A Review of the Influences of Road Crossings on Warmwater Fishes in Ouachita Mountain Streams, Ouachita National Forest

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Abstract: Several studies have measured the influence of road crossings on fish movement and on fish communities within the Ouachita National Forest. In an initial study, passage of more than a hundred darters through a baffled pipe and over a grouted rip-rap ramp was documented over nine weeks. A broader study of fish movements associated with nine crossings ranging from natural-bottomed fords to piped crossings showed that natural ford and box culverts allowed unrestricted fish passage, but other designs were associated with reduced passage or none at all. Six piped crossings were examined in more detail including three that were modified in an attempt to improve fish passage. Fish were less likely to move across reaches with these low-water bridges compared to nearby natural reaches without low-water bridges. Average species richness was higher for fish communities downstream of the crossings compared to upstream (12.5 versus 6.3). Two rip-rapped low-water crossings were the only ones where upstream fish passage was detected. In a study of leopard darters, only one individual was detected moving downstream through a low-water crossing and none were found moving upstream. In an extensive study of twenty-one randomly selected low-water crossings, species richness was greater downstream versus upstream (9.4 versus 7.1, respectively). Total abundance (total number of all individuals of all species) was also significantly lower in the combined upstream reaches versus the combined downstream reaches. New box culvert installations indicated limited success in upstream passage, though detection of marked fish was quite low. Watershed-scale road and crossing densities were not significantly related to diversity and abundance of warmwater fishes or smallmouth bass density and biomass. Another study looking strictly at the effects of low-water crossings on stream geomorphology found stream widening upstream, stream incision downstream and changes in substrates when compared to a representative reach without a crossing. Work continues in designing, constructing and monitoring crossings that will pass fish.

Introduction

While dams have long been acknowledged as barriers to fish movements (Yeager 1993), published studies of road crossing impacts were scarce through the 1980's and the few exceptions were limited primarily to migrating adult salmon and steelhead trout (Anderson and Bryant 1980). It was not until the mid 1990's that research on road crossing impacts and fish passage needs for warmwater fish species began to receive much notice (USDA Forest Service 1998, Newbrey et al. 2001). In 1991, when confronted with a newly acquired tract of land containing a multi-culvert road crossing apparently blocking access to a historic spawning site for the Ouachita Mountains endemic, paleback darter (*Etheostoma pallididorsum*), we completed a literature search for relevant information and possible solutions. Relevant publications appeared limited to a single paper on the critical swimming speed of two warmwater darter species (Matthews 1985). Thus began the Ouachita National Forest's studies of various aspects of fish passage at road crossings, mostly with university cooperators, which have continued to date.

Physiography of the Study Area

The Ouachita National Forest is located in western Arkansas and southeastern Oklahoma and includes nearly 741,000 ha (1.83 million acres) of federally managed land. The Ouachita National Forest lies within the Subtropical Division of the Humid Temperate Domain. Most of the Forest is within the Ouachita Mountains Section of the Ouachita Mixed Forest-Meadow Province. The study areas contain high to mid-elevation mountains to hills with wide valleys and east-west trending ridges with very steep to moderately steep north facing slopes and moderately sloping south-facing slopes. Elevations range from 122 meters (400 feet) in the valleys to 701 meters (2,300 feet) above sea level in the mountains. Arkansas study sites were within the Ouachita River drainage and Oklahoma sites were within the Little River drainage, both tributaries of the Red River and eventually the Mississippi River. Maximum mean monthly temperatures range from 9.4°C (49°F) in January to 34.2°C (93.5°F) in July for the Forest. Mean annual precipitation ranges from 100 centimeters (39.4 inches) per year to 141 centimeters (55.5 inches) per year across the Forest. (USDA Forest Service 2005).

Case Studies

Jessieville Culvert Repair Study

In an effort to improve fish passage at a culvert barrier less critical than the one mentioned for the paleback darters, a 1.8 meter diameter (70 inch) corrugated metal pipe with a nearly 36 centimeter (14 inch) drop (figure 1) was paved inside with depressions and small rocks inserted as fish cover and to break up velocities. A grouted riprap ramp was added to eliminate the drop (figure 2).

Figure 1. Rusted out pipe with drop. Figure 2. Grouted pipe and riprap ramp.

Prior to culvert modification, the lead author (Standage et al. 1993) electrofished upstream of the culvert and found no fish. After modification, the ramp, the culvert and 60 meters upstream of the culvert (to a natural fish barrier) was electrofished weekly for nine weeks from February through early April of 1992. Captured orangebelly darters (*E. radiosum*) from each section received a batch fin-clip, by section and were released downstream of the ramp at the creek's confluence with a larger stream. Significant numbers of these darters were captured and recaptured upstream of the culvert where none had been captured prior to the modifications (figure 3). These darters were also captured and recaptured on the ramp and in the culvert. However, no other species were found upstream of the modified culvert even though green sunfish (*Lepomis cyanellus*), central stonerollers (*Campostoma anomalum*) and longear sunfish (*Lepomis megalotis*) were common downstream of the study tributary.

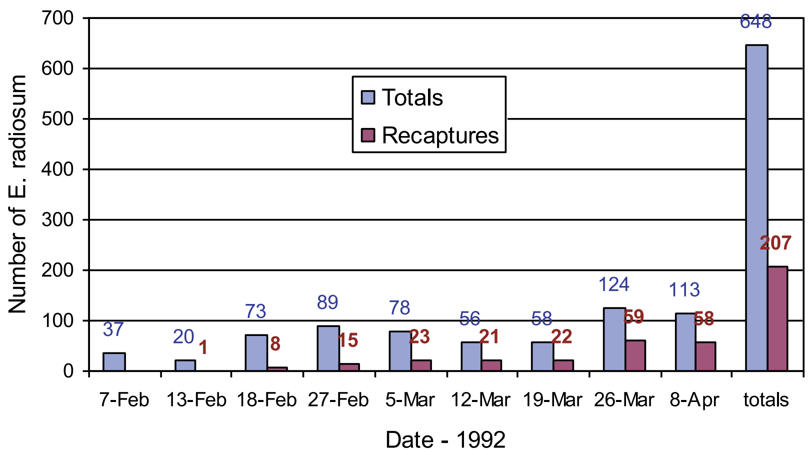

Figure 3. Captures and recaptures of orangebelly darters upstream of the modified ramp and culvert.

Swimming speed studies

In searching for guidance in designing the culvert and ramp modifications for the previous project, the paucity of literature for warmwater fish swimming speeds justified the need for study of local species. A cooperative study by Layher and Ralston (1997a-h) was initiated with the newly formed US Fish and Wildlife Service Research Project at the University of Arkansas, Pine Bluff to assess swimming characteristics of Ouachita drainage species (table 1).

Table 1: Sustained and Burst Swimming Speeds of Selected Warmwater Species (Layher and Ralston 1997a-h)

Species	Sustained swimming speed	Burst swimming speed
Central stoneroller (*Campostoma anomalum*)		36.6-54.6 cm/s
Bigeye shiner (*Notropis boops*)	19.8 cm/s	39.6 cm/s
Golden shiner (*Notemigonous crysoleucas*)	48 cm/s	58 cm/s
Greenside darter (*Etheostoma blennioides*)		22.9 cm/s
Orangebelly darter (*Etheostoma radiosum*)		18.7 cm/s
Redfin darter (*Etheostoma whipplei*)		16.7 cm/s
Longear sunfish (*Lepomis megalotis*)	19 cm/s	33.5 cm/s

These data were incorporated into a fish passage modeling software package developed by the Forest Service called FishXing (http://stream.fs.fed.us/fishxing/index.html) (Love et al. 1999).

Fish movements relative to crossing types

Warren and Pardew (1998) conducted an electrofishing mark-recapture study utilizing a three segment design to detect individual fish movements upstream or downstream through various stream crossing types and between the down-stream and further downstream similar-sized segments to detect natural movements unencumbered by a crossing. The natural-bottomed ford and the box-culvert crossings had movements of marked fish through the crossings comparable with or higher than marked fish movements detected for natural reaches. The vented low-water crossings with smooth concrete or corrugated plastic pipes had significantly reduced fish passage and there was no fish passage at an un-vented, slab low-water crossing that functioned as a low-head dam. They hypothesized that the increased water veloc-ity through the vented crossings constituted a major mechanism by which the crossings restricted fish movements.

Fish movements focusing on low-water vented crossings

To further explore the impacts of vented low-water fords on the Forest, six of the more than 300 such crossings on the Forest were examined by Gagen and Landrum (2000) utilizing the same study design as Warren and Pardew (1998). After one year of sampling (1997), three of the crossings were modified by backfilling with riprap to eliminate drops from the structures' aprons into plunge pools (1998) (figures 4 & 5). The same study design was repeated following these modifications (Rajput, 2003).

Figure 4. Vented low-water ford fish barrier.

Figure 5. Vented low-water ford modified.

Prior to modification, species richness upstream of the crossings was found to be only half that found downstream (6.3 species upstream versus 12.5 species downstream and 10.0 species further downstream at the natural/reference reach). Recapture of marked fish that had moved across reaches with low-water fords was less than half that of marked fish found to have moved across the natural/reference reaches. Marked fish found to have moved were twice as likely to move downstream than upstream. After the three crossings were modified to eliminate the jump, two of the modified crossings had improved fish passage as detected by marked fish. For the two years of mark-recapture efforts at the three modified and three unmodified low water vented fords, 27 fish moved upstream across the modified crossings and 35 moved downstream across them. At the unmodified crossings, no upstream fish movements were detected and only 6 downstream movements were detected through the crossings. Fish moving across low-water crossings included creek chubs (*Semotilus atromaculatus*), green sunfish and longear sunfish. Fewer fish were found to have moved through the culverts of the low-water crossings than across natural reaches in either direction, leading to the conclusion that these crossings constituted various degrees of filter barriers relative to movements of warmwater fishes.

Leopard Darter Movement Studies

In 1995, the Ouachita National Forest completed a land trade with Weyerhaeuser in which the Forest acquired over 44,400 hectares (110,000 acres) of land in the Glover River tract of Southeastern Oklahoma including nearly 23 kilo-meters (14 miles) of the Glover River which is designated as Critical Habitat for the threatened leopard darter (*Percina pantherina*). Within this acquisition were six, man-made low-water crossings. To assess the fish barrier potential of the six crossings, a study was developed with Oklahoma University researchers to compare leopard darter movements at one of the low-water crossings to movements across a natural shallow riffle that was occasionally used as a natural low-water ford. In addition, laboratory trials were conducted to provide guidance in crossing design for replacement river crossings. The constructed crossing had two round culverts, each roughly 60 centimeters in diameter, and four box-culverts, each approximately 3 meters wide. Schaefer et al. (2001) implemented a mark-resight study on these two sites in 1998 and 1999 with two study sections upstream and two downstream for each site. Leopard darters from the nearest section on each side of the natural riffle and the low-water crossing were marked but all four sections were surveyed for marked leopard darters to detect upstream or downstream movements.

They found few leopard darters moved from their original capture sites at either location. At the natural riffle site, two to three leopard darters moved downstream across the riffle and leopard darters also moved upstream into deeper water when water temperatures exceeded 29˚C (84˚F). At the low-water crossing, only movement of one to two leopard darters downstream through the structure was detected (batch marking precluded determination of whether it was the same darter that had moved on two resight occasions). Leopard darter movements into deeper (4-5 meter deep) pools from shallower areas (1 meter or less deep) corresponding with 3-4˚C (5-7˚F) cooler temperatures when their preferred shallower habitats warmed to 29˚C had not been previously documented (Schaefer et al. 2001).

In laboratory trials examining leopard darter movements between clusters of preferred habitats, Schaefer et al. (2001) found that imposing a simulated crossing structure into the artificial stream channel not only reduced movement through the crossing structure but also overall movements between the habitat clusters either side of the structure. Square wide openings appeared less disruptive than square narrow and small smooth or ribbed round openings. The researchers recommended that replacement crossings be positioned to avoid precluding access to thermal refugia and that openings in the crossing be as large as possible.

Community-level impacts of low-water vented crossings

More extensive surveys were implemented to assess the extent to which reduced movement due to vented crossings might influence fish diversity and abundance (Rajput 2003). The rationale for these concerns was based on the observation that relatively long segments of relatively large streams in the Ouachita Mountains experience discontinuous surface flow during summer (e.g. Homan et al., 2005a). The resulting widespread mortality of associated fishes produces ecosystems that can be highly influenced by extinction-recolonization dynamics, thus pointing to the importance of movement in determining community structure (Gagen et al., 1998). The survey included 28 randomly selected low-water vented fords over a range of stream orders/sizes. The approach included two upstream and two downstream segments to balance a one-time sampling effort (without the follow-up mark-recapture movement phase). Field measurements of the stream crossing velocity, slope, drop, etc. from each site were applied to the FishXing program (Love et al. 1999) to predict the barrier potential and to the then-draft National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organism Movement at Road-Stream Crossings (USDA Forest Service 2000). Model predictions were compared to observed patterns of fish occurrence where presence downstream, but not upstream of a crossing was defined as a “loss” to the community.

The low-water crossings averaged a two species loss in diversity from downstream to upstream and fish were less abundant upstream with an average loss of thirty individuals. As expected, fewer species were captured at sites farther upstream in watersheds. In 67% of the 21 study streams sampled for fish, fewer species were found upstream of the crossings which had spring baseflow velocities ranging from 16 to 85 cm/s (0.5-2.8 ft/sec). Species losses occurred upstream of all crossings with a spring baseflow equal to or greater than 60 cm/s (1.9 ft/sec). Bluegill (*L. macrochirus*), northern hogsucker (*Hypentelium nigricans*) and pirate perch (*Aphredoderus sayanus*) were never found upstream of low-water crossings.

FishXing software provided a slightly greater percentage of congruence with species loss than did the draft Assessment Procedure guide. The FishXing software utilized Layher and Ralston’s (1997 a-h) swimming speed data for Ouachita species; whereas, the Assessment Procedure employed an example matrix for trout. An assessment matrix for local species and sizes of fish was not developed as recommended. Seventy-one percent of the predictions from FishXing were congruent with the empirical data for species losses. Forty-eight percent of the Assessment Procedure guide results were congruent with the empirical data for losses with twenty-four percent of the guide results placed in an indeterminate passage category requiring additional study. Based on recommendations from this study, the Assessment Procedure guide was modified prior to finalizing to change the measurement of drop at the invert of the pipe to the measurement of any drop at the outlet, specifically including a drop from the crossing’s apron to the stream below the structure. Crossing/culvert aprons in the Ouachita National Forest were typically designed without a drop at the pipe(s). Consequently, a drop measurement at that point would result in a spurious assessment of no drop; whereas, apron drops often emerged as crossings age.

Latest Study of Fish Passage Through Box-Culverts

Based on the results of the early fish passage studies, particularly Warren and Pardew (1998) and Gagen and Landrum (2000), the Ouachita National Forest abandoned the vented low-water crossing design and began replacing failing low-water crossings with either on-grade slabs or low-water box-culverts where traffic conditions dictated a higher standard crossing. With these concrete cast-in-place box-culverts costing a minimum of $100,000 and upwards of $150,000 or more, the concern is whether these crossings are in fact better for fish passage than their predecessors. Three recent box-culvert replacements were sampled in the spring of 2003 with fish marked separately in two downstream segments and two upstream segments (Homan et al. 2005b). Two of the streams with box-culverts were electrofished and the fish were marked in June, sampled twice during their driest times and then sampled once after fall flows resumed. The third crossing was on the Cossatot River which is double to triple the size of the other two streams. There, approximately 2,500 fish were electrofished and marked on three occasions between September 29 and October 12 during low flows with nearly equal numbers upstream and downstream of the crossing. Unfortunately, just prior to what would have been the last Cossatot sampling under renewed fall baseflow, the drainage received a large storm event with resultant flows too high to safely resample for the remainder of the season. Thus, this site had to be dropped from the analysis of results. The recently installed Muddy Gibbs crossing (designed to be “fish friendly”), had a marked fish population of 102 fish and a recapture rate of 11%. Five of the 11 recaptures had moved, with four having moved from downstream to upstream across the box culvert. These included two redfin pickerel (*Esox americanus*; formerly grass pickerel), and two central stonerollers. The Bear Creek crossing had a total of 785 marked fish with a recapture rate of 15%, but none of the recaptured fish indicated any movement from the study sections in which they were originally captured. The Bear Creek structure has a drop from the concrete apron into a plunge pool that likely constituted a barrier to upstream fish movements (figure 6). The Muddy Gibbs crossing's apron was designed to prevent plunge pool creation (figure 7).

Figure 6. Bear Creek box culvert with drop.

Figure 7. Muddy Gibbs crossing without a drop.

Search for watershed-scale relationships between road networks and fish communities

In 2004, Homan et al. selected three matched-size watersheds representing a gradient of road densities and road crossings to search for relationships between fish communities and the respective road measures. The Caney Creek watershed was within the Caney Creek Wilderness thus there were no roads or road crossings. Interestingly, it had the lowest species richness and lowest mean fish density based on bankfull areas and linear stream distance relative to adjacent roaded watersheds with crossings. However, Caney Creek also had the lowest conductivity, alkalinity and calcium concentrations which might have overridden effects of road density and crossing abundance. Ultimately, no clear relationship was found between road density or abundance of road crossings and the fish communities. Also as part of the study, smallmouth bass productivity was measured at similar points in the watersheds of Brushy Creek and the Cossatot River headwaters in the spring, summer and fall of 2004. While road density was similar for both watersheds, the total number of road crossings was higher in the Cossatot River headwaters which surprisingly had higher smallmouth bass production. Thus, this attempted watershed-scale approach did not indicate clear negative effects of roads on fish communities or smallmouth production. However, the small sample size, effects of a pre-fall flood event, possible spurious differences in angler induced smallmouth bass mortality, and inability to control or accurately measure smallmouth bass ingress and egress render conclusions quite tenuous at this time.

Oklahoma Department of Wildlife Conservation's Glover River Stream Morphology Study

Due to the results from the Schaefer et al. study (2001), the need to replace low-water crossings on the Glover River was evident in order to restore fish passage, particularly for the threatened leopard darter. In a cooperative study with the Oklahoma Department of Wildlife Conservation, Vincent et al. (2005) examined the road 53000 low-water crossing of the Glover River (figure 8), and compared it to a representative natural reach to assess the impacts of the current crossing and provide appropriate design criteria relative to streambed slope, elevation and wetted width for a new crossing. They used the Rosgen (1996) Level II assessment protocol measuring longitudinal profile, cross-section surveys, pebble counts and subsequent calculations of entrenchment ratio, and width/depth ratios relative to bankfull flows.

Figure 8. Glover River 53000 low-water crossing.

They found bankfull stage to occur near the 1.25 year flood interval for this hydrophysiographic province. The longitudinal baseflow slope at the Glover site was 0.015% upstream of the crossing and 6.13% downstream; whereas, the reference reach exhibited a mean baseflow slope of 0.25%. The median grain diameter was 109 millimeters (4.3 inches) in the reference reach versus 69 millimeters (2.7 inches) upstream of the Glover crossing and 237 millimeters (9.3 inches) downstream. Cross sections upstream of the crossing have widened as smaller aggregates were not transported and filled interstitial gravel spaces. Streambed scouring downstream of the crossing, presumably associated with excessive shear strength, has incised the stream and coarsened the substrate. Average natural stream width at the Glover Crossing should be approximately 24.5 meters (80 feet); however, it is nearly double that now. The pool habitat, width:depth ratio for the Glover crossing was 43.24 versus 18.96 at the reference site. For riffles, the width: depth ratios were 29.84 and 42.30 for the crossing and the reference sites, respectively. Thus it appears clear that the current crossing configuration profoundly affects all channel parameters measured and consequently affects habitat quality/availability for associated fishes.

Conclusion

Fifteen years of fish passage studies on the Ouachita National Forest clearly indicate that road crossings not only impact fish diversity, community composition and population abundance but also the physical characteristics of the stream channel/habitat upstream and downstream the crossings. While engineered crossings may consider swimming speeds of targeted species, there also appear to be behavioral considerations that are subtle to us but important to fishes (e.g. longear sunfish are within the group of species found to have moved upstream through low-water vented-fords; whereas, closely-related and morphologically similar bluegill were not found upstream of these structures). Even when design considerations are made for fish passage at new or replacement road crossings, if bottom elevations are incorrectly set either at the planning or the construction phase and/or sediment balances and scour potentials are not adequately addressed, large sums of money can be spent on a very long-lived structure that limits fish passage. The Weyerhaeuser Bear Creek box culvert installation pictured above (figure 6) is a prime example of such.

Tools, most developed in the western states, are available for designing and assessing fish passage at crossings; however, these models need to be fine-tuned to meet local environmental conditions and fish species. While mark-recapture or mark-resight surveys can detect fish movements through crossings or the lack thereof, logistics and expenses may be prohibitive to conduct this level of work at a very broad scale. One-time sampling for fish species diversity, while less labor intensive, may not be precise enough for some applications; thus, results are likely seasonally influenced and the practice is probably most appropriate for small streams high in watersheds and without extensive species diversity. We see a need for new approaches to detect fish movements in unsecured remote sites (e.g. passive monitoring equipment). The most useful approaches must be effective during a wide range of water flows to best advance our understanding of how associated environmental conditions affect species and size-specific timing of fish movements. These issues must be addressed to fully evaluate the importance of movements to natural ecosystem functions and to protect those ecosystem functions.

The Ouachita National Forest will continue to examine its efforts in restoring aquatic organism passage at newly constructed crossings to further its understanding of how to reconnect fragmented aquatic habitats.

Biographical Sketch: Richard Standage received his B.S. degree in fisheries management from Utah State University in 1973. He worked five years for the Kansas Fish and Game Commission, three years of that as a District fisheries biologist and two years as biologist and project leader for their water quality assessment team. Beginning in 1978 he moved to the USDA Forest Service as fisheries biologist for the Sequoia National Forest in California working on the recovery of the Little Kern golden trout. In 1984 he moved to Virginia as the Forest Fisheries Biologist/Program Manager for the George Washington National Forest and also covered the Jefferson National Forest. In 1990 he transferred to the Ouachita National Forest as the Forest Fisheries Biologist/Program Manager also with responsibility for the aquatic threatened and endangered species program and he is the Forest's hydropower coordinator. He has been working with fish passage restoration research and design applications since the early '90's and initiated some of the first studies on warmwater stream fish passage issues and swimming speed studies for warm water fish species through cooperative efforts with university researchers in Arkansas and Oklahoma.

Charles J. Gagen received his B.S. degree in Wildlife Biology from the University of Tennessee, and M.S. and Ph.D. in Ecology from Penn State University in 1991. Since that time, he has been a professor of fisheries science at Arkansas Tech University, where he currently serves as the Head of the Biology Department. His research has focused on determining the effects of environmental variables on fish populations and communities, especially in streams. Early studies documented direct effects of acid rain on coldwater fishes; whereas, more recent studies have looked at warmwater fish responses when sections of streams go dry in summer. In both cases, movement and mortality have emerged as important aspects of the population dynamics involved. Thus, tendencies for road crossings to affect fish movement patterns are viewed as potential impacts on community structure.

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