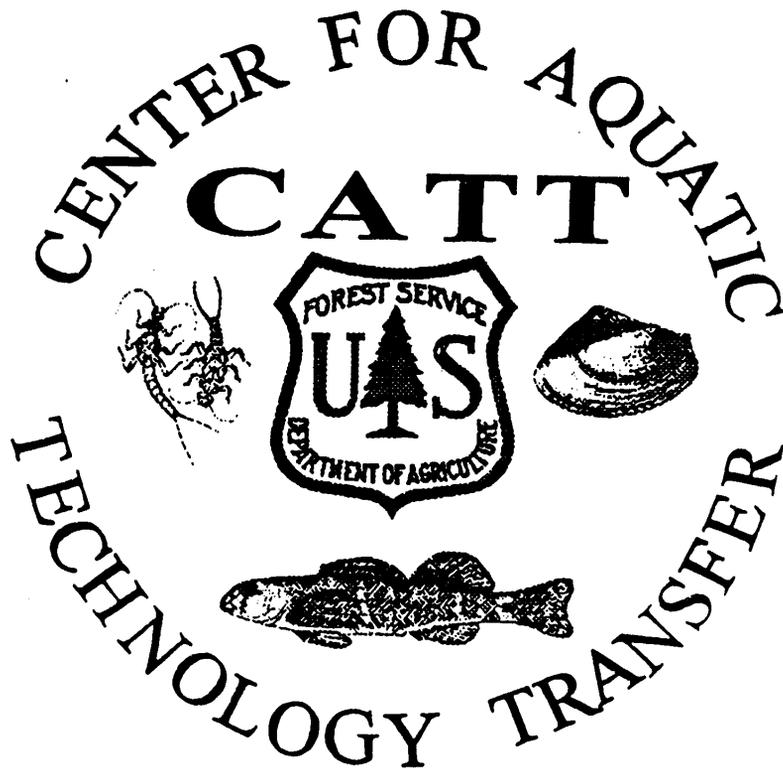


Road Crossings as Barriers to Small-stream Fish
Movement



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Abstract. -- We used mark-recapture techniques to examine the effects of four road crossing types on fish movement during spring base flows and summer low flows in small streams of the Ouachita Mountains, west-central Arkansas. We assessed movement for 21 fish species in seven families through culvert, slab, open-box, and ford crossings and natural reaches. We detected no seasonal or directional bias in fish movement through any crossing type or the natural reaches. Overall fish movement was an order of magnitude lower through culvert than other crossings or natural reaches; no movement was detected through the slab crossing. In contrast, open-box and ford crossings showed little difference from natural reaches in overall movement of fishes. Numbers of species that traversed crossings and movement within three of four dominant fish families (Centrarchidae, Cyprinidae, and Fundulidae) also were reduced at culverts relative to other crossing types and natural reaches. In spring, retention of fishes was consistently highest in stream segments upstream of crossings and lowest in downstream segments for all crossing types, a response attributed to scouring associated with spring spates. Water velocity at crossings was inversely related to fish movement; culvert crossings consistently had the highest velocities and open-box crossings, the lowest. A key requirement for improving road crossing designs for small-stream fish passage will be determination of critical levels of water velocity through crossings.

The ability to disperse is often critical to fishes for access to spawning habitat (Fausch and Young 1995), maintenance of populations in areas unsuitable for reproduction (Schlosser 1995; Schlosser and Angermeier 1995), and access to prey or avoidance of predators (Power 1987; Harvey et al. 1988; Harvey 1991). Barriers to dispersal may delay or preclude recovery of fish assemblages following disturbance (Detenbeck et al. 1992) and increase extinction risk by fragmentation (Bestgen and Platania 1991; Winston et al. 1991).

Road crossings are potential barriers to the movement of small-stream fishes. Road crossing designs vary from simple, low-water fords to massive concrete or earth-filled structures. Some crossing types may act as semi-permeable or seasonal barriers to fish movement, similar to shallow riffles (Matthews et al. 1994), and others may preclude all movement by fishes, similar to effects of dams (Winston et al. 1991; Watters 1996).

