber that were 60cm X 60cm X 120cm. A plunge pool depth of 23 cm was used. Water pumps were used to pump water from the lower chamber into the upper chamber at a rate of 72 L/min (Ficke et al. 2011). The fish were tested with 17.5^{o} Celsius. Ten fish of one species were randomly selected from available fish and placed into the bottom chamber and were left for 24 hours unless a successful jump was observed. Only lotic topminnow were tested for jumping due to limited availability of lentic topminnow. A video camera was used to ensure fish attempted to jump and all successful jumps were recorded. Once the trial was completed all fish were removed and the weir height was raised one centimeter. Ten new fish were then placed in the lower chamber for the next trial. If no fish reach the upper chamber another trial at this height was repeated. If no successful jump occurred during the second test, this height was considered the maximum jumping performance.

Figure 2-2: Artificial waterfall used to test fish jumping ability.

2.34 Data analysis

The maximum swimming speed of the two topminnow groups was compared using a T-test and a critical value of 0.05. Linear correlation was done on the swimming ability of each fish species to determine if there is a correlation between length and swimming velocity.

2.4 Results

2.41 Swim trial results: The mean maximum swimming velocity for the ten species tested were variable (Figure 2-3). Largemouth bass had the highest mean swimming velocity at 65.0 ± 1.6 cm/s and western mosquitofish had the lowest mean swimming velocity at 37.5 ± 1.2 cm/s (Table 2-1). Red shiner had the single overall highest maximum swimming velocity at 90.1 cm/s (Table 2-1). Mosquitofish had the lowest maximum swimming velocity at 50.1 cm/s (Table 1). There was no significant difference between the mean maximum swimming velocity of the topminnow from the hatchery (40.6 ± 1.13 cm/s) or the rearing pond (38.7 ± 0.9 cm/s) (*t*-stat=1.36, df=58, *P*=0.09). All species had a positive correlation between length and velocity. As length increased maximum swimming velocity also increased. The R^2 values for each species was variable with mosquitofish having the lowest correlation at 0.21 and red shiners having the highest with 0.74 (Table 2-1).

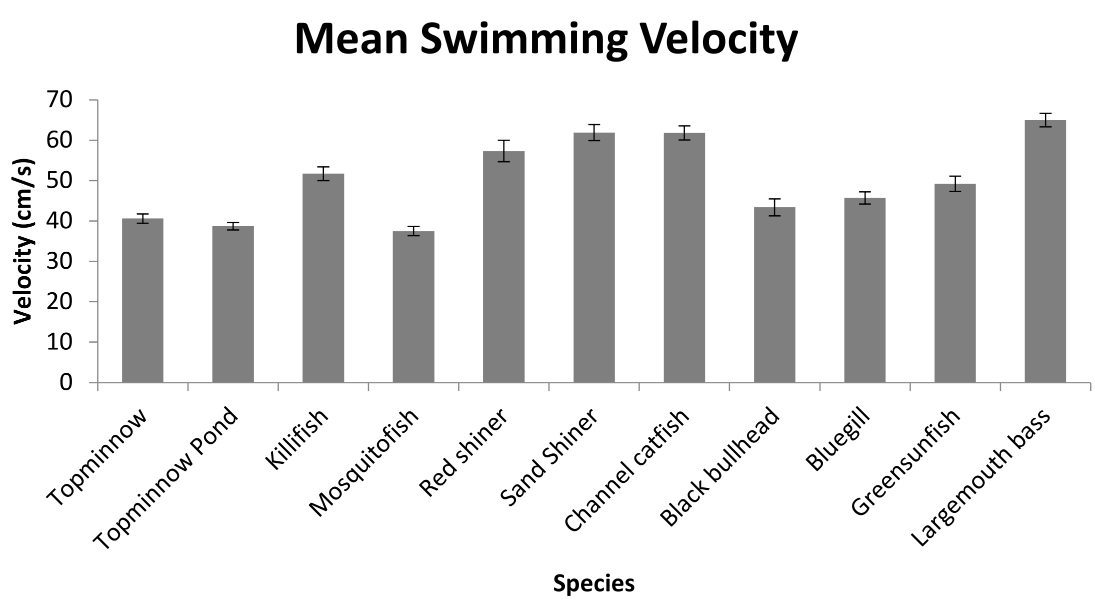

Figure 2-3. Mean maximum swimming velocity of fish species tested with standard error bars.

Table 2-1. The mean swimming velocity (± 1 SE) and mean length of each species of fish tested with standard error. Maximum velocity recorded for each species is also listed. The R squared value is listed for the correlation between length of fish and maximum velocity for each species.

Fish	Mean total length	Mean swimming velocity (cm/s)	Maximum swimming velocity (cm/s)	R^2 value
Topminnow from stream	55.3 ± 1.1	40.7± 1.1	51.6	0.43
Topminnow from pond	47.1 ± 1.0	38.7 ± 0.9	50.0	0.39
Killifish	69.3 ± 1.4	51.8 ± 1.7	73.2	0.38
Mosquitofish	48.4 ± 1.5	37.5 ± 1.2	50.1	0.21
Red shiner	56.1 ± 1.8	57.3 ± 2.6	90.1	0.74
Sand shiner	58.1 ± 1.3	62.0 ± 1.9	85.6	0.57
Black bullhead	59.7 ± 1.9	43.4 ± 2.1	69.7	0.46
Channel catfish	75.7 ± 2.1	61.8 ± 1.7	>82.1	0.28
Bluegill	47.0 ± 1.5	45.7 ± 1.5	63.7	0.62
Green sunfish	63.4 ± 2.0	49.2 ± 1.9	73.8	0.54
Largemouth bass	69.0 ± 1.0	65.0 ± 1.7	85.0	0.32

All of the fish except for the catfish species started to swim as soon as the flows began. As the velocities increased, the fish used short bursts to hold their position in the swimming apparatus. The catfish species would try and hold their position on the bottom of the chamber until the flows were too strong and they were forced to use swimming burst.

2.42 Jumping ability: The jumping results were varied. Results differed even within the same family. The highest jump and lowest jump occurred by Centrarchidae species (Figure 2-4). The green sunfish cleared the highest jump at 13 centimeters while the lowest was the bluegill which did not attempt a jump and are reported at zero centimeters. In most cases, once the fish were placed in the jumping apparatus they attempted to jump almost immediately, with in the first two hours. If the fish were not successful in the first two hours usually a successful jump did not happen. The exception to this is the channel catfish which often waited until dark to jump.

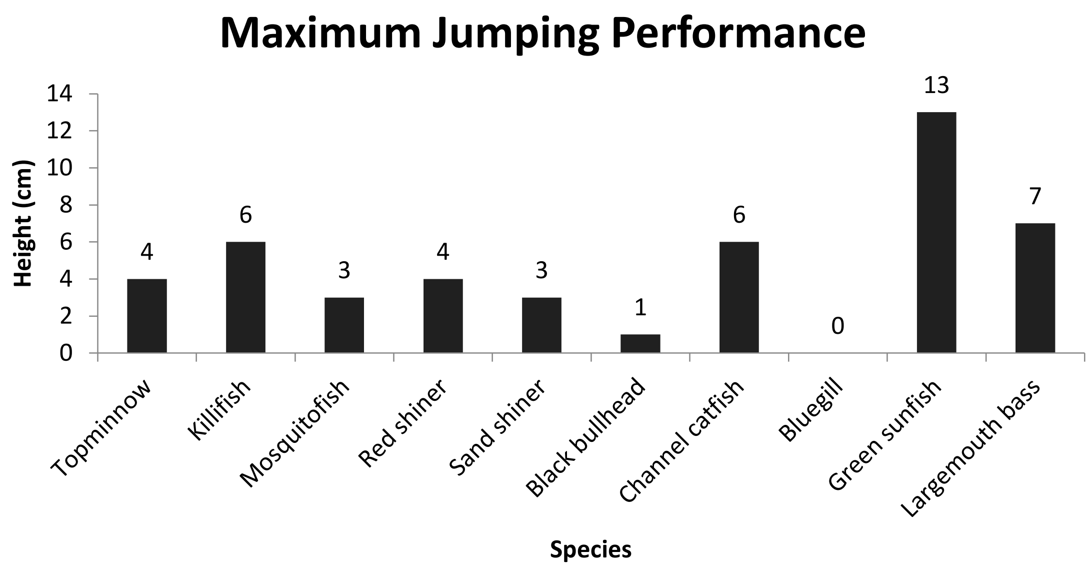

Figure 2-4. Highest jump cleared by each fish species tested.

2.5 Discussion

The results found in this study suggest that road crossings that increase the velocity of the water above 40 cm/s could reduce fish passage through the road crossing. A culvert that creates any waterfall could hinder the passage of some prairie stream fish. To ensure passage through culverts the culvert should be installed so flows remain under 40 cm/s and no waterfall is created. The swimming and jumping ability data can be used in models such as the Fish Xing model to predict which road crossings are barriers to which fish.

The fish used in these experiments were collected from a stream, if possible, and had experienced flows. Some fish were not in high enough abundance in the streams to complete the trials so hatchery and pond fish were used. The two topminnow groups showed that there was no difference between those raised in lotic or lentic waters. The issue with using topminnow as the test species is that topminnows are a backwater specialist and do not prefer areas of high flows. Collecting the other fish such as bluegill or channel catfish from a stream and testing them would be beneficial.

Ward et al. (2003) tested the swimming ability of mosquitofish, red shiner, green sunfish and the Gila topminnow, *Poeciliopsis occidentalis,* and found similar values to those in this study. The Gila topminnow had a mean failure rate of 36.5 cm/s and the mosquitofish had a mean failure rate of 38.5 cm/s. Green sunfish had similar failure rate at 46.2 cm/s. Ward et al. (2003) found a higher mean failure rate for the red shiner at 77.5 cm/s, but the mean length of the red shiner tested in their study was 68.9 mm, which is almost 13 mm longer than those used in this study. Leavy and Bonner (2009) tested red shiners and sand shiners as well and found their maximum values were lower than those found in this experiment. Leavy and Bonner (2009) found that red shiners and sand shiners had a maximum swimming velocity of 71.2 cm/s and 66.5 cm/s. One explanation for this could be if they tested smaller fish as we found a positive correlation between fish length and maximum swimming velocity. One factor that might explain the variability between species is that the Cyprinidae, Fundulidae and Poeciliidae species are fully developed under 100 millimeters whereas the Centrarchidae and Ictaluridae species are still juveniles.

The swim tunnel used limited the size of the fish that could be tested to be below 100 millimeters in total length. Thus, only juvenile channel catfish, black bullhead, green sunfish, bluegill and largemouth bass could be tested. As seen with many of the species as length increased so did the velocity they could swim. This suggests that larger channel catfish, black bullheads, green sunfish, bluegills and largemouth bass would be able to overcome swifter currents.

All of the fish of a single species that were tested were collected the same time of the year to reduce variance. Even though all fish were allowed to acclimate, the water temperature that the fish were tested could affect the results. The swimming velocity and jumping ability could change depending on time of year. Food is likely limited over the winter so a fish collected in early spring may not be in peak physical condition. Biro et al. (2004) found lipid reduction in rainbow trout after winter which was a major factor in overwinter mortality. Similar results may be seen in fish of the Great Plains. This reduced fitness may lead to reduced performance. Late spring and early summer is also the breeding time for many species. Plaut (2002) found that female mosquitofish swimming performance decreased as the pregnancy advanced and increased again after birth. James and Johnson (1998) found that swimming performance in post spawning fish was significantly higher than those that were gravid. If a female is carrying eggs or young, as with the mosquitofish, that individual may not be able to swim as well as a non-reproductive individual.

The fish tested were kept at 17.5^{o} Celsius as that temperature was used in other studies testing small stream fish. Ficke et al. (2011) found that temperature altered the swimming and jumping performance for some species of fish. Leavy and Bonner (2009) found similar results in that temperature was a significant covariate. Hasler et al. (2009) found that lower water temperatures decreased the swimming performance of largemouth bass. These results suggest testing different temperatures could be beneficial when trying to determine maximum swimming ability. Testing fish at water temperatures similar to those at the time of year the fish might try traversing barriers could be looked at.

When testing jumping ability, in most of the cases, if a fish was going to jump it jumped early in the trial. Fish attempted to jump almost immediately after being placed in the jumping apparatus, which is similar to the results reported by Ficke et al. (2011). Very few times did a fish successfully jump after the first two hours. After the first few hours if a successful jump had not happened, the fish usually quit attempting the jump. No stimulus was needed to provoke the fish to jump. The two exceptions to this were the bluegill and channel catfish. Once bluegill were placed in the jumping apparatus they were content and never attempted to jump. This may be due to the fact that bluegills are often lentic species and seldom experience elevated flow. Ellis (1974) found jumping activity and performance was influenced by the rate of flow, and time of day or year. The results found in Ellis (1974) suggest that changing the flow rate in the jumping apparatus may change the jumping performance. Channel catfish on the other hand often times waited until night to complete the jump which coincides when channel catfish are most active.

3.0 Management Implications

Site two was one of two culverts where a hang height was observed with a hang height of at least 14 cm during four of the seven months that were surveyed, and a maximum hang height of 20 cm that was observed in September. Site five also had a hang height of 1.25 cm for one month, but the FishXing model predicted that the hang height was not large enough to impede the movement of nine fish species. No culvert studied displayed a hang height throughout the entire sampling period.

Fish abundance and diversity followed the same pattern as fish movement. Abundance and diversity was generally lower at the single-barrel pipe culvert sites relative to the double-barrel pipe culverts and bridges, but not significantly. However, no significant differences between downstream abundance and diversity compared to upstream abundance and diversity for single-barrel pipe culverts were observed. Prairie stream culverts do appear to support piscivorous and non-native species in the downstream plunge pools and abundance of both piscivorous and non-native species was significantly higher downstream from single-barreled culverts. This trend was not observed at double-barrel culverts or bridges. Single-barrel pipe culverts produced downstream plunge pools significantly larger than double-barrel culverts and bridges, indicating that plunge pools produced by culverts support piscivorous species. Previously, Litvan et al. (2008) determined that the piscivorous largemouth bass have higher abundances in downstream pools created by gradient control structures.

In Nebraska, sediment scouring downstream culverts could be limited by using riprap. According to the Food and Agriculture Organization of the United Nations (FAO)

(2002), a fish ramp in rivers with sandy bottoms can be constructed with riprap of multi-layered rock fills that is 7 to 10 times the length of the ramp height. The ramp height is defined as the height from the base of the pool to the upstream end of the ramp (FAO 2002). For single-barrel pipe culvert three, five, and six, the riprap should be filled as much as 30 m. Unfortunately, riprap material is expensive, and could cost more than $10,000 (Litvan et al. 2008).

The scope of this study does not allow generalized conclusions of the effect of culverts on Midwestern prairie fishes because of the low sample size and the limits to one watershed. There appears to be many variables that can influence the results of a culvert movement study, and a randomized study with a high sample size is needed to obtain such generalized conclusions. For example, each culvert has a slightly different slope, length, width, height, bottom roughness, outlet pool, is at a different distance from the stream origin, and has a different stream community. This variability among different culverts is likely to influence the results.

For example, a culvert that creates a downstream plunge pool creates habitat to support a relatively high abundance and diversity of fishes. The plunge pool could also be producing a staging area for fishes attempting to pass through the culvert. Therefore, a culvert with a plunge pool could be hindering fish passage, but because there is a large number of fishes downstream of the culvert, proportional movement observations could be inflated. Another variable that complicates culvert studies is the river continuum concept. Culverts are usually placed on lower order streams compared to bridges. Bridges are usually used when a stream width becomes too large and/or stream discharge becomes too great to accommodate a culvert. Culverts or bridges that are farther downstream are more likely to contain higher fish abundance and diversity. As with the plunge pool variable, culverts farther downstream could have higher proportional movement observations because of higher fish abundances.

Overall, the results suggest that a multi-step approach should be followed when evaluating the passability of culverts in prairie streams. Similar to conclusions from other studies, the results of the FishXing model are conservative in predicting impassability of culverts in a system (Burford et al. 2009). Because of this, if a FishXing analysis is conducted on a culvert and it is found to not be a barrier to movement of a fish species, there can be high confidence that the culvert is not a barrier to that fish. However, if the FishXing analysis concludes that the culvert is a barrier to a fish species, then a survey should be conducted upstream of the culvert to determine the accuracy of the FishXing model in that system. If the fish species that is/are being evaluated is found upstream of the culvert, then it is likely that the culvert is passable at some point in time. However, this assumption can only be made if the fish have not been introduced by other means or that have persisted after the culvert has been placed. For example, bait fish can be introduced and upstream lakes or ponds can occasionally flood into the stream. If the fish species found below the culvert is not found upstream from the culvert, then it is likely that the culvert is a barrier to that fish species' passage (Figure 3-1). If a culvert is not found to be a barrier to fish passage it still could be altering stream morphology, and therefore, could be affecting non-native and piscivorous fish abundance.

Barriers can in fact also be useful in limiting the spread and consequent negative impacts of non-native species. In some cases, such as in watersheds where an exotic species occurs, intentionally creating or maintaining a barrier to prevent upstream spread of the species may be desired, and used to preserve biodiversity of native species. In this study, the mean swimming velocity of the non-native mosquitofish was 37.5 cm/s while the native red shiner had a mean swimming velocity of 57.3 cm/s. Constructing a barrier that increases the water velocity to over 40.0 cm/s would greatly hinder the spread of the mosquitofish while allowing the red shiner to pass.

Ultimately, more research is needed to determine the effects culverts have on fishes in Midwestern prairie streams. Efforts should start by inventorying all culverts in Nebraska. To reduce the effects of location on results, a stratified random study should be conducted with the stratified factor being culvert type. This study also did not acquire seasonal movement of fishes, and only obtained movement during low flow periods of summer. An extension to this would examine seasonal movement of fishes through culverts because different fish species display upstream or downstream movement at different times of the year, and/or higher abundances of different fish species can be captured at different times of the year. Conducting a seasonal movement study of more species would also be valuable. Lastly, fish swimming and jumping abilities need to be determined for more fish species. Every species that is will be analyzed for passability of culverts using the FishXing model requires swimming and jumping abilities to be determined.

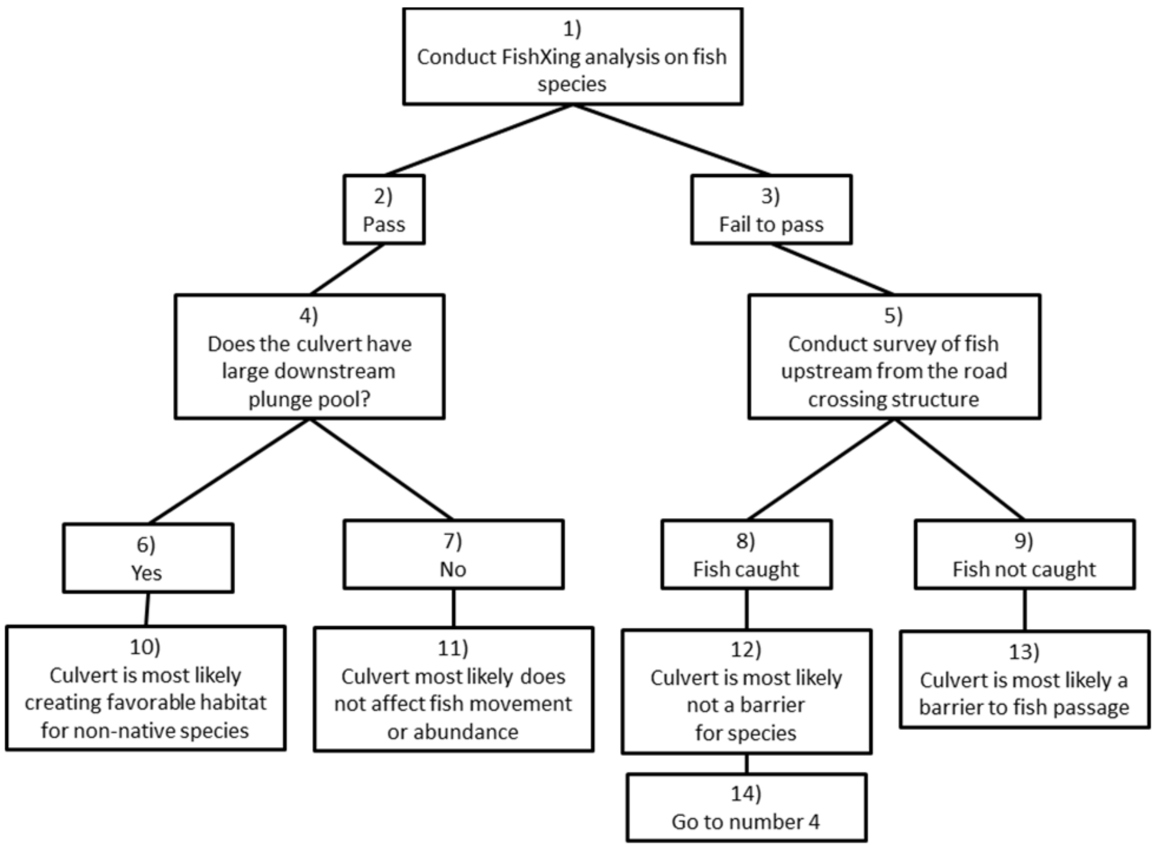

Figure 3-1: Flow of management decisions to determine if a culvert is likely a barrier to fish movement.

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Appendix

Table A-1: Total CPUE of all fish species caught at single-barrel pipe culverts.

Single-barrel pipe Culvert				
	Downstream		Upstream	
Family	Species	CPUE (fish/hour)	Species	CPUE (fish/hour)
Catostomidae	River Carpsucker	1.06	River Carpsucker	0.00
	White Sucker	3.33	White Sucker	3.66
Centrarchidae	Bluegill	14.63	Bluegill	11.65
	Green Sunfish	21.54	Green Sunfish	5.57
	Largemouth Bass	1.04	Largemouth Bass	1.60
Cyprinidae	Brassy Minnow	0.25	Brassy Minnow	0.00
	Common Carp	7.45	Common Carp	4.46
	Fathead Minnow	0.78	Fathead Minnow	0.00
	Red Shiner	322.94	Red Shiner	209.72
	Sand Shiner	28.28	Sand Shiner	25.14
Esocidae	Northern Pike	0.95	Northern Pike	0.00
Fundulidae	Plains Topminnow	0.51	Plains Topminnow	1.88
Ictaluridae	Channel Catfish	1.51	Channel Catfish	2.48
	Stonecat	2.14	Stonecat	1.16
Percidae	Iowa Darter	0.71	Iowa Darter	0.00
	Total	407.12	Sum	267.32

Table A-2: Total CPUE of all fish species caught at double-barrel pipe culverts.

Double-Barrel Pipe Culvert				
	Downstream		Upstream	
Family	Species	CPUE (fish/hour)	Species	CPUE (fish/hour)
Catostomidae	River Carpsucker	0.00	River Carpsucker	0.66
	Shorthead Redhorse	1.29	Shorthead Redhorse	1.31
	White Sucker	1.90	White Sucker	1.38
Centrarchidae	Bluegill	0.61	Bluegill	4.35
	Green Sunfish	5.50	Green Sunfish	8.63
	Largemouth Bass	0.00	Largemouth Bass	0.72
Cyprinidae	Common Carp	9.91	Common Carp	2.04
	Red Shiner	342.61	Red Shiner	314.92
	Sand Shiner	34.19	Sand Shiner	13.85
Esosidae	Northern Pike	0.61	Northern Pike	1.45
Fundulidae	Plains Topminnow	1.22	Plains Topminnow	1.45
Ichtaluridae	Channel Catfish	2.58	Channel Catfish	2.69
	Stonecat	0.00	Stonecat	0.66
Percidae	Iowa Darter	0.61	Iowa Darter	0.72
	Total	401.05	Total	354.83

Table A-3: Total CPUE for all fish species caught at bridge crossings.

	Bridge			
	Downstream		Upstream	
Family	Species	CPUE (fish/hour)	Species	CPUE (fish/hour)
Catostomidae	River Carpsucker	3.67	River Carpsucker	1.53
	Shorthead Redhorse	1.22	Shorthead Redhorse	2.26
	White Sucker	27.31	White Sucker	16.01
Centrarchidae	Bluegill	0.41	Bluegill	0.00
	Green Sunfish	4.81	Green Sunfish	3.06
	Largemouth Bass	0.51	Largemouth Bass	0.00
Cyprinidae	Brassy Minnow	8.56	Brassy Minnow	14.01
	Fathead Minnow	13.76	Fathead Minnow	14.86
	Flathead Chub	0.81	Flathead Chub	0.00
	Plains Minnnow	1.63	Plains Minnnow	0.00
	Red Shiner	721.75	Red Shiner	737.65
	Sand Shiner	214.48	Sand Shiner	293.39
	Silver Chub	7.33	Silver Chub	0.55
Fundulidae	Plains Topminnow	1.95	Plains Topminnow	0.00
Ichtaluridae	Channel Catfish	2.76	Channel Catfish	0.98
	Stonecat	1.03	Stonecat	0.85
Percidae	Iowa Darter	0.41	Iowa Darter	0.00
	Total	1012.40	Total	1090.67

Table A-4: Maximum, minimum, and mean (± SE) physical characteristics downstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing		Crossing Velocity (cm/s)	Downstream Plunge Pool Depth (cm)	Hang Height (cm)	Stream Velocity (cm/s)	Discharge (CMS)
PC 2	Max	166.50	50.00	20.00	32.12	0.51
	Min	69.00	32.00	0.00	10.75	0.05
	Mean	130.91(12.25)	43.67(2.58)	9.00(3.27)	18.32(2.87)	0.18(0.06)
PC 3	Max	140.00	195.00	0.00	26.65	0.39
	Min	80.50	170.00	0.00	4.25	0.02
	Mean	120.90(7.13)	180.71(3.35)	0(0)	16.91(3.17)	0.18(0.05)
PC 5	Max	172.80	185.00	5.00	30.06	0.74
	Min	110.50	165.00	0.00	13.69	0.15
	Mean	139.14(6.97)	175.00(2.67)	1.25(0.94)	21.33(2.08)	0.39(0.08)
PC 6	Max	132.00	230.00	0.00	43.75	0.90
	Min	61.30	180.00	0.00	13.38	0.10
	Mean	105.49(9.72)	212.14(7.23)	0(0)	26.62(3.78)	0.45(0.09)
DB 4	Max	21.81	88.00	0.00	29.58	0.40
	Min	12.15	50.00	0.00	12.36	0.09
	Mean	16.98(2.58)	63.25(6.78)	0(0)	19.66(2.8)	0.21(0.05)
DB 7	Max	100.00	175	0.00	34.31	0.79
	Min	61.90	150	0.00	17.73	0.23
	Mean	76.3(7.82)	167.86(3.25)	0(0)	25.16(2.21)	0.5(0.08)
BG 8	Max	48.00	3.90	0.00	39.00	1.09
	Min	26.50	0.00	0.00	16.38	0.20
	Mean	37.39(2.76)	0.98(0.74)	0(0)	28.88(2.98)	0.57(0.11)
BG 9	Max	53.90	0.00	0.00	58.55	3.90
	Min	29.00	0.00	0.00	30.76	0.00
	Mean	46.89(3.36)	0(0)	0(0)	42.65(3.67)	2.49(0.52)

Table A-5: Maximum, minimum, and mean (± SE) physical characteristics upstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing		Crossing Velocity (cm/s)	Upstream Plunge pool depth (cm)	Hang Height (cm)	Stream Velocity (cm/s)	Discharge (CMS)
PC 2	Max	166.50	0.00	0.00	30.39	0.37
	Min	17.00	0.00	0.00	9.08	0.05
	Mean	52.66(19.82)	0(0)	0(0)	19.15(3.21)	0.16(0.04)
PC 3	Max	119.70	0.00	0.00	31.75	0.43
	Min	24.80	0.00	0.00	6.75	0.03
	Mean	58.39(11.5)	0(0)	0(0)	20.6(3.75)	0.17(0.06)
PC 5	Max	112.00	46.00	10.00	30.59	0.65
	Min	31.00	0.00	0.00	12.94	0.08
	Mean	74.71(11.74)	6.57(6.57)	1.43(1.43)	22.11(2.97)	0.35(0.07)
PC 6	Max	91.76	0.00	0.00	36.39	3.5
	Min	36.00	0.00	0.00	21.30	0.24
	Mean	60.84(6.58)	0(0)	0(0)	27.21(1.87)	0.91(0.44)
DB 4	Max	90.38	0.00	0.00	29.52	0.51
	Min	20.75	0.00	0.00	16.56	0.09
	Mean	55.57(18.61)	0(0)	0(0)	22.02(2.01)	0.22(0.06)
DB 7	Max	57.15	0.00	0.00	32.33	1.47
	Min	33.70	0.00	0.00	16.13	0.18
	Mean	43.28(4.65)	0(0)	0(0)	25.05(2.45)	0.61(0.18)
BG 8	Max	47.32	0.00	0.00	41.01	1.08
	Min	12.50	0.00	0.00	18.19	0.21
	Mean	26.09(4.99)	0(0)	0(0)	28.55(3.38)	0.56(0.12)
BG 9	Max	53.90	0.00	0.00	52.63	4
	Min	15.00	0.00	0.00	24.04	1.15
	Mean	35.81(5.91)	0(0)	0(0)	40.86(4.17)	2.5(0.42)

Table A-6: Maximum, minimum, and mean (± SE) chemical characteristics downstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

		Downstream				
Crossing		Temp (C^{O})	DO (mg/L)	Turbidity (NTU)	Conductivity (µS/m)	pH
PC 2	Max	19.00	9.00	65.00	294.00	9.63
	Min	5.20	3.91	7.00	138.00	7.71
	Mean	14.24(1.82)	7.53(0.70)	25.57(7.50)	188.43(22.85)	8.33(0.24)
PC 3	Max	19.60	8.96	48.00	291.00	9.62
	Min	5.60	2.86	12.00	141.00	7.64
	Mean	15.07(2.05)	7.52(0.88)	28.57(5.36)	183.14(21.86)	8.38(0.25)
PC 5	Max	21.70	9.92	67.00	190.00	8.20
	Min	9.39	6.00	13.00	116.00	7.82
	Mean	16.77(1.77)	8.56(0.48)	29.43(7.25)	134.14(9.64)	8.04(0.05)
PC 6	Max	22.30	9.33	45.00	198.00	8.30
	Min	2.17	7.54	15.00	118.00	7.63
	Mean	15.68(2.79)	8.6(0.23)	28.43(4.63)	141.14(10.97)	8.07(0.09)
DB 4	Max	20.90	9.11	83.00	266.00	8.43
	Min	1.55	6.74	11.00	142.00	7.20
	Mean	15.74(2.42)	8.52(0.32)	35.67(9.75)	182.14(17.42)	8.02(0.16)
DB 7	Max	22.60	9.43	55.00	199.00	8.39
	Min	2.86	7.34	17.00	117.00	7.73
	Mean	15.75(2.60)	8.44(0.31)	33.86(6.12)	143.71(11.24)	8.07(0.08)
BG 8	Max	21.60	9.98	65.00	181.00	8.25
	Min	3.90	7.90	24.00	121.00	7.68
	Mean	14(2.89)	8.98(0.28)	52.2(6.10)	152.5(8.30)	8.01(0.07)
BG 9	Max	24.20	9.96	124.00	354.00	11.30
	Min	5.60	0.09	34.00	296.00	8.42
	Mean	15.34(2.70)	7.24(1.36)	70(12.30)	317.71(8.62)	9.02(0.38)

Table A-7: Maximum, minimum, and mean (± SE) chemistry characteristics upstream of all stream road crossing types (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

		Upstream				
			DO	Turbidity	Conductivity	
Crossing		Temp (C^o)	(mg/L)	(NTU)	(µS/m)	pH
PC 2	Max	19.60	8.92	29.00	295.00	9.58
	Min	5.20	4.55	8.00	136.00	7.67
	Mean	14.55(1.88)	7.50(0.58)	18.86(2.69)	185.00(22.34)	8.33(0.23)
PC 3	Max	20.00	8.94	56.00	292.00	9.72
	Min	5.30	4.00	13.00	140.00	7.63
	Mean	15.33(2.11)	7.62(0.69)	38(6.81)	182.43(22.23)	8.29(0.26)
PC 5	Max	21.20	10.54	47.00	190.00	8.57
	Min	10.23	5.36	0.00	118.00	7.84
	Mean	17.05(1.71)	8.56(0.61)	25.71(6.80)	136.14(9.68)	8.11(0.10)
PC 6	Max	22.00	9.63	45.00	198.00	8.35
	Min	2.29	8.06	17.00	118.00	7.74
	Mean	15.97(2.83)	8.78(0.23)	28.57(4.15)	140.86(11.12)	8.12(0.08)
DB 4	Max	21.20	9.58	84.00	225.00	8.44
	Min	2.20	8.12	9.00	142.00	7.83
	Mean	16.01(2.37)	8.87(0.22)	42.20(10.69)	175.57(13.08)	8.15(0.1)
DB 7	Max	23.20	9.37	51.00	197.00	8.40
	Min	3.08	7.41	17.00	120.00	7.84
	Mean	16.14(2.63)	8.62(0.3)	31.00(4.85)	143.57(10.99)	8.10(0.08)
BG 8	Max	25.20	9.58	79.00	180.00	8.44
	Min	4.70	8.42	29.00	121.00	7.83
	Mean	14.96(3.16)	9.22(0.18)	58.00(7.05)	152.33(8.14)	8.06(0.08)
BG 9	Max	26.20	10.01	97.00	353.00	8.79
	Min	5.40	4.81	17.00	98.00	3.46
	Mean	16.00(2.86)	8.46(0.69)	62.29(10.74)	289.57(32.83)	7.89(0.74)

Table A-8: Road crossing structure characteristics (PC = single-barrel pipe culvert, DB = double-barrel pipe culvert, BG = bridge).

Crossing	Transect Length (m)	Slope (%)	Crossing Height (m)	Crossing Width (m)	Crossing Length (m)	Inlet Elevation (m)	Outlet Elevation (m)	Notes
PC 2	150	0.37	1.52	1.98	8.1	867.1	867.07	Hang height
PC 3	150	2.82	1.52	0.71	7.1	863.2	863	Large plunge pool
DB 4	150	1.16	Double 1.07	Double 0.84	5.17	859.00 (north) 859.05 (south)	858.94 (north) 859.00 (south)	Low clearance
PC 5	150	1.10	1.63	1.98	11.82	849.79	849.66	Hang height
PC 6	150	-0.46	1.57	2.59	10.89	847.48	847.53	Large plunge pool
DB 7	175	2.90	1.52 (north) 2.13 (south)	1.98 (north) 2.74 (south)	12.05	846.72 (north) 846.49 (south)	846.37 (north) 846.31 (south)	Large plunge pool
BG 8	200	0.49	NA	8.58	6.1	835.46	835.43	
BG 9	300	0.84	NA	23.14	11.96	725	724.9	

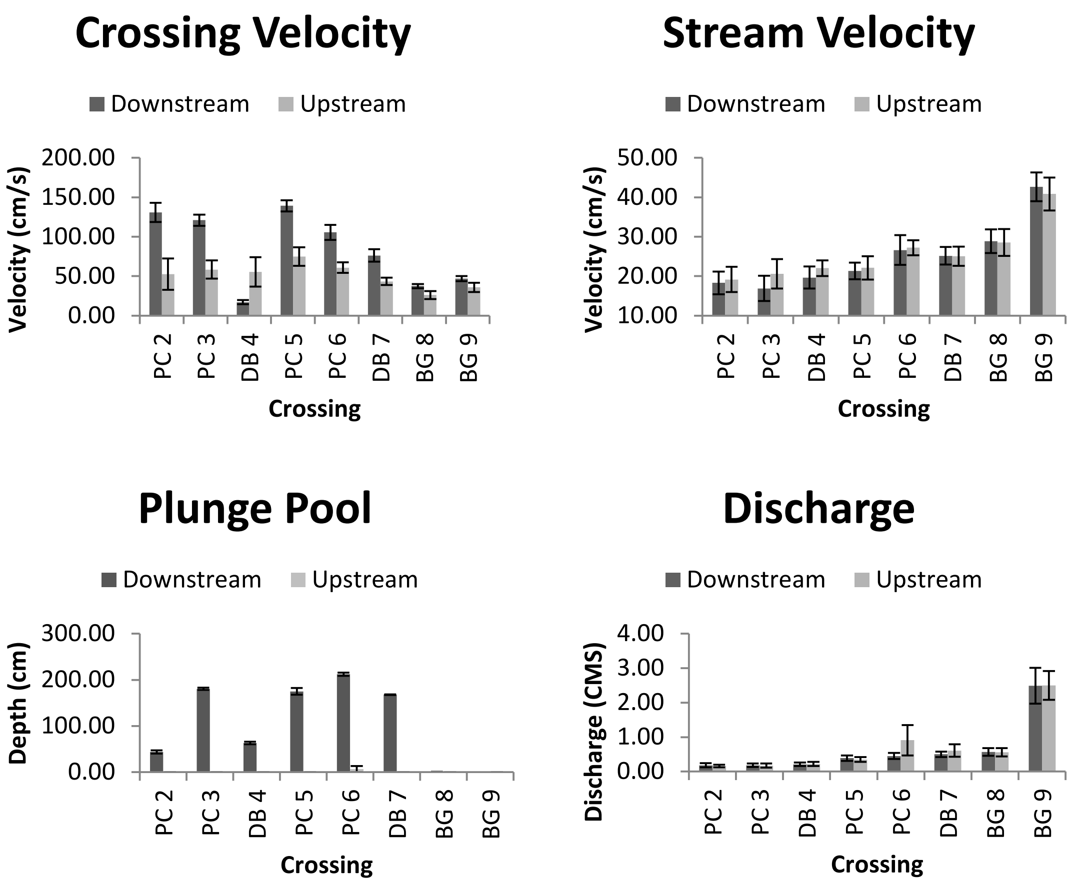
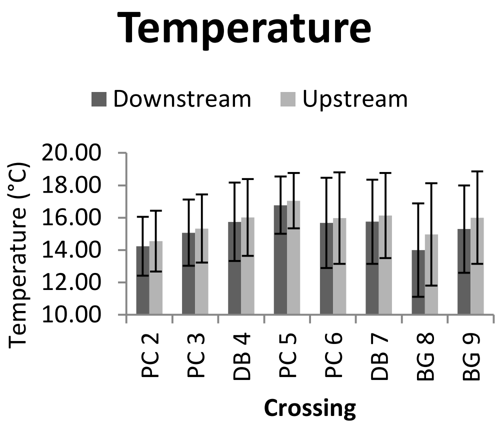
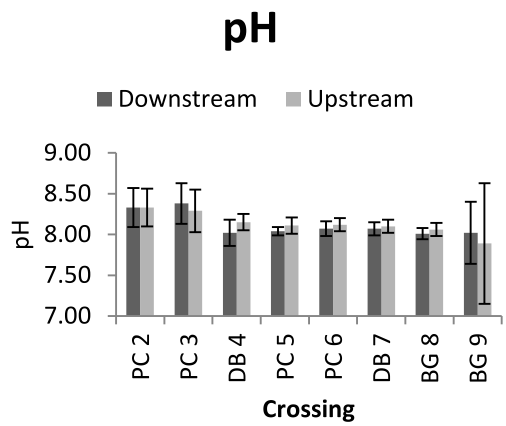
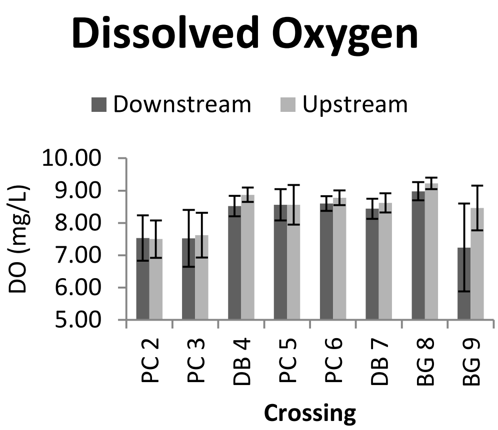
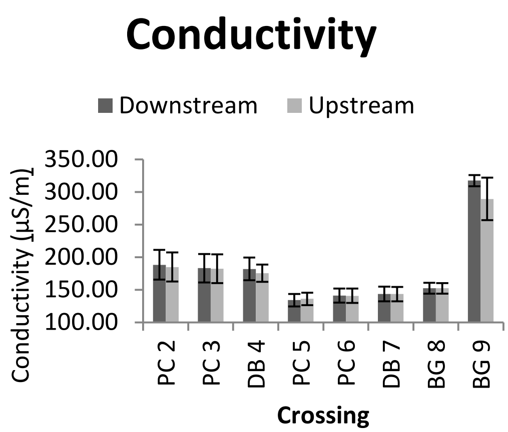


Figure A-1: Mean (± SE) physical characteristics of all stream road crossing structures from farthest upstream to farthest downstream. Minimum y-axis scale set to highlight differences.


Temperature
Downstream
Upstream
Temperature (°C)
20.00
18.00
16.00
14.00
12.00
10.00
PC 2
PC 3
DB 4
PC 5
PC 6
DB 7
BG 8
BG 9
Crossing


pH
Downstream
Upstream
pH
9.00
8.50
8.00
7.50
7.00
PC 2
PC 3
DB 4
PC 5
PC 6
DB 7
BG 8
BG 9
Crossing


Dissolved Oxygen
Downstream
Upstream
DO (mg/L)
10.00
9.00
8.00
7.00
6.00
5.00
PC 2
PC 3
DB 4
PC 5
PC 6
DB 7
BG 8
BG 9
Crossing


Conductivity
Downstream
Upstream
Conductivity (µS/m)
350.00
300.00
250.00
200.00
150.00
100.00
PC 2
PC 3
DB 4
PC 5
PC 6
DB 7
BG 8
BG 9
Crossing

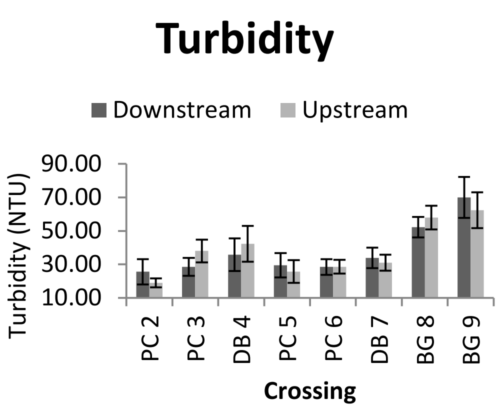

Turbidity
Downstream
Upstream
Turbidity (NTU)
90.00
70.00
50.00
30.00
10.00
PC 2
PC 3
DB 4
PC 5
PC 6
DB 7
BG 8
BG 9
Crossing

Figure A-2: Mean (± SE) chemical characteristics of all stream road crossing structures from farthest upstream to farthest downstream. Minimum y-axis scale is set to highlight differences.

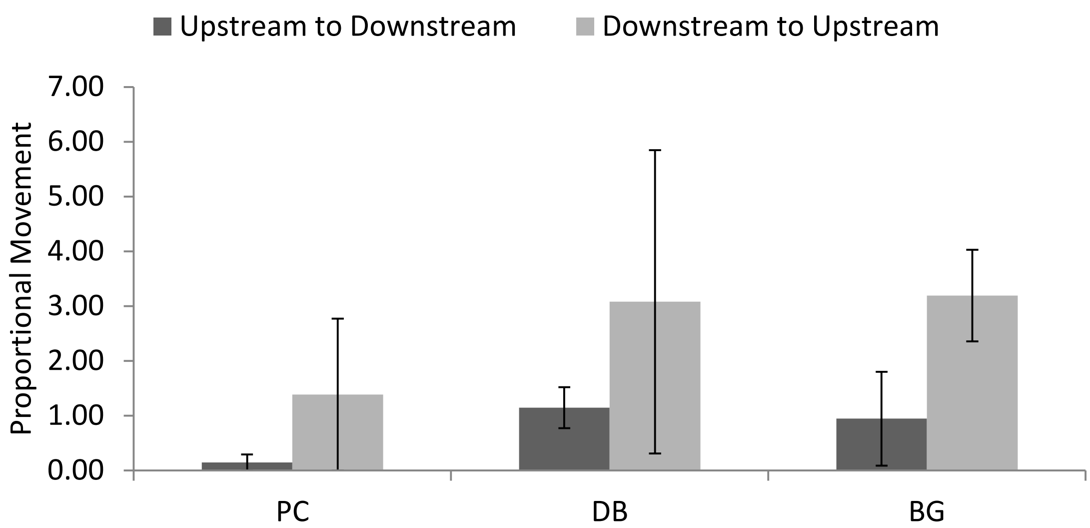


Figure A-3: Community mean proportional movement (± SE) for all sites upstream to downstream and downstream to upstream.

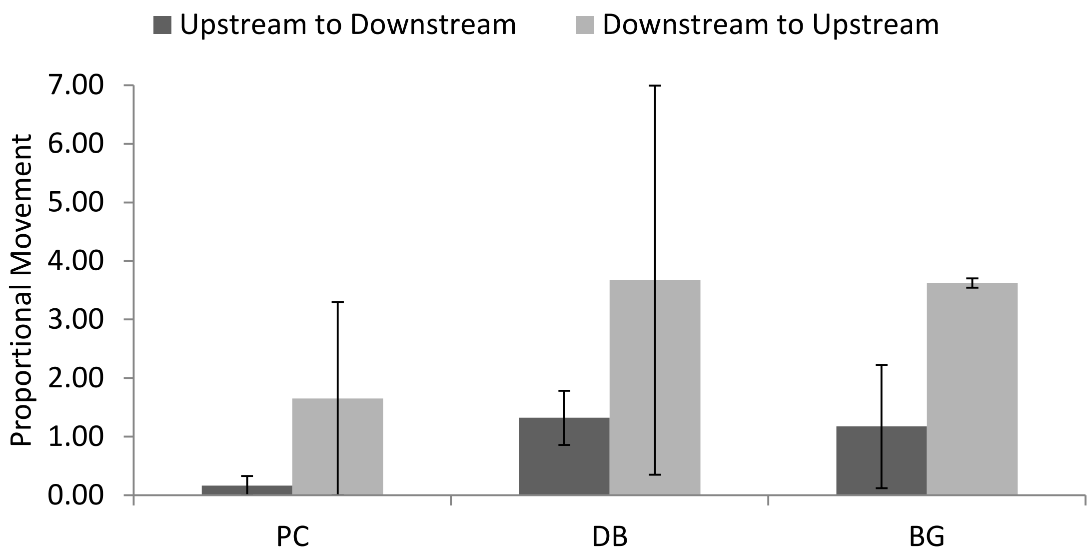


Figure A-4: Red shiner mean proportional movement (± SE) for all sites upstream to downstream and downstream to upstream.

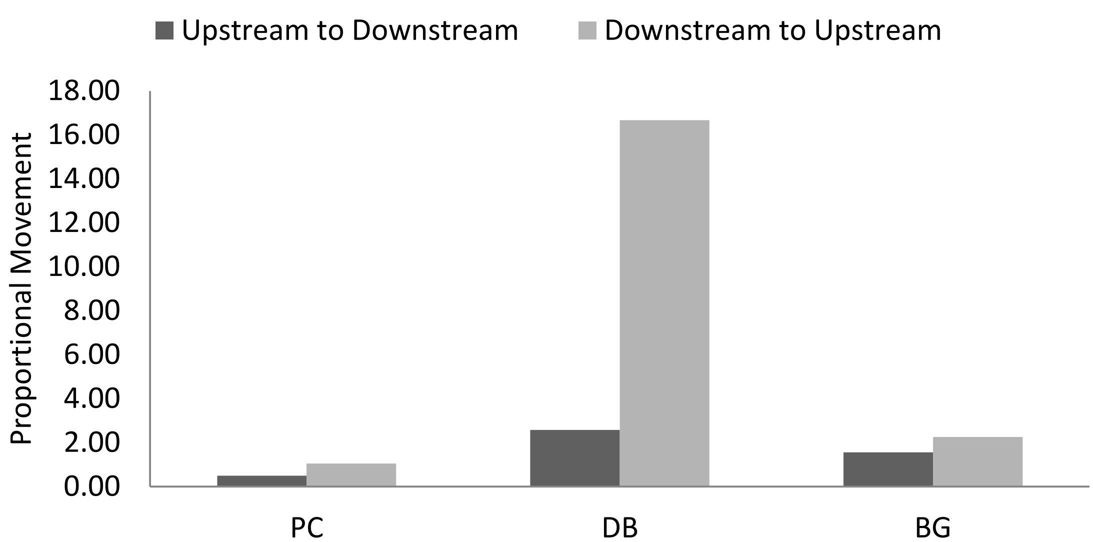


Figure A-5: Plains topminnow proportional movement for all sites upstream to downstream and downstream to upstream.