Transactions of the American Fisheries Society 128:155-161, 1999
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Swimming Performance of the Threatened Leopard Darter in Relation to Road Culverts

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Abstract. — *We* investigated the relationship between swimming performance of the leopard darter *Percina pantherina* evaluated in the laboratory and current velocities measured at the ends of corrugated-pipe and open-box culverts through road crossings. We tested leopard darters at each of six current velocities ranging from 0 to 60 cm/s and measured burst frequency and distance. We used analysis of variance (ANOVA) to analyze burst frequency and total distance covered during a 10-min period and found that at a current velocity of 25 cm/s, fish swam more frequently and for greater total distances than at higher or lower velocities. When a nested ANOVA was used to remove variation due to individual fish, we found that distancesof individual bursts also differed significantly and that fish in intermediate velocities had longer bursts. Current velocities in box and pipe culverts tended to be higher than the velocities measured in the lab, and several crossings had structural barriers, in addition to high current velocities. Although there is no evidence that culverts act as long-term barriers to migration or dispersal of leopard darters, they may prevent migratory activity during certain years, thereby negatively affecting localized populations.

Current velocity through poorly designed culverts may act as a barrier to migration and dispersal of fishes (Baker and Votapka 1990; Clay 1995). For example, Derksen (1980) concluded from a mark–recapture study that water velocities in five culverts acted as a near-total barrier to migration of spring-spawning Arctic grayling *Thymallus arcticus,* northern pike *Esox lucius,* and longnose suckers *Catostomus catostomus.* In addition to potential current velocity barriers, poorly designed culverts also may present barriers such as shallow water depths within the culvert, absence of refuge pools at either end, a hydraulic jump at the inlet, or a large drop from the outlet to the stream surface (Baker and Votapka 1990). All of these are considered barriers for large fishes but may have even greater effects on smaller fishes. Although estimates of critical swimming speed or swimming performance of fishes (e.g., Brett 1967; Dorn et al. 1979; Berry and Pimentel 1985) have used experimental flumes or tunnels that resemble culverts, few studies have directly related swimming performance to culvert passage by fish. Jones et al. (1974) evaluated swimming speeds of 17 fish species in the Mackenzie River and generated curves to show the smallest size of each species that could be expected to traverse a 100-m culvert at a range of current velocities.

The leopard darter *Percina pantherina* is a small percid endemic to the Little River drainage of southeastern Oklahoma and southwestern Arkansas (Miller and Robison 1973) that is federally listed as a threatened species (USFWS 1978). Abundance and distribution of the species may be limited by anthropogenic factors such as silviculture and associated road development, gravel removal, runoff from agriculture and poultry-rearing operations, and reservoirs (James and Collins 1993). For example, leopard darters historically inhabited the lower Mountain Fork and Cossatot rivers (Eley et al. 1975), but these populations were extirpated by construction of Broken Bow and Gillham reservoirs (James and Collins 1993). In addition, spawning habitat appears limited because not all riffles in the drainage contain gravel

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Received December 27, 1996 Accepted April 14, 1998

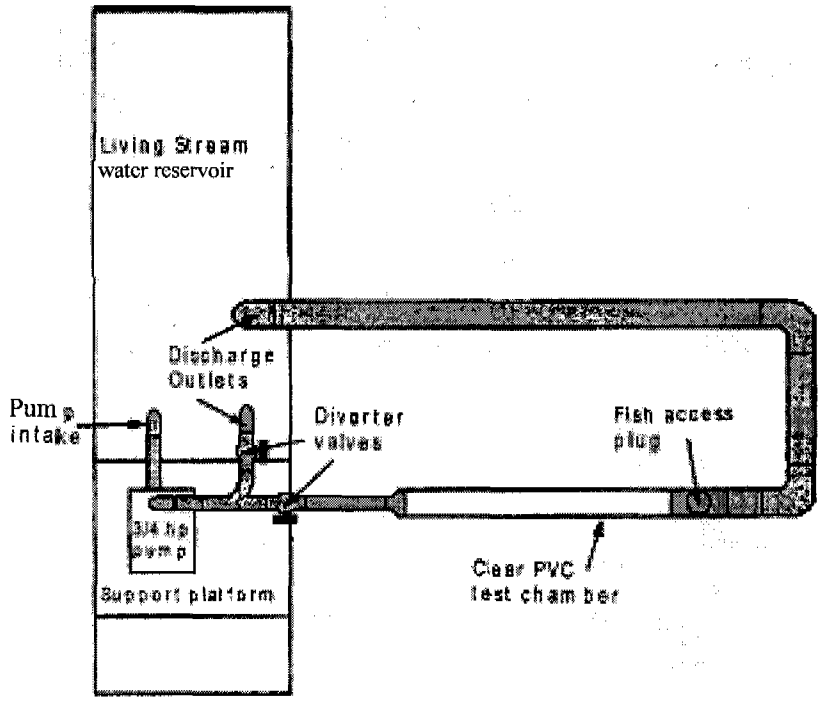

FIGURE 1.—Schematic of the flow-through swimming performance apparatus (top view).

suitable for spawning (James 1989). These factors make the leopard darter potentially vulnerable to localized extirpation, and the presence of physical barriers, such as culverts, may have adverse effects on recolonization or spawning migrations.

Leopard darters inhabit pools during most of the year and spawn in riffle tailwaters from early March to mid-May (James and Maughan 1989). Individuals are usually found in water 25–75 cm deep over cobble and boulder substrates and in areas with little to no current (James et al. 1991). Leopard darters typically swim 5–10 cm above the substrate and are rarely seen resting on the bottom (James et al. 1991; C.S. Toepfer, personal observation). Leopard darters spawn in areas with current velocities as high as 50 cm/s (James and Maughan 1989), but in such situations, they are usually observed resting on gravel and cobble substrates and appear to have difficulty swimming in swift currents (James et al. 1991; Toepfer, personal observation). Swimming activity in swifter currents involves short movements directly on the surface of the substrate, and individuals that enter the water column are generally swept downstream (Toepfer, personal observation).

Warren and Pardew (1998) found that a current velocity of around 40 cm/s restricted passage of most fish through different crossing types in eight streams of the Ouachita National Forest in Arkansas. That study did not include leopard darters, however, so our objective was to relate swimming abilities of leopard darters at different current velocities to swimming abilities observed during the spawning season in culverts within the Glover River drainage of Oklahoma.

Methods

Laboratory study.—Forty-eight leopard darters (57.85 +/- 6.22 mm standard length) were captured from Big Eagle Creek in southeastern Oklahoma during September 1996 and 1997 and transported to Oklahoma State University in north-central Oklahoma. The swimming performance apparatus (Figure 1) was a flow-through system modified from a design by Layher (1993) and was connected to a 560-W (3/4 horsepower) pump with a 3.81-cm intake and outlet. Water for the experiment was recirculated through a Living Stream (Frigid Units, Toledo, Ohio) with a capacity of approximately 760 L. Two diverter valves were placed at the outlet of the pump to allow control of flow through the apparatus. An expanding joint was used to di-

rect flow from the pump into a test chamber consisting of a 91.5-cm-long clear polyvinyl chloride (PVC) pipe with a 7.62-cm diameter. The flow continued through two 90° turns to return to the living stream reservoir. We marked both diverter valves with five equally spaced marks designating a range from completely closed to completely open and used the valves to generate a range of current velocities. A petcock valve at the upstream end of the test chamber allowed excess air to be bled from the system, and an access plug at the downstream end was used to introduce and remove fish from the apparatus. Plastic mesh was placed at both ends of the test chamber to restrict fish to the chamber and minimize turbulent flow.

We measured the swimming performance of leopard darters at six current velocities. In 1996, we used 32 leopard darters in four different velocities. After failing to find a velocity at which swimming was reduced, we tested two higher velocities in 1997. In both years, we placed individual leopard darters into the test chamber, gradually filled the entire apparatus with water, and allowed the fish to acclimate for 5 min. After acclimation, fish were exposed to the test current velocity, and we immediately began recording observations.

We observed the fish and used an audiotape recorder to dictate the beginning, end, and distance covered during each burst over a period of 10 min. We could not use a video system to record fish swimming performance because visual distortion caused by tube curvature and the position of the mesh in the chamber made the fish difficult to see. Eight randomly chosen leopard darters were used in each treatment, and each individual was used once. Data transcribed from the tapes included burst frequency (number of bursts/10 min), distance (cm), and total distance of bursts (cm). Swimming bursts consisted of an individual orienting into the current and making a rapid burst upstream. Only forward movement was considered part of the burst. All fish swam along the bottom of the test chamber. After active swimming ceased, the fish drifted backward to the mesh at the back of the test chamber. The point at which active forward movement stopped was considered the end of a burst.

For presentation, mean values were calculated from all burst events without consideration of variation by individual fish. Data for burst frequency and total distance of bursts were analyzed with analysis of variance (ANOVA). Because individual fish showed varying numbers of bursts, burst distance was analyzed with a nested ANOVA to separate out the variance due to individuals. A Tukey's test was used for multiple comparisons.

Immediately following the last treatment in 1996, we used a dye injected into the petcock valve to measure current velocity at each mark on the diverter valve. Velocity was determined by timing movement of the dye over 50 cm. Five replicates were taken for each valve setting and the mean was used as the current velocity for that treatment. the four velocities in 1996 were approximately equal to 0, 5, 12, and 25 cm/s. In 1997, we used higher current velocities, and the dye moved too rapidly for calculation of the velocities. We measured the volume of water pumped over a time period and divided the water volume per unit of time by the cross-sectional area of the swimming chamber to obtain current velocities. Eight replicates were taken at each of the two valve settings, and we calculated mean velocities of 42 and 60 cm/s.

Field measurements.—We measured current velocity at the inlet and outlet of open-box and corrugated-pipe culverts at road crossings in the Glover River drainage. Because spawning typically begins in early March (James and Maughan 1989), measurements were taken once in mid-February and once in early March 1996. One current velocity measurement was taken near the bottom surface of the inlet and outlet of small pipe culverts with a Marsh-McBirney meter (model 201). In larger pipe culverts, we measured velocities at two points along a perpendicular transect at both ends, and we measured four to five points in a perpendicular transect across both ends of box culverts. We pooled the velocity measurements from all culverts and both sampling dates for each road crossing. Data from crossings with both pipe and box culverts were pooled by culvert type.

Results

Behavior of leopard darters in the swimming apparatus was similar to that observed at high current velocities in the field. After being placed in the apparatus, each leopard darter typically rested on or near the plastic mesh at the back of the test chamber. At velocities of 0 and 5 cm/s, most individuals remained in the same position for the entire 10 min. Individuals were more active at velocities of 12 and 25 cm/s, and at a velocity of 25 cm/s, fish occasionally began a new burst before drifting completely back to the mesh. At velocities of 42 and 60 cm/s, the fish made a few bursts immediately after exposure to the current and were flush against the mesh for the remainder of the 10

TABLE 1.—Mean values (+/-SD) of swimming performance variables for leopard darters. For the means we included only data from individuals that showed swimming activity; for statistical analyses we included zeroes for nonswimming fish. Also shown are results of the analysis of variance (ANOVA) for the treatment and nested effects. Within a column, values without a letter in common were significantly different according to Tukey's multiple-comparisons test; NA = not applicable.

Current velocity (cm/s)	Number of swimming fish	Burst frequency	Burst distance (cm)	Total distance (cm)
		Swimming performance		
0	1	2.00 +/- 0.00 y	2.00 +/- 0.00 y	4.00 +/- 0.00 y
5	1	8.00 +/- 0.00 y	2.13 +/- 0.83 y	17.00 +/- 0.00 y
12	5	5.00 +/- 3.32 zy	2.56 +/- 1.19 y	12.80 +/- 10.40 y
25	8	5.88 +/- 2.90 z	14.23 +/- 20.01 z	90.75 +/- 57.79 z
42	8	3.50 +/- 0.93 zy	7.50 +/- 2.85 zy	26.25+/- 4.20 y
60	7	2.43 +/- 1.13 y	7.29 +/- 5.02 zy	17.71 +/-11.66 y
		ANOVA F (*P*)		
Velocity		6.35 (<0.0001)	11.31 (<0.0001)	15.37 (<0.0001)
Fish (velocity)		NA	1.55 (<0.039)	NA

min. No fish were observed to actively swim downstream.

Leopard darter swimming activity was higher in the 25-cm/s current velocity than in the other velocities (Table 1). Although burst distance was not significantly different in the three highest velocities (25–60 cm/s), it was nearly twice as high in the 25-cm/s velocity as in the two higher velocities and was significantly higher than the distances in the lower velocities. In addition, the total distance covered in 10 min was significantly greater in the 25-cm/s water velocity than in all other velocities. Another notable difference was that only one fish showed any swimming activity at current velocities of 0 and 5 cm/s, but all eight fish were active at velocities of 25 and 42 cm/s. Active leopard darters in the intermediate velocities (12–42 cm/s) also swam more frequently than those in higher (60 cm/s) and lower velocities (0 and 5 cm/s).

Box plots for water velocities measured at both ends of culverts through several road crossings indicated that values for the majority of culverts were greater than the laboratory velocity with the greatest amount of swimming activity (Figure 2). At five of the seven road crossings with pipe culverts, 13–31% of the points were below 25 cm/s, indicating that each crossing may have had one or more culverts with low velocities. One crossing (EF2) had only one point with a velocity higher than 25 cm/s; another crossing (MG1) had extremely high velocities (median > 1.4 m/s; only one observation below 60 cm/s). Water velocities within box culverts tended to be lower and less variable than those in pipe culverts. Velocities at two of the crossings were near 25 cm/s, whereas almost 100% of the velocities at three crossings were higher than 25 cm/s.

Water velocity is only one of the potential barriers at road crossings, and 6 of 10 crossings had culverts with multiple barriers. These barriers included scour-created cascades immediately downstream from a culvert, absence of refuge pools at the downstream or upstream end of culverts, and a high hydraulic head at the inlet of culverts. Also, all of the culverts were considerably longer (mean box culvert length = 4.6 m, mean pipe culvert length = 5.4 m) than the total distance traversed by leopard darters in the laboratory apparatus (Table 1).

Discussion

Many culverts in the Glover River drainage may pose a problem for passage of leopard darters during certain discharge levels. Water velocities at most culverts were well above the laboratory velocity that produced the greatest amount of swimming activity (25 cm/s), although it appeared that at least one culvert at each crossing had velocities lower than 25 cm/s. However, single culverts with low current velocities are effective only if they are in the pathway of fish migration (Baker and Votapka 1990), and leopard darters may not be able to locate that particular culvert. In addition, current velocities in pipe culverts at one crossing (MG1; Figure 2) and box culverts at two crossings (EF4 and MG3) were nearly always greater than 25 cm/. Although swimming activity was greatest at an intermediate water velocity, it appeared that velocities greater than 25 cm/s did not prevent swimming activity. However, both mean burst dis-

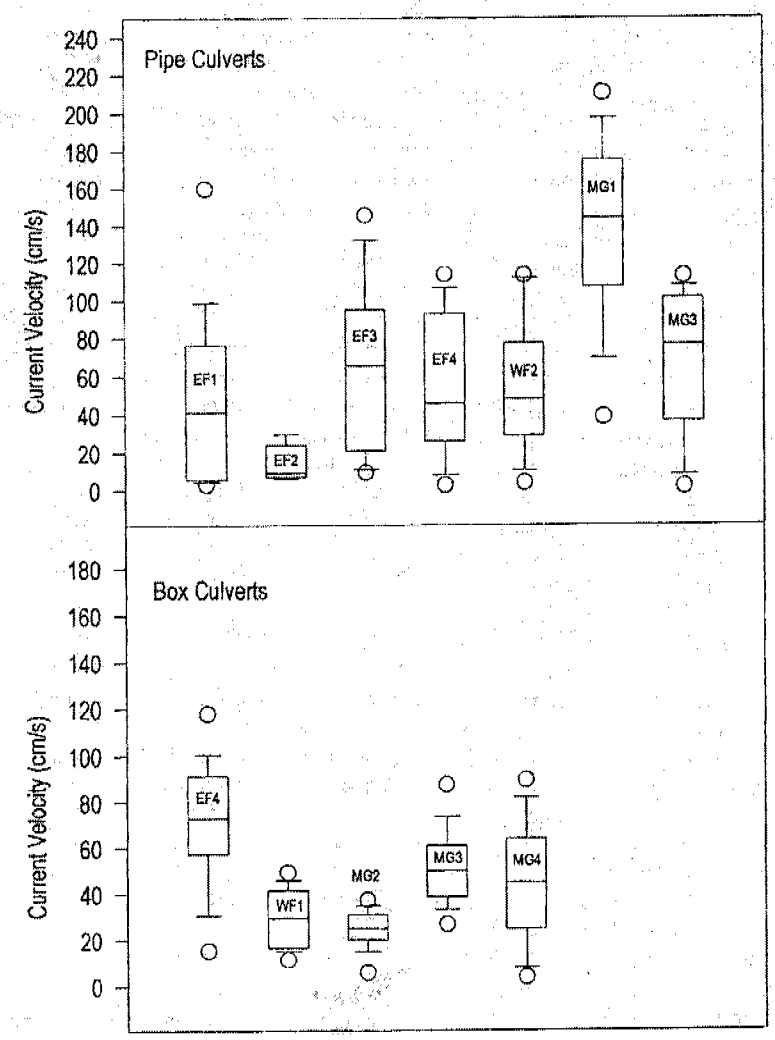
Pