

2008

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Recommended Citation

Benton, P.D., Ensign, W.E., & Freeman, B.J. (2008). "The Effect of Road Crossing on Fish Movements in Small Etowah Basin Streams." *Southeastern Naturalist*. 7(2): 301-310.

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Source: *Southeastern Naturalist*, Vol. 7, No. 2 (2008), pp. 301-310

Published by: Eagle Hill Institute

Stable URL: <http://www.jstor.org/stable/20203997>

Accessed: 29-06-2016 13:20 UTC

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The Effect of Road Crossings on Fish Movements in Small Etowah Basin Streams

Paul D. Benton^{1,2}, William E. Ensign^{1,*}, and Byron J. Freeman³

Abstract - Increased road construction associated with urbanization may result in fragmentation and loss of fish populations in streams. In this study, we documented frequency of movement of fishes through three separate types of road-crossings (clear-span bridges, box culverts, and tube culverts) in six small streams using mark-recapture sampling. Upstream movement between areas separated by either box or tube culverts was lower than upstream movement between similar areas not separated by a road crossing. Downstream movement between areas separated by box culverts was also lower than downstream movement between areas without obstructions. Upstream and downstream movement between areas separated by clear-span bridges was generally similar to patterns of movement between areas not separated by a road crossing. Our results indicate that culverts may limit, to some degree, movements of fishes in small streams.

Introduction

The southeastern United States is the center of freshwater fish diversity in North America (Warren and Burr 1994, Warren et al. 2000) and fish diversity in the streams and rivers of Georgia reflects this pattern. The upper Etowah River basin, located north of the Atlanta metropolitan area, is a major contributor to this diversity with over 76 extant species of native fishes (Burkhead et al. 1997), 4 that are endemic to the basin and 7 that have either state or federal protected status. Urbanization in the Atlanta metropolitan area poses a threat to this unique fish assemblage (Walters et al. 2003). Increased impervious surface and resulting changes to hydrology and water quality are the most obvious threats to fish diversity in urbanizing areas (Paul and Meyer 2001, Roy et al. 2005, Schueler 1994, Walsh et al. 2005, Wang 2001). Urbanization also results in increased density of roads and an associated increase in the number of streams crossed by roads (Wheeler et al. 2005).

Road crossings can affect fish movement by acting as physical barriers or by altering flows, thereby limiting a fish's ability to traverse a crossing (Gibson et al. 2005, Warren and Pardew 1998). Increased fragmentation of the stream network reduces the probability of individual movement from one stream segment to another, potentially altering both population and community structure of stream fishes (Winston et al. 1991). Stream

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reaches experimentally defaunated or reduced in abundance (or richness) by droughts, floods, or anthropogenic stress show rapid recovery if source populations have access to the affected reach (Adams and Warren 2005, Bayley and Osborne 1993, Ensign et al. 1997, Lonzarich et al. 1998, Olmstead and Cloutman 1974, Peterson and Bayley 1993, Sheldon and Meffe 1995). Road crossings may prevent or significantly reduce the ability of fishes to recolonize a reach from which they have been extirpated. Stream fish movements are also influenced by habitat structure and availability of preferred habitat for a given species (Albanese et al. 2004, Matheny and Rabeni 1995); therefore, indirect effects on fish movements may also occur as a result of localized geomorphologic changes in the stream channel upstream and downstream of the crossing. In this study, we focused on road crossings as physical barriers and attempted to determine if different types of road crossings have differential effects on fish movements.

Methods

Six Blue Ridge ecoregion streams in the upper Etowah drainage basin were sampled twice during the summer of 2003 (Table 1). Two streams had clear-span crossings, two had box culverts, and two had tube culverts. Clear-span crossings consisted of a solid road platform suspended above the stream, usually between concrete pilings set in the channel or on the stream banks. Box culverts consisted of one or more four-sided, open-ended concrete boxes set into the stream channel, while tube culverts consisted of one or more round, galvanized pipes set in the stream channel. In each of the six streams, sampled reaches were divided into six cells based on pool and riffle sequences, with three cells upstream and three cells downstream of the road crossing. Only five cells were sampled in Noonday Creek since the pool in the most upstream cell was atypically long (>200 m). During collections, individual cells were isolated before sampling by placing a block net at the upstream and downstream end of each cell. On each of the two sampling dates, two separate

Table 1. Summary of site characteristics and time interval between mark and recapture for each of the sampled streams.

Site	Crossing type	Watershed area (km ²)	Average width (m)	Average sample-cell length (m) (± std. dev.)	Days between mark and recapture
Noonday Creek	Clear span	10.1	5.7	22.4 (± 12.1)	33
Clark Creek	Clear span	12.0	6.1	24.5 (± 7.0)	34
Sweat Mountain Creek	Box culvert	8.2	5.1	32.8 (± 18.2)	29
Scott's Mill Creek	Box culvert	12.8	7.2	37.0 (± 8.6)	31
Possum Creek	Tube culvert	14.9	4.5	9.9 (± 11.3)	33
Hickory Log Creek	Tube culvert	11.1	4.7	25.3 (± 9.7)	31

electroshocking passes were made through each of the cells, and all fishes collected transferred to holding buckets for processing. After capture, fishes were anaesthetized lightly with tricaine methanesulfonate, identified to species, counted, and measured for standard length. On the first sampling date, each fish was marked with a fluorescent elastomer tag. A unique combination of tag color and tag position was used to indicate the capture cell for each fish. To check for tag loss, all fishes were given a secondary mark by clipping a small piece of the upper portion of the caudal fin (for sections above the road crossing) or the lower portion of the caudal fin (for sections below the road crossing). After processing, fish were placed in instream holding nets, allowed to recover completely, and returned to the units in which they were captured. At the end of the recovery period, any mortalities found in the holding net were deleted from the data sets. All sections were sampled one month later (average time between between samples was $31.8 \text{ days} \pm 1.8 \text{ days}$; Table 1) in the same manner. Again, fish were identified to species, measured, and examined for the presence of marks. For marked fish, the position and color of the mark was recorded along with the capture cell.

The effect of road crossings on fish movement was determined by comparing movement between adjacent cells that were not separated by a road crossing (unobstructed adjacent cells) to movement between adjacent cells that were separated by one of the three types of road crossings (obstructed adjacent cells). Fishes that moved more than one cell upstream or one cell downstream of their marking cell were not included in the analysis. Given this, a fish's location during recapture sampling relative to its cell of marking could be treated as a binomial random variable. The two possible outcomes were that the fish was found either in its original cell or the cell immediately adjacent to its original cell. Expected movement values were based on unobstructed adjacent cell data and compared to observed values drawn from obstructed adjacent cells separated by one of the three types of road crossings. Significant differences ($p < 0.05$) between expected and observed values were determined using a binomial goodness-of-fit test. Since the relative frequency of upstream and downstream movement varies seasonally for many fish species (Albanese et al. 2004, Hall 1972, Matheny and Rabeni 1995), separate analyses were conducted for both adjacent cell upstream movements and adjacent cell downstream movements.

Results

Overall, 1264 fish representing 22 species were marked across the six streams in the first sampling period (Table 2). Four species captured during the marking period were not marked. *Etheostoma scotti* Bauer, Etnier and Burkhead (Cherokee Darter) is listed as a federally threatened

species and was not marked to avoid potential mortality. Three species in the genus *Notropis*—*N. chrosomus* (Jordan) (Rainbow Shiner), *N. lutipinnis* (Jordan and Brayton) (Yellowfin Shiner), and *N. xaenocephalus* (Jordan) (Coosa Shiner)—suffered appreciable mortality as a result of capture and marking during the marking episodes at the first two streams sampled and were also eliminated from consideration. In the second sampling period, 418 marked fish representing 14 species were recaptured, a 33.1% recapture rate (Table 2). Of the 418 fish recaptured, 284 were recaptured in the same cell and 134 moved upstream or downstream at least one cell (Table 2). Of the 14 species recaptured, only one, *Semotilus atromaculatus* (Creek Chub) failed to move either upstream or downstream. Of the 134 fish that moved, 83 moved upstream, 51 moved downstream, and 26 moved across a road crossing. Of the latter 26 fish, 23 fish from five different species moved through clear-span crossings, while only 2 fish moved through a box culvert (1 *Micropterus coosae* [Redeye Bass] and 1 *Cottus carolinae* [Banded Sculpin]), and

Table 2. Summary of number of fish marked and recaptured across all streams and the presence or absence of movements through a road crossing by that species. For the number recaptured, separate totals are given for fish recaptured in the cell of marking (same cell) or a cell different from that of marking (different cell). For crossing movements, the type of crossing is indicated in parentheses where CS = clear-span, BO = box culvert, and TU = tube culvert.

Species	# marked	# recaptured			Crossing movements (type of crossing)
		Same cell	Different cell	% recaptured	
<i>Camptostoma oligolepis</i> Hubbs and Greene	248	41	51	37.1	Yes (CS)
<i>Cottus carolinae</i> (Gill)	210	47	18	31.0	Yes (BO)
<i>Lepomis macrochirus</i> Rafinesque	205	50	6	27.3	No
<i>Lepomis auritus</i> (Linnaeus)	168	69	16	50.6	Yes (CS)
<i>Lepomis cyanellus</i> Rafinesque	90	35	2	41.1	Yes (CS)
<i>Hypentelium etowanum</i> (Jordan)	90	18	23	45.6	Yes (CS)
<i>Semotilus atromaculatus</i> (Mitchill)	54	7	0	13.0	No
<i>Micropterus coosae</i> Hubbs and Bailey	41	5	3	19.5	Yes (BO)
<i>Fundulus stelliifer</i> (Jordan)	39	1	5	15.4	Yes (TU)
<i>Percina nigrofasciata</i> (Agassiz)	30	3	1	13.3	No
<i>Nocomis leptocephalus</i> (Girard)	18	7	3	55.6	No
<i>Percina kathae</i> Thompson	16	1	2	18.8	No
<i>Pomoxis nigromaculatus</i> (Lesueur)	12	0	0	0.0	-
<i>Cyprinella trichroistia</i> (Jordan and Gilbert)	9	0	0	0.0	-
<i>Cyprinella callistia</i> (Jordan)	9	0	1	11.1	No
<i>Micropterus salmoides</i> (Lacepède)	8	0	3	37.5	Yes (CS)
<i>Noturus leptacanthus</i> Jordan	6	0	0	0.0	-
<i>Etheostoma stigmaeum</i> (Jordan)	3	0	0	0.0	-
<i>Moxostoma duquesni</i> (Lesueur)	3	0	0	0.0	-
<i>Lepomis gulosus</i> (Cuvier)	2	0	0	0.0	-
<i>Perca flavescens</i> (Mitchill)	2	0	0	0.0	-
<i>Ameiurus natalis</i> (Lesueur)	1	0	0	0.0	-
All species	1264	284	134	33.1	

1 fish (*Fundulus stellifer* [Southern Studfish]) moved through a tube culvert (Table 2). In the recapture sampling, a single fish was found with a fin clip and no discernible elastomer mark. All fish with elastomer marks had observable fin clips.

In adjacent cells where there was no road crossing separating the two cells, 24.9% of recaptured fish had moved from the downstream cell to the adjacent upstream cell, while 13.6% of recaptured fish had moved from the upstream cell to the adjacent downstream cell (Table 3). There was no significant difference in frequency of movement between unobstructed cells and cells separated by a clear-span crossing, where 22.9% of recaptured fish had moved from the downstream cell to the upstream cell while 15.8% of recaptured fish had moved from the upstream cell to the downstream cell (Table 3). Both box culverts and tube culverts significantly reduced the frequency of upstream movement (6.9%, $p = 0.021$ and 0.0%, $p = 0.046$, respectively; Table 3) and box culverts also reduced downstream movement (0.0%, $p = 0.026$; Table 3). Although no downstream movements were observed through tube culverts, sample sizes were too small to allow significance testing.

Discussion

Our results indicate that road crossings often serve as potential barriers to fish movement and the type of crossing determines, at least in part, the magnitude of reduction in movement observed. Box and tube culverts restricted short-term movements by fish between adjacent cells separated by the culverts in four small streams in the Etowah Basin. In experimental stream trials, Schaefer et al. (2003) found that movement through simulated culverts varied by culvert type, with highest passage rates through square-wide culverts (similar to the box culverts in this study), lowest rates through

Table 3. Summary of the number of marked fish found in the cell in which they were marked or the adjacent upstream or downstream cell. Unobstructed adjacent cells were not separated from the marking cell by a road crossing, while clear span, box culvert, and tube culvert indicate the type of road crossing separating the adjacent cell from the marking cell. The binomial p-value indicates whether the pattern of movement observed in the road crossing cells differed from that seen in unobstructed cells. For downstream movement through tube culverts, sample size was too small to allow significance testing.

	Unobstructed	Clear span	Box culvert	Tube culvert
Upstream				
Same cell	175	27	27	11
Adjacent cell	58	8	2	0
Binomial p-value		0.481	0.021	0.043
Downstream				
Same cell	197	32	25	8
Adjacent cell	31	6	0	0
Binomial p-value		0.865	0.026	No test

round-smooth culverts, and intermediate rates through round-ribbed culverts (similar to the tube culverts in this study). In all instances, movement rates were lower between patches separated by simulated culverts than between patches not separated by barriers. Similarly, Warren and Pardew (1998) found culvert crossings limited movement to a greater degree than either box or ford crossings.

Warren and Pardew (1998) found that movement across their box crossings was higher than movement between two "natural reaches," a result that conflicts with findings in our study. Although the design in their study is not entirely consistent with ours, movement between their "natural reaches" is in many ways analogous to movement across our clear-span crossing. The greater movement probabilities they observed across their box crossings is most likely related to differences in water depth and water velocity of box culverts in the two studies. The box culverts in the Warren and Pardew (1998) study had low water velocities and depths ranging from 30 cm to 80 cm. Although we did not quantify either depth or velocity in either of the box culverts we sampled, in both Sweat Mountain Creek and Scott's Mill Creek, depths did not appear to exceed 5 cm at the time of sampling and much of the flow through any of the culvert bays at either stream was less than 2 cm in depth. Water velocity in the culverts was moderately fast (greater than 20 cm/s), and laminar sheet flow was apparent at many points in our box culverts. Box culvert depths similar to those described in Warren and Pardew (1998) would have been present only under conditions of elevated flow in our streams. Similarly, flow through the tube culverts in our study was also moderately fast, and depths were similar to those observed in the box culverts. While depth and velocity in the tube and box culverts was noticeably shallower and faster than that in the adjacent upstream and downstream reaches, depth and velocity in the clear-span crossings was similar to that in the adjacent reaches. The difference between our results and those of Warren and Pardew (1998) highlights the importance of not only assessing the type of culvert, but also the physical characteristics of the culvert and stream conditions.

The frequency of movement between adjacent cells we observed in our streams is higher than that observed in other studies of fish movements in natural reaches. In our study, one of every three fish recaptured was found in a cell other than the one in which it was marked. In contrast, Smithson and Johnston (1999) found only 12% of marked Creek Chub, 12% of marked *Lepomis cyanellus* (Green Sunfish), and 14% of marked *L. megalotis* (Rafinesque) (Longear Sunfish) outside of the units in which they were marked. A fourth species, *Fundulus olivaceus* (Storer) (Blackspotted Topminnow) exhibited movement rates similar to those we observed, with one of every three individuals of this species being recaptured outside its cell of marking. In a study of movement by three

species of darters over a recapture period similar to ours, Roberts and Angermeier (2007) found between 3% and 7% of recaptured fish outside their original marking unit. In a much larger stream, Freeman (1995) recaptured 88% of *Percina nigrofasciata* (Blackbanded Darter) and 93% of juvenile *L. auritus* (Redbreast Sunfish) within 33 m of their original point of capture. Similarly, Matheny and Rabeni (1995) found that *Hypentelium nigricans* (Lesueur) (Northern Hog Sucker) tend to remain within a single pool-riffle sequence over the course of a year, but frequently moved back and forth from pool to riffle areas during the course of a 24-hour period. Other studies have suggested that most small stream fishes have relatively limited home ranges, often analogous in size to a single pool-riffle sequence (Gerking 1959, Hill and Grossman 1987). Given the diversity of approaches, species, and stream types used in other studies, direct comparison of our movement rates is speculative at best. However, Albanese et al. (2004) showed that movement of fishes through areas of unsuitable habitat was higher than movement through areas of suitable habitat. Improperly designed culverts can result in significant changes to streambed morphology directly upstream and downstream of the crossing. This can include scouring and channel erosion on the downstream side of the culvert and sediment deposition and reduction in average water depth on the upstream side of the culvert (Bates et al. 2003). Although we did not quantify stream channel features, visual inspection of areas upstream and downstream of the road crossings indicated that these types of habitat alterations were present in both of the tube culvert streams and one of the box culvert streams (Sweat Mountain Creek). The higher rates of movement we observed may have been a response to this alteration in habitat structure.

Methodologically, summer sampling may have resulted in an underestimation of adjacent cell movement frequencies in our stream. Evidence indicates that many temperate stream fishes show limited movement between erosional-depositional units during the warmer summer months (Roberts and Angermeier 2007) and increased movement activity during fall and spring (Hall 1972, Matheny and Rabeni 1995). Longer, directed movements by stream fishes are often associated with seasonal activities such as spawning, and even non-migratory forms may show increased local movements during periods of high flow. Hall (1972) found that over 70% of upstream fish movements through weirs in a North Carolina Piedmont stream occurred during spring spawning migrations. This seasonal bias may be balanced at least in part by increased movements associated with high-flow events. Albanese et al. (2004) found increased upstream movement of four cyprinid species and a catostomid species and increased downstream movement of three cyprinid species in response to elevated flows. During the period between mark and recapture in our study, there was at least one rain event that resulted in markedly elevated flows.

In summary, we feel confident that both box and tube culverts decreased fish passage between upstream and downstream reaches in our streams. There is also some evidence to suggest that high between-cell movement rates may have resulted from habitat alterations associated with the road crossings. Future research should focus on the relationship between culvert structure (i.e., depth and velocity characteristics) and fish passage to ensure appropriate structures are used to protect the diversity of our running waters.

Acknowledgments

This study was completed as part of an undergraduate research project by P. Benton under the supervision of W. Ensign. Funding was provided by a grant from the Georgia Department of Natural Resources and the US Fish and Wildlife Service for the development of a Habitat Conservation Plan for the Upper Etowah River Basin. Additional funding was provided by a Mentor-Protégé grant from the College of Science and Mathematics at Kennesaw State University. Field assistance was provided by Rani Reece, Chad Landress, Ryan Leitz, and Tim Shirley.

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