Road Crossing Designs and Their Impact on Fish Assemblages of Great Plains Streams

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Abstract.—A mark–recapture field study was conducted to determine fish passage at 5 concrete box culverts and 5 low-water crossings (concrete slabs vented by culverts) as well as 10 control sites (below a natural riffle) in Flint Hills streams of northeastern Kansas. Additionally, we tested the upstream passage of four fish species native to Great Plains streams (Topeka shiner *Notropis topeka*, green sunfish *Lepomis cyanellus*, red shiner *Cyprinella lutrensis*, and southern redbelly dace *Phoxinus erythrogaster*) through three simulated crossing designs (box culverts, round corrugated culverts, and natural rock riffles) at water velocities of 0.1 to 1.1 m/s in an experimental stream. The field study indicated that cyprinids were twice as likely to move upstream of box culverts than low-water crossings and 1.4 times as likely to move upstream of control reaches than any crossing type. The best models indicated that the proportion of cyprinids that moved upstream increased with decreased culvert slope and length, perching, and increased culvert width. Our controlled experiment indicated that fish can move through velocities up to 1.1 m/s in a 1.86-m simulated stream and that the proportion of fish that moved upstream did not differ among crossing designs for southern redbelly dace, green sunfish, or Topeka shiner; however, natural rock riffles had lower proportional movements (mean = 0.19) than the box (0.38) or corrugated culvert designs (0.43) for red shiners. Water velocity did not affect the proportional upstream movement of any species except that of Topeka shiners, which increased with water velocity. Crossing design alone may not determine fish passage, and water velocities up to 1.1 m/s may not affect the passage of many Great Plains fishes. Barriers to fish movement may be the result of other factors (e.g., perching, slope, and crossing length). The use of properly designed and installed crossings has promise in conserving Great Plains stream fishes.

Structures such as dams and road crossings may have negative impacts on fishes by reducing or eliminating upstream or downstream movement (Warren and Pardew 1998). Because movement may be critical for foraging (Clapp et al. 1990), spawning (Pess et al. 2003), refuge from predators (Harvey 1991), or thermal refugia (Matthews and Berg 1997), barriers to these movements may be detrimental to fish conservation. Barriers to movement can also result in habitat fragmentation, reduced species abundance and diversity, loss of genetic diversity, and even species extirpation (Winston et al. 1991; O'Hanley and Tomberlin 2005; Sheer and Steel 2006), including fishes common in the Great Plains (Warren and Pardew 1998; Toepfer et al. 1999).

Stream crossing design may also affect fish passage.

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Warren and Pardew (1998) found reduced proportional fish passage through culvert and slab crossings compared with open-box and ford (submerged road-bed) crossings in Arkansas streams, and research has shown corrugated culvert crossings may reduce fish movement (Schaefer et al. 2003; Coffman 2005). Barriers to passage at vehicle crossings can also include perching at the crossing inlet or outlet (Mueller et al. 2008), turbulence or velocity within the crossing caused by channel constriction or gradient, and inadequate water depth within the crossing (Votapka 1991; Wall and Berry 2004; Coffman 2005). Water velocity through road culverts may affect swimming distance and frequency (Toepfer et al. 1999), and as velocity increases, the likelihood of fish passage through a crossing is reduced while energetic stress is amplified (Adams et al. 2000).

The majority of North American studies involving fish passage have focused on salmonids (O'Hanley and Tomberlin 2005; Sheer and Steel 2006) and other anadromous or catadromous species (e.g., Beasley and Hightower 2000). However, little has been done to address fish passage in the Great Plains, where

awareness on the effects of barriers has increased for the federally endangered Topeka shiner *Notropis topeka* and other native stream fishes. Our objective was to further identify the physical limitations that crossing design and water velocity have on prairie stream fishes, and provide managers and transportation engineers with information to assist them in constructing fish-friendly crossings.