Unlike salmonids (Fausch and Young 1995), little is known about movement of small-stream, warmwater fishes (Hill and Grossman 1987a; Bart 1989; Peterson and Bailey 1993; Freeman 1995) and even less about effects of road crossings on these fishes. Despite traditional views to the contrary (e.g., Gerking 1959), recent work has shown that small-stream fishes can be highly mobile (Decker and Erman 1992; Matheney and Rabeni 1995) and show rapid recolonization into defaunated stream reaches (Peterson and Bayley 1993; Sheldon and Meffe 1994). The effects

of road crossings on fish movement in small warmwater streams, however, are unknown.

The potential of a road crossing to act as a barrier to fishes likely is related to the alteration of flow through the crossing. We hypothesized that crossing types that minimally alter natural flow may be less likely to influence fish movement. We examined the effects on fish movement of four road crossing types with different potentials to alter flows. Fish movement through crossings was determined at spring base and summer low flows in small streams in forested watersheds of the Ouachita Mountains, Ouachita National Forest, west-central Arkansas. We specifically asked four questions: 1) does crossing type affect overall, directional, or seasonal fish movement; 2) is crossing type associated with diversity of fishes or fish families able to traverse the crossing; 3) are patterns of fish retention affected by crossings; and 4) is there a relationship between fish movement and water depth and velocity through crossings?

Methods

Road crossings.-- We selected nine crossings on eight streams in the Ouachita National Forest (Ouachita River drainage), Montgomery County, Arkansas, for study of fish movement at summer low flows (July-August 1993) and spring (March-May 1994) base flows. Crossing types included two fords, two open-box bridges, four circular culvert crossings, and one solid, concrete slab with no culverts (included only in summer samples). Gradients of study stream reaches, determined from 1:25,000 scale topographic

maps, averaged 0.8% (SE = 0.14%); substrates were predominantly cobble, bedrock, and gravel. We characterized crossings by determining average velocity (m/s, by timing of a neutrally buoyant object through the crossing a minimum of three times or by digital current meter), length (m, upstream to downstream distance of the crossing), and average depths (cm). Depths of culvert and open-box crossings were averages of the upstream and downstream opening depths; for other crossings, depths along the thalweg were averaged.

Ford crossings (Little and Big Cedar creeks, stream order II) were gently sloping, submerged roadbeds composed of compacted gravel substrate. Velocities through the fords were 0.10 m/s in summer and ranged from 0.12 to 0.28 m/s in spring. Lengths were 7 and 8 m, and depths were 6 cm (both) in summer and ranged from 12 to 20 cm in spring.

Open-box crossings (Twin and Martin creeks, order II and III, respectively) had one to three bays (3 - 4 m wide, 24 - 30 m in length) topped with a concrete roadbed and underlain with a concrete or gravel bottom. Velocities were negligible in both spring and summer (<0.05 m/s), and depths ranged from 30 to 75 cm in summer and 40 to 80 cm in spring.

Culvert crossings (Murphy Creek and Walnut Fork, Order II; Little Cedar Creek, Order III; South Fork, Order IV) consisted of two to four, 1-m diameter circular, concrete or corrugated plastic culvert pipes positioned on a concrete pad overlain by concrete or earth and gravel filled roadbed with a concrete apron

extending downstream 3-4 m. Culvert crossing velocities were 0.4-1.4 m/s in summer and 0.8-1.4 m/s in spring; lengths, 6-10 m; and depths, 5-16 cm in summer and 14-47 cm in spring. One culvert (Murphy Creek) had a vertical drop of 5-8 cm in summer on the downstream edge of the concrete apron, and another (Walnut Fork), a drop of 8 and 5 cm off the edge of the apron in summer and spring, respectively. Other culvert crossing aprons were submerged throughout the study.

The concrete slab crossing (East Fork Twin Creek, Order I) was a low dam across the stream with a 25-cm vertical drop off the downstream edge to the surface of the receiving pool. Velocity over the slab was negligible; length, 4 m; and depth, 5 cm during the summer.

Study design.--At each crossing, we divided the stream into three segments of about equal length (\bar{x} = 36 m, SE = 1.2 m, n = 51) in both seasons. We located the first segment (upstream segment) immediately upstream of the crossing and the second segment immediately downstream (downstream segment 1). We located the third segment (downstream segment 2), downstream of downstream segment 1 and separated from it by a natural stream reach equal in length to the crossing. At each crossing, the natural reach was a shallow riffle or run with a range in depths of 10-40 cm in summer and 20-70 cm in spring. We did not determine velocities through natural reaches.

Fish sampling.--At each site, we placed block nets at the ends of each stream segment and conducted two-pass electrofishing

through the segment. We batchmarked all fishes with a subcutaneous injection of acrylic paint (Lotrich and Meredith 1974; Hill and Grossman 1987b; Freeman 1995) of a color unique to that stream segment and season.

After initial marking, we resampled each site twice during each season by blocking segments and conducting two-pass electrofishing. Mean interval between samples was 17 d (SE = 1 d) in the spring and 12 d (SE = 0.8 d) in the summer. We resampled one open-box crossing (Martin Creek) only once during the summer because shallow water precluded efficient sampling. During the first resample, unmarked fishes were marked, and fishes that had moved were re-marked with a color unique to the segment where recapture occurred.

Data analyses.--At each site, we assessed fish movement through the crossing (between the upstream segment and downstream segment 1) and across the natural reach (between downstream segments 1 and 2). We expressed fish movement as proportional daily movement, $M \cdot R^{-1} \cdot D^{-1}$, where M was the number of fish that had moved, R, the total number of recaptures in both segments, and D, the number of days since the first marking. We expressed directional movement similarly (i.e., now M is the number of fish moved upstream or downstream, respectively). We used an arcsine-square root-transform of proportional daily movement to achieve equality of variances and normality for analyses of variance but present re-transformed means and error terms (Sokal and Rohlf 1981). Significance values were $P < 0.05$ for all tests.

We tested for effects of crossing type and season on fish movement using two-factor analysis of variance with orthogonal contrasts of mean proportional daily movement (Sokal and Rohlf 1981) among crossing types and natural reaches (Table 1). No differences were found among natural reaches in mean proportional daily movement (ANOVA; summer, $F = 1.54$, $df = 3, 5$, $P < 0.3127$; spring, $df = 2, 5$, $F = 0.78$, $P < 0.5084$), and natural reaches were pooled. For contrasts, we hypothesized that crossings with the greatest ostensible alteration of flow would show the greatest effects on fish movement (Table 1). The slab crossing was excluded from this analysis because of its inclusion only in summer samples. We analyzed directional movement separately for each season using analysis of variance for all crossings pooled and for each crossing class separately.

We tested for association of the diversity of fishes or fish families that moved through a crossing with crossing type using G-tests (Sokal and Rohlf 1981) with exact p-values (Mehta and Patel 1992). For the diversity test, rows were crossing types, and columns, the number of recaptured species that had moved or had not moved through a crossing. We excluded the slab crossing from this analysis because of low species richness. For tests of association between family and crossing type, we used the four families with the highest percentage of recaptures (Centrarchidae, Cyprinidae, Fundulidae, and Percidae) (Table 2). We performed separate tests for each family where rows were crossing types, and columns, the number of recaptured individuals

that had moved or had not moved through a crossing. Because of sparse cell frequencies, we pooled slab and culvert crossings for this analysis.

We tested for differences in fish retention among upstream segment, downstream segment 1, and downstream segment 2 using recapture data for each stream segment at each site. We estimated fish retention in each stream segment for each season as R/T , where R is the total number of fishes recaptured and T , the total marked in that segment. Under the null hypothesis that segment position relative to a crossing has no effect on fish retention, migration would be allocated randomly among segments within a site and show no among-site patterns. To test this hypothesis, we used Friedman's method for randomized blocks where within-site fish retention was ranked by segment and blocked by site (Sokal and Rohlf 1981).

We tested for relationships between physical characteristics (velocity and depth) of a crossing and fish movement using Kendall's coefficient of rank correlation (Kendall tau-b). We correlated V , D , and V/D , where V is average velocity and D , average depth, with proportional daily movement for crossings ($n = 9$, summer; $n = 8$, spring) for both seasons together and separately by season.

Results

We marked 6,113 individuals (2,721 summer and 3,392 spring) representing 26 species and 8 families of fishes during the study. Average numbers of individuals marked per site were 302

(SE = 69.4) for summer and 424 (SE = 87.9) for spring. For all sites, we recaptured 18% of fishes in spring and 21% in summer. We recaptured 21 species representing 7 families (Table 3). Four fish families, Centrarchidae (sunfishes), Cyprinidae (minnows), Fundulidae (topminnows), and Percidae (darters) comprised >97% of all recaptures (Table 2).

Discharge and rainfall data from South Fork Ouachita River, Mt. Ida, Arkansas (USGS 1994, 1995; NOAA 1993a,b, 1994a,b,c) and personal observations indicate study streams had lower than average summer flows and near average spring flows. Average daily discharges of the river were 2.7 m/s for summer and 26.9 m/s for spring samples. The corresponding 52-year average discharges of the river were 4.9 m/s (July and August) and 34.6 m/s (March, April, and May) (USGS 1994, 1995). In summer sampling, rainfall was negligible (NOAA 1993a,b); no bankfull conditions occurred in study streams. In spring sampling, four rainfall events >1.2 cm/d (NOAA 1994a,b,c) produced bankfull to overflowing conditions at least three times in the study streams.

Movement of fishes was significantly affected by crossing type (Table 1; Figure 1). No differences were found in seasonal movement, and interaction was not significant. Contrasts indicated mean movement was significantly higher for open-box (0.0096), ford (0.0056), and natural reaches (0.0038) than for culvert crossings. Movement through natural reaches was lower than through open-box and ford crossings. No differences were

detected between open-box and ford crossings. No movement was detected through the slab crossing.

Fish movement through crossings was bidirectional. No differences were detected between upstream and downstream movement across crossing types and natural reaches (summer, $F = 0.36$, $df = 1,32$, $p < 0.5514$; spring, $F = 0.40$, $df = 1,30$, $p < 0.5315$). Likewise, neither individual crossing types nor natural reaches showed significant directionality in spring or summer.

The number of fish species that moved was associated significantly with crossing type ($G = 13.28$, $df = 3$, $P < 0.0146$; Table 3). Diversity of fishes traversing crossings increased along a gradient of slab, culvert, open-box, and ford crossings and natural reaches.

Movement of three of four fish families showed significant associations with crossing type (Table 2). Sunfish and minnow movement was lowest through culvert and slab crossings, intermediate through natural reaches and ford crossings, and highest in open-box crossings. Topminnows showed lowest movement through open-box, culvert, and slab crossings, intermediate movement in natural reaches, and highest movement in fords. Darter movement was independent of crossing type and generally was low relative to other families for all crossings.

Crossings showed consistent upstream to downstream differences in retention of marked fishes in spring (Figure 2) but not in summer. In spring, segments upstream of crossings ranked significantly higher in retention of marked fishes

(upstream segment, $\bar{x} = 27.1\%$) than segments downstream of the crossing (downstream segment 1, $\bar{x} = 14.6\%$; downstream segment 2, $\bar{x} = 18.3\%$) ($\chi^2 = 13.00$, $df = 2$, $P < 0.005$; Figure 2). Downstream segment 1 generally ranked lowest in retention; only two of eight of these were ranked higher than downstream segment 2. In summer, there was no effect of segment position on retention of fishes ($\chi^2 = 0.60$, $df = 2$, $P < 0.90$).

Movement of fishes through crossings was related inversely to velocity and the ratio of velocity to depth. Velocity was negatively correlated with proportional daily movement of fishes across seasons and in the summer (Table 4), but the relationship was nonlinear (Figure 3). The ratio of velocity to depth showed consistent negative correlations with fish movement for seasons pooled and for each season, but the strength of the association was similar to that shown for velocity alone. Depth was not correlated with fish movement. Mean velocities generally increased across road crossings from spring to summer but were consistently highest in culvert crossings (> 0.90 m/s), intermediate in ford crossings (< 0.19), and lowest in open-box crossings (< 0.03).

Discussion

Culvert and slab crossings reduced overall fish movement, diversity of movement, and movement of fish families relative to natural reaches. In contrast, movement through open-box and ford crossings generally was comparable to or higher than movement through natural reaches. Neither natural reaches nor any

crossing type showed seasonal or directional bias for fish passage. For the slab crossing, we detected no movement of fishes in either direction suggesting this crossing type may act as a total barrier for much of the year. Culvert crossings were bidirectional barriers to fish movement in both seasons despite a range of flow conditions (e.g., bankfull flows).

Retention of fishes at all crossings was higher in upstream than downstream segments in spring but not summer. Although short-term, high turnover (i.e., low retention) of fishes in stream reaches is not unusual (Fausch and Young 1995), the reason for different retention rates between segments upstream and downstream of crossings is not readily apparent. The difference could be attributed to the interaction of crossings and elevated stream discharge in spring. Fishes immediately below the crossings may have been displaced downstream by scouring (Matthews 1986; Harvey 1987; Stock and Schlosser 1991), and those above, using the crossing as a hydraulic refuge, may have tended to aggregate.

The degree to which a crossing acted as a barrier was related to alteration of flow through the crossing. Culvert crossings had the highest mean velocities and lowest fish passage, and open-box crossings, the lowest mean velocities and highest fish passage. All culverts had water velocities that exceeded 40 cm/s (Figure 4). At constant fish size and water depth, increasing water velocities limit swimming abilities of fishes. This relationship led to the suggestion that maximum

water velocities of 30 to 40 cm/s for 100-m length culverts would allow passage of most mature migratory fish species; shorter culverts could sustain passage at higher velocities (Jones et al. 1974). Fish passage over short distances (< 10 m in culverts) in our study streams was reduced substantially at water velocities above 40 cm/s, suggesting flows through crossings for nonmigratory, small-stream fishes need to be much lower than the maximum suggested for migratory fishes.

Our familial-level analysis suggests passage also was mediated by taxon-specific responses to crossings. Both sunfishes (mostly Lepomis megalotis and L. cyanellus) and minnows (mostly the genera Campostoma, Notropis, and Semotilus), the dominant fishes in our streams, are capable of rapid dispersal (Detenbeck et al. 1992) and routine crossing of habitat boundaries (Berra and Gunning 1970, 1972; Ellis 1974; Bart 1989; Freeman 1995). However, the two families have different body morphologies and sizes, two primary determinants of swimming ability (Beamish 1978; Berry and Pimentel 1985; Harvey 1987). Culvert crossings produced fast flows that apparently were bidirectional barriers to passage for sunfishes and minnows despite a presumed range in swimming ability in the two families, and their observed ability to bidirectionally negotiate other crossings and natural reaches. In contrast, topminnows showed low movement through both open-box and culvert crossings, the two extremes in observed water velocities. Recaptured topminnows in our streams were predominantly northern studfish (Fundulus

catenatus), a diurnal feeder that may undergo extensive seasonal movements (Fisher 1981). Their inability to cross culverts may be attributed to velocity, but their response to other aspects of crossing configurations also apparently influenced passage success. Darter movement, primarily comprised of the riffle-dwelling orangebelly darter (Etheostoma radiosum), was relatively low for all crossings. Similarly, Scalet (1973) observed little movement in orangebelly darters in a natural stream setting. Movement studies of darters generally indicate long-term residence in relatively small areas although interhabitat movements by a small proportion of individuals are not uncommon (e.g., Mundahl and Ingersoll 1983; Freeman 1995).

Our results indicate that culvert and slab crossings reduced or precluded movement of fish of most species. Ford and open-box crossings showed little difference from natural reaches in movement of fishes. We present evidence that increased water velocity through culverts is part of the mechanism by which these crossings restrict fish passage. Given the necessity of dispersal for fishes to meet their life history requirements (Schlosser and Angermeier 1995), road crossings should be designed to minimize effects on fish movement. Determination of critical levels of water velocity through crossings may be key to designs that facilitate rather than prevent movement of small-stream, warmwater fishes.

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Table 1. Results of two-factor analysis of variance with orthogonal contrasts comparing proportional daily movement of fishes through three road crossing types and natural reaches.

Source of variation	df	F	P
Crossing type	3	7.54	0.0009
Season	1	3.39	0.0775
Interaction	3	1.78	0.1766
Orthogonal contrasts			
Natural, open-box, ford vs culvert	1	21.01	0.0001
Natural vs open-box, ford	1	4.28	0.0490
Open-box vs ford	1	1.49	0.2342
Within	25		
Total	32		

Table 2. Results of G-tests (df = 3, all tests) on the proportion of recaptured fishes that moved through four crossing types in each of four families. Total number of recaptured fishes are given in parentheses below each proportion.

Family	G	P	Crossing Type			
			Natural	Ford	Open Box	Culvert and Slab
Centrarchidae	16.44	0.0011	0.112 (321)	0.104 (144)	0.220 (50)	0.038 (166)
Sunfishes						
Cyprinidae	33.02	0.0001	0.191 (210)	0.146 (123)	0.297 (101)	0.028 (107)
Minnows						
Fundulidae	10.87	0.0216	0.140 (43)	0.333 (24)	0.032 (31)	0.077 (26)
Topminnows						
Percidae	0.56	0.9061	0.048 (105)	0.038 (26)	0.063 (16)	0.030 (69)
Darters						

Table 3. Summary of movement of fish species recaptured at four road crossing types and natural reaches. A "Y" indicates the species had moved through a crossing type, "N", the species was not detected having moved through a crossing, an asterisk (*) that the species was marked but never recaptured, and a dash (-) that the species was not encountered for that crossing type.

Fish Species	Crossing Type			
	Slab	Culvert	Open Ford	Natural reach
<u>Fundulus catenatus</u>	-	Y	Y	Y
Northern studfish				
<u>Lepomis megalotis</u>	-	Y	Y	Y
Longear sunfish				
<u>Semotilus</u>	N	Y	Y	Y
<u>atromaculatus</u>				
Creek chub				

<u>Etheostoma radiosum</u>	N	Y	Y	Y	Y
Orangebelly darter					
<u>Ameiurus natalis</u>	-	Y	*	N	Y
Yellow bullhead					
<u>Notropis boops</u>	-	Y	N	Y	Y
Bigeye shiner					
<u>Etheostoma blennioides</u>	-	Y	*	-	*
Greenside darter					
<u>Lepomis cyanellus</u>	N	N	Y	Y	Y
Green sunfish					
<u>Luxilus chrysocephalus</u>	-	N	Y	Y	Y
Striped shiner					
<u>Pimephales notatus</u>	-	N	Y	Y	Y
Bluntnose minnow					
<u>Campostoma anomalum</u>	-	N	N	Y	Y
Central stoneroller					

<u>Micropterus salmoides</u>	-	N	-	Y	Y
Largemouth bass					
<u>Hypentelium nigricans</u>	-	N	N	*	Y
Northern hogsucker					
<u>Lepomis macrochirus</u>	-	N	-	-	Y
Bluegill					
<u>Erimyzon oblongus</u>	-	*	-	N	Y
Creek chubsucker					
<u>Micropterus punctulatus</u>	-	*	*	-	Y
Spotted bass					
<u>Fundulus olivaceus</u>	-	N	N	N	*
Blackspotted topminnow					
<u>Nocomis asper</u>	-	*	N	-	N
Redspot chub					
<u>Aphredoderus sayanus</u>	-	N	-	-	-
Pirate perch					

Micropterus dolomieu - * * - N

Smallmouth bass

Lythrurus umbratilis - * * * N

Redfin shiner

Percent of recaptured

species that moved 0 44 58 77 83

Table 4. Correlations (Kendall tau-beta) of proportional daily fish movement and the ratio of velocity to depth, velocity, and depth of four road crossing types. The P-value is given in parentheses.

Variable	Seasons Pooled	Spring	Summer
Velocity	- 0.566 (0.0022)	- 0.500 (0.0833)	- 0.585 (0.0382)
Depth	0.294 (0.1053)	0.214 (0.4579)	0.377 (0.1666)
Velocity to Depth	- 0.538 (0.0034)	- 0.571 (0.0478)	- 0.606 (0.0300)

Figure Captions

Figure 1. Means (+ SE) of daily proportional movement of fishes through four road crossing types and natural reaches.

Figure 2. Mean percentages (+ SE) of recaptured fishes in stream segments upstream and downstream of road crossings during spring.

Figure 3. Scatterplot of velocity and proportional daily movement of fishes through road crossings at summer and spring flows.