Methods

Study area.—Fieldwork was conducted in the Flint Hills of Northeast Kansas in streams that have been classified as critical habitat for the federally endangered Topeka shiner (Mammoliti 2004). Five box culverts and five low-water crossings located on five different streams were selected as study sites. Crossings that exhibited obvious barriers to passage (e.g., perching > 0.3 m at base flow) were not considered for testing (Vander Pluym et al. 2008).

Field study sampling design.—Field sampling was conducted between April and August 2007. At each study site, fish were sampled in the pool immediately downstream of the crossing using straight seines measuring 4.6 × 1.8 m or 9.1 × 1.8 m (4.8-mm mesh). Pools were sampled to depletion when possible, and an effort was made to collect the majority of fish from each pool; no block nets were used. Pool lengths ranged from 20 to 43 m. All fish were identified and enumerated by species. A uniquely colored visible implant elastomer (VIE) tag was injected underneath the dermis, parallel to the skin, to batch mark fish from sites below the road crossing. After tagging, fish were placed in mesh holding enclosures located in the stream to allow for recovery from handling before being released. A pool below a natural riffle downstream of each crossing was sampled as a control site to compare with the vehicle crossing site, and fish were marked with a different colored VIE tag (Figure 1). An effort was made to locate control sites at least one stream meander length away from crossings (a maximum of 400 m downstream) so control sites did not overlap with the experimental site, were not affected by the road crossing, and maintained their natural channel and flood plain.

Each site was revisited in June, July, and August to recapture fish and determine passage through the crossings. During recapture sampling, all pools and runs were sampled by at least three seine hauls. The recapture sampling reach extended 200 m upstream and downstream of crossings and controls. At one site, sampling was conducted 100 m upstream and downstream of the crossing and control because trespass permission prevented sampling farther downstream. Any recaptured fish were retagged with another VIE
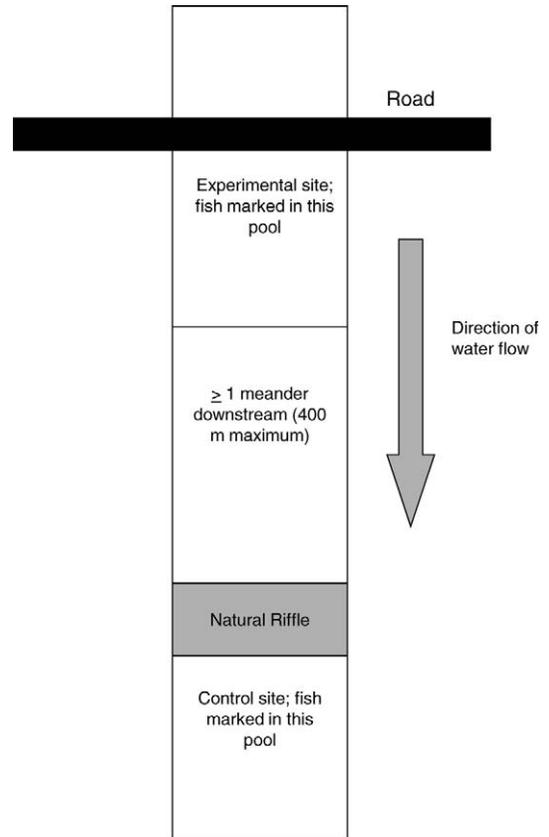

FIGURE 1.—Diagram of the control and experimental sites in relation to the road crossing for 10 sites in Flint Hills streams.

mark to aid in identification during future recapture events.

Water velocity (m/s) was measured at five locations across the crossing inlet and outlet with a Marsh-McBirney Flow-Mate 2000 flowmeter at the bottom of the crossing and averaged. Water depth was measured as the maximum depth (cm) at the inlet and outlet of each crossing. Other measurements included length (m), width (m), height (m), perching (cm), and slope of the crossing (%). Velocity, depth, and perching were measured during the initial tagging in April or May, and again during the July and the August recapture sampling. When crossings included multiple openings (e.g., box culverts with multiple cells and low-water crossings with multiple culverts), we used the means for all the cells combined.

Experimental stream sampling design.—Fish passage was tested in experimental streams at Konza Prairie Biological Station near Manhattan, Kansas, from June to August 2008. The experimental stream system consisted of alternating round 1.8-m-diameter ×

0.9-m-deep fish culture tanks (pools) connected by straight-sided, 1.83-m-long × 0.46-m-wide and 0.38-m-deep fiberglass riffles (Matthews et al. 2006). All pools contained rock substrate (3–6-cm diameter) from an adjacent natural stream. Each stream unit consisted of an upstream and downstream pool connected by the riffle. A constant supply of water from a natural spring was provided to each pool, and stream units were equipped with overflow drains to maintain water depths. To generate the desired water velocities, we used a combination of variable speed electric trolling motors and large sump and utility pumps.

We tested road crossing designs similar to designs observed and tested in the field (Bouska 2008), including box culverts and round, corrugated pipe culverts. In addition, a stream simulation with a flat, natural rock substrate served as a control. Box culvert models were constructed by lining the bottom of the fiberglass riffle with concrete landscaping blocks and covering the top of the crossing with plywood to simulate a covered concrete box. Corrugated pipe culvert models were constructed using round, corrugated plastic pipe 15 cm in diameter. To create the natural substrate control, the bottoms of the fiberglass riffles were covered with natural river rock and left uncovered to better resemble a natural riffle.

We tested fish movement at all crossing designs and the control riffle using water velocities from 0.1 to 1.1 m/s at 0.1-m/s intervals. Water velocity was measured at 60% of the water depth at nine locations through the model box culverts and the natural substrate treatments, and then averaged. Water velocity was only measured at the corrugated culvert crossing exit because the flowmeter could not be placed in the middle of a covered culvert design. Water depth through the crossing in all treatments was maintained at 10 cm. These depths and velocities are comparable to crossing conditions in northeast Kansas (Bouska 2008).

Fish species analyzed for movement were the Topeka shiner, green sunfish *Lepomis cyanellus*, southern redbelly dace *Phoxinus erythrogaster*, and red shiner *Cyprinella lutrensis*. Southern redbelly dace and red shiners were collected from local streams. Topeka shiners and green sunfish were obtained from the University of Kansas rearing facility operated by the Kansas Biological Survey, Lawrence, Kansas. Fish length was measured prior to testing to ensure similar sizes of fish were used in each treatment. An effort was made to test fish only once, but due to permitting restrictions, some Topeka shiners had to be used in more than one experiment.

Fish were first housed in 700-L rectangular fiberglass holding tanks equipped with standpipe drains and freshwater from the natural spring, and fed flake food and frozen chironomid larvae. Fish were allowed to acclimate at least 48 h to the fiberglass tanks before being used in the experiments. Fish were tested two species at a time (Topeka shiners and green sunfish; southern redbelly dace and red shiners) with 20 of each species per treatment. Fish were placed in the experimental streams for a period of 24 h. Minnow traps were attached in the upstream pool to the top of the model crossings to capture fish that successfully moved upstream through the crossing and to prevent fish from returning downstream after passage. At the end of each treatment, fish were collected from the trap and measured, the pools were drained, and the remaining fish were removed.

Data analysis.—Fish passage at each site of the field study was assessed through the crossing (treatment) and through the natural reach (control). All analysis was conducted by taxonomic groups based on family (Pflieger 1997): percids, ictalurids, catostomids, centrarchids, and cyprinids. Taxonomic groups with fewer than five recaptured fish at a site were omitted from the analysis. Fish passage was expressed as proportional movement (P), derived as

$$P = M/R,$$

where M is the number of recaptured fish moving past the treatment or control barrier and R is the number of recaptures at each segment (Warren and Pardew 1998). Therefore, only recaptured were used in this analysis. Logistic regression was used to determine whether the proportion of fish that moved upstream was related to crossing design, mean bottom velocity through the crossing, mean depth, culvert slope, culvert length, mean velocity to depth ratio, and perching. Mean water depth and velocity were used because multiple measurements were taken at each site. We used an information theoretic approach to develop a suite of a priori models that may influence fish movement near these crossings. Our first analysis was to determine if the proportion of fish that moved upstream was influenced by crossing design and treatment, and included three models: (1) culvert type (box culvert or low-water crossing), (2) treatment (experimental or control reach), and (3) a global model that included both crossing design and treatment type. The second suite of models focused on if the proportion of fish that moved upstream was influenced by physical crossing measurements. In this analysis, only crossing treatments were used because these variables (e.g., perching, crossing slope, etc.) were not measured at control sites. This analysis included a suite of five models: (1) crossing type, (2) perching, (3) crossing

TABLE 1.—Mean proportional upstream movements (SEs in parentheses) for cyprinids and all species combined at two crossing designs (10 sites) in the Flint Hills; N = the total number of recaptured fish (control and crossing combined).

Crossing design	Taxon group	Control	Crossing	N
Box culvert	Cyprinids	0.41 (0.17)	0.64 (0.18)	216
	Overall	0.41 (0.17)	0.53 (0.17)	247
Low water	Cyprinids	0.45 (0.09)	0.23 (0.11)	408
	Overall	0.41 (0.09)	0.19 (0.09)	451

dimensions (crossing slope, length, and width), (4) water parameters (bottom velocity, crossing, water depth, and velocity-to-depth ratio), and (5) a global model including all variables above. For both analyses, we used Akaike's information criterion corrected for small sample sizes (AIC_c) to help determine the best fit models given the data; all models were ranked using AIC_c, and Akaike weights (w_i) were calculated. Models with ΔAIC_c less than or equal to 2 were considered competitive models (Burnham and Anderson 2002). A repeated-measures analysis of variance (ANOVA) was used to determine if mean depth, bottom velocity, slope, length, and perching differed by crossing design using site as the repeated variable because sites were visited more than once.

An ANOVA was used to determine if mean fish lengths by species differed among velocity treatments in our experimental stream study. Upstream fish movement was again expressed as proportional movement as in the field study. An analysis of covariance (ANCOVA) with velocity as the covariate was conducted to determine if the mean proportion of fish that moved upstream was related to crossing type and water velocity. A significant interaction indicated that the relationship between fish movement and water velocity was not consistent among crossing designs (ANCOVA test for slopes; Zar 1996). In all analyses, a significance level was set at 0.05.

Results

Field Study Fish Movement

A total of 6,159 fish were marked from 18 April to 31 May 2007, and 698 (11%) were recaptured in June, July, and August 2007. Four species contributed 76% of all fish collected: southern redbelly dace (29%), common shiners *Luxilus cornutus* (16%), redfin shiners *Lythrurus umbratilis* (16%), and red shiners (16%). Upstream movement of fish was detected for both crossing designs. Movement of ictalurid, catostomid, centrarchid, and percid could not be calculated for both designs because of low recaptures ($N < 5$). Therefore, the remaining analysis focused on movement of cyprinids. The mean proportion of cyprinids that moved upstream ranged from 0.23 at low-water crossings to 0.64 at box culverts (Table 1). For all taxa combined, the results were similar. The best approximating models for the effects of crossing type of upstream movement of cyprinids included treatment (control or experimental, weight = 0.649) and the global model (treatment and crossing design, weight = 0.305; Table 2). Compared with control reaches, cyprinids were twice as likely to move upstream of box culverts than low-water crossings, and overall cyprinids were 1.4 times more likely to move upstream of control reaches compared with crossings. A total of 199 Topeka shiners were tagged below low-water crossings (173) and box culverts (26). Of the 32 recaptured Topeka shiners at low-water crossings, none were recaptured upstream of the crossing. Of the 5 recaptured at box culverts, one was collected upstream of the crossing.

The physical variables measured at our 12 crossings varied among crossing design. Water velocity at crossings ranged from 0.01 to 1.42 m/s (mean = 0.34 m/s) and was higher at low-water crossings than other designs ($P = 0.002$). Water depths ranged from 1.0 to

TABLE 2.—Highest-ranked logistic regression models of the proportion of cyprinids that moved upstream of five low-water crossings and five box culverts and reference reaches without a barrier. The information presented for each model includes the number of parameters (K), the deviance ($-2 \times$ log likelihood), Akaike's information criterion corrected for small sample size (AIC_c), the difference between the AIC_c value of the model in question the model and that of the best model (ΔAIC_c), and the Akaike weight of the model (w_i).

Model	K	Deviance	AIC_c	ΔAIC_c	w_i
Control and experimental reaches					
Treatment (control, experimental)	2	215.5	84.4	0.0	0.649
Global	3	196.6	85.9	1.5	0.305
Culvert type (box, low water)	2	199.3	89.7	5.3	0.046
Experimental reaches					
Crossing dimensions (slope, length, width)	4	63.89	31.9	0.0	0.581
Perch	2	89.25	32.7	0.8	0.386
Crossing type (box, low water)	2	74.49	37.7	5.8	0.033
Water (bottom velocity, depth, velocity–depth ratio)	4	16.65	87.9	56.0	0.000
Global	9	0.00	276.2	244.3	0.000

TABLE 3.—Physical characteristics at 10 road–stream crossings in the Flint Hills from May to August 2007; LW = low-water crossings, BC = box culverts, and numbers are site numbers.

Site	Width (m)	Height (m)	Length (m)	Perching (cm)	Slope (%)	Depth (cm)	Bottom velocity (m/s)
LW1	0.85	0.88	14	23.33	1.44	20.38	0.79
LW2	0.75	0.69	6.69	16.75	2.13	13.94	0.78
LW3	0.95	0.95	6.15	14.75	1.71	5.91	0.39
LW4	0.75	0.75	6.05	11	4.28	14.38	0.60
LW5	1.62	0.88	7.68	10	1.79	12.4	0.64
Grand mean	0.98	0.83	8.11	15.17	2.27	13.40	0.64
SE	0.16	0.05	1.50	2.38	0.51	2.31	0.07
BC1	4.68	2.98	13.56	17.5	0.73	4.58	0.26
BC2	4.3	3	8.7	0	0.12	4.4	0.02
BC3	3.05	3	10.1	0	0.17	8.88	0.01
BC4	4.2	4.25	16.25	14	0.23	1.5	0.03
BC5	6.2	4.25	16.95	0	0	42.07	0.02
Grand mean	4.49	3.5	13.11	6.30	0.25	12.29	0.07
SE	0.51	0.31	1.63	3.90	0.13	7.54	0.05

60.0 cm (mean = 12.7 cm) but did not differ among crossing design ($P = 0.891$). Perching of culverts (which all had a perching <0.30 cm at base flows) ranged from 0.0 to 25.0 cm (mean = 9.3 cm; Table 3) and also did not differ between crossing types ($P = 0.089$). Slopes ranged from 0.0% to 4.30% (mean = 1.09%; Table 3) and was higher at low-water crossings ($P = 0.005$), and lengths ranged from 6.05 to 16.95 m (mean = 10.3 m; Table 3), box culverts being longer ($P = 0.050$). The models best supported by the data to relate the proportion of cyprinids that moved upstream to the physical variables measured at the crossings included crossing dimensions (slope, length, and width) and the amount of perching (Table 2). The proportion of cyprinids that moved upstream increased with decreased culvert slope and culvert length, and increased culvert width. In addition, a well-supported model (weight = 0.386; Table 2) indicated that increased proportion of cyprinids that moved upstream of a crossing decreased with increased perching. However, the model with crossing type was not well supported (weight of 0.03).

Experimental Streams

Mean lengths of fish used in each of the 11 water velocities and three crossing designs did not differ for Topeka shiner (mean = 56 mm; range = 41–79 mm; $P = 0.612$), green sunfish (mean = 44 mm; range = 30–83 mm; $P = 0.175$), southern redbelly dace (mean = 46 mm; range = 38–60 mm; $P = 0.823$), and red shiner (mean = 51 mm; range = 40–71 mm; $P = 0.135$). The slopes of the regression lines of the relationship between velocity and proportional fish movement did not differ among crossing designs for Topeka shiner ($P = 0.362$), green sunfish ($P = 0.186$), southern redbelly dace ($P = 0.268$), or red shiner ($P = 0.569$;

Figure 2). Therefore, the proportion of fish moving upstream was consistent among crossing designs for each velocity tested. The proportion of fish that moved upstream did not differ by crossing design for southern redbelly dace ($P = 0.146$) and green sunfish ($P = 0.820$) nor by velocity for southern redbelly dace ($P = 0.184$) or green sunfish ($P = 0.220$; Figure 2). Upstream movement of Topeka shiners did not differ among crossing designs ($P = 0.322$), but greater movement was observed at higher velocities ($P < 0.0001$; Figure 2). Even at velocities of 1.1 m/s, Topeka shiner proportional movement was as high as 0.60. The proportion of red shiners that moved upstream did not differ by water velocity ($P = 0.927$), but the natural rock control had lower movement than box or culvert crossings ($P = 0.027$; Figure 2). For all velocities and crossings, Topeka shiners and green sunfish never exhibited proportional movement greater than 0.60, while southern redbelly dace and red shiners displayed proportional movement up to 0.95 (Figure 2). Overall, the mean proportion of fish that moved upstream was 0.17 (SE = 0.032) for Topeka shiners, 0.19 (SE = 0.024) for green sunfish, 0.36 (SE = 0.039) for red shiners, and 0.45 (SE = 0.041) for southern redbelly dace, regardless of crossing design or velocity.

Discussion

Road crossings acted as semipermeable barriers, low-water designs having a greater effect on fish movement than box culverts. These results support the findings of Warren and Pardew (1998) who also found reduced passage through low-water crossings compared to fords (wet crossings) and 2–4-m-wide open-box crossings, but contrasted findings by Vander Pluym et al. (2008) who found no differences in fish
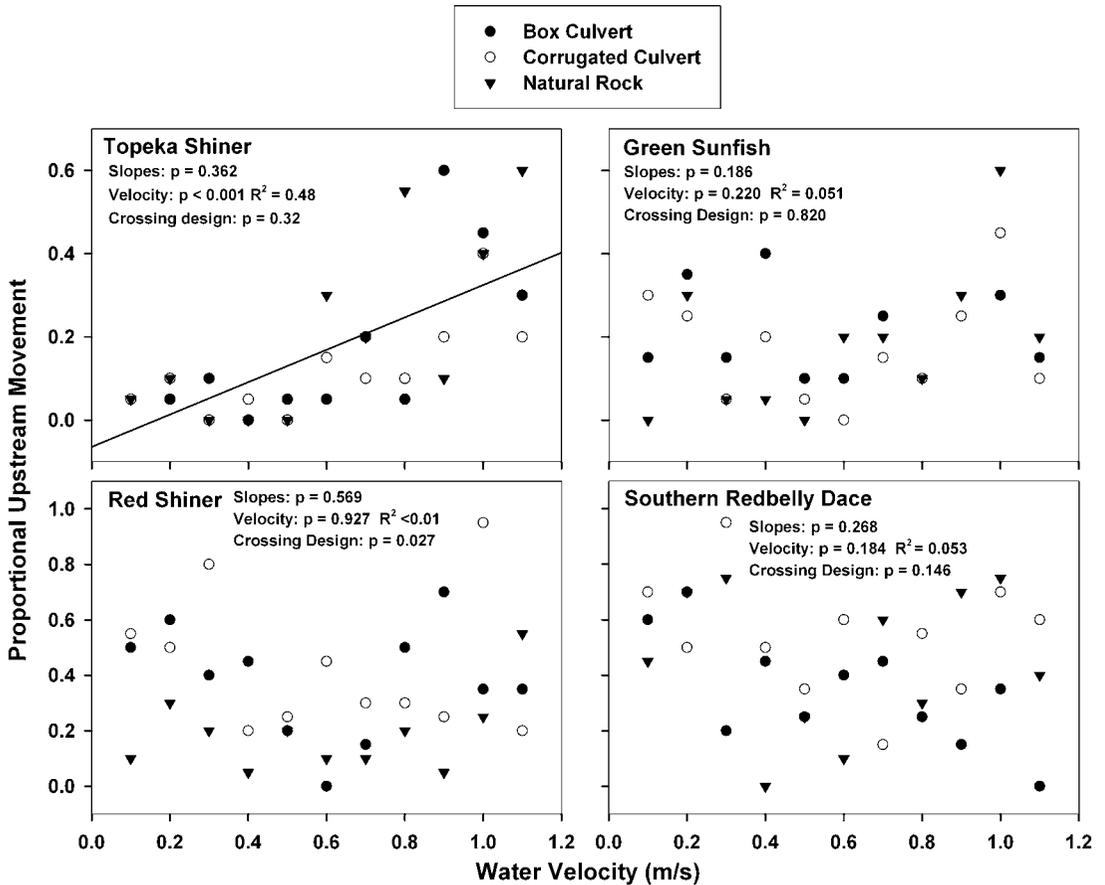
FIGURE 2.—Relationship between the proportion of fish that moved upstream and water velocity for four prairie stream fishes through three crossing designs in an experimental stream. The *P*-values indicate whether the proportion of fish that moved upstream differed by crossing design, velocity, or their interaction (ANCOVA test for equal slopes).

movement among bridges and arch, box, and pipe culvert crossing designs (but they did not include low-water crossings in their analysis). Their results also may be due to the extremely low mean percentage of recaptures (1.91% to 9.96% per month; Vander Pluym et al. 2008). Rosenthal (2007) found one low-water crossing (which was 2.4 m wide and had similar slopes to our study) had limited affects on movement of prairie fishes, although there was no perching at the crossing.

Overall proportional upstream of movement of cyprinids was lower at low-water crossings compared with box culverts in the field study, but the proportional upstream movement of fishes in the experimental streams did not appear to be affected by crossing design, except for red shiners, which surprisingly indicated reduced movement through the natural rock design. However, the scale of our experimental stream may have influenced our results. The field study

indicated crossings lengths of 8–17 m and widths of 0.75–6.2 m, whereas the experimental streams were only 0.46 m wide and 1.83 m long. Velocity through road culverts may affect swimming distance and frequency (Toepfer et al. 1999), and as velocity increases, passage through a crossing is reduced (Adams et al. 2000). Adams et al. (2000) found that 45–55-mm total length Topeka shiners could swim for about 60 s at 0.75 m/s water velocity. Using this endurance and velocity data as well as an equation by Peake et al. (1997) and Adams et al. (2000) for predicted passable water velocities of

$$V_f = V_s - (D/E_{\text{versus}}),$$

where V_f is the velocity through the crossing (m/s), D is the distance of the crossing (m), and E_{versus} is endurance in seconds at V_s, we would predict passage of Topeka shiners through our experimental crossings only up to 0.72 m/s. Using the same equations and the

mean length of low-water crossings (8.1 m) and box culverts (13.1 m), we would predict passage of Topeka shiners through low-water crossings up to 0.61 and 0.53 m/s at our box culverts. However, observed mean water velocities at four of five low-water crossings exceeded these measurements, whereas no box culvert exceeded 0.53 m/s. However, these results were based on mean water velocity, and there was a possibility that pockets of lower water velocities occurred in sections of the culverts. Our study indicated passage of Topeka shiner (of similar sizes to those in Adams et al. 2000) at velocities up to 1.1 m/s through our 1.86-m crossings, suggesting Topeka shiner endurance and swimming performance may be greater than previously reported. Ward et al. (2003) determined average failure velocities (velocity at which fish could no longer maintain position in a recirculating swim tunnel) of 0.78 m/s for red shiners (mean length = 69 mm), 0.46 m/s for green sunfish (mean length = 70 mm), and 0.70 m/s for speckled dace *Rhinichthys osculus* (mean length = 68 mm). In contrast, our experimental study revealed that 24–43% of our stream fishes moved upstream even at velocities greater than 0.8 m/s. Additionally, our tested fish were all smaller compared with those tested by Ward et al. (2003), which would reduce swimming ability (Adams et al. 2000; Wolter and Arlinghaus 2003). Our results suggest that prairie fishes may be able to pass through various crossing designs at water velocities up to 1.1 m/s. The reduced proportional movement by red shiners through this design was unexpected as the rock substrate was intended to mimic a natural riffle. Because the top of the natural rock design was open (allowing in light) and the box culvert and corrugated culvert models were enclosed and dark, there is a possibility that red shiners had an aversion to the uncovered rock substrate (i.e., behavioral barrier), which may explain the reduced movement through this design. Light may attract some species and repel others occupying the same location, indicating different responses by different species to light stimuli (Popper and Carlson 1998).

Low-water crossings consistently had higher mean bottom velocities than box culverts in our field study, and increased slope and crossing length was related to decreased fish movement through crossings. Low-water crossings had slopes about eight times greater than box culverts, which may be part of the reason these crossing designs had reduced fish passage. Mean water velocity in the field study was up to 0.79 m/s but was not part of the best approximating models from the field study. However, our measurements of water velocity and perching were snapshots, and we could not determine specifically when fish passed the crossing. There were no gauging stations on these streams, but it is likely all streams were not perched during higher water events for some period of the study. In addition, our experimental work indicated that water velocity had little effect on fish passage. Topeka shiners actually exhibited greater movement at increased water velocities, while the movement of southern redbelly dace, red shiners, and green sunfish through the model crossings was not altered by changes in velocity. Movement during these increased flows could be a spawning cue. Peak spawning in Topeka shiners begins in May (Pflieger 1997; Kerns and Bonneau 2002), which coincides with periods of increased streamflow and higher velocities. All of our tested species exhibit overlapping spawning periods, and green sunfish, red shiners, and Topeka shiners are often observed spawning simultaneously (Pflieger 1997). This suggests that other variables or behavior may be responsible for fish movement and passage at crossings.

Stream crossing design and installation may also have affected stream function, and negative effects of road crossings are minimized if they mimic the form and function of the adjacent stream. Stream crossings can cause disturbance to the stream channel through sediment degradation or aggradation by altering the starting and stopping of debris flows. Wellman et al. (2000) determined that sediment accumulation and sediment depth was greater in streams with culverts than at streams with bridges. Box culverts had increased riffle spacing, mean bank-full depths, and width-to-depth ratios upstream of the crossings compared with downstream in our study streams (Bouska 2008). Low-water crossings were stream constriction points which does not allow transport of water, sediment, and debris during high flows (Clarkin et al. 2005; Bouska 2008). Therefore, an inappropriate crossing design or installation can alter a stream's geomorphologic pattern and sediment transport, which can, in turn, result in changes to aquatic habitat.

The crossing designs we tested were semipermeable barriers, allowing some degree of fish passage for most Great Plains species. However, the degree of passage necessary to maintain biological and genetic diversity in a stream over time is unknown. Nonetheless, our study suggests that low-water crossings may have an effect on fish passage.

Acknowledgments

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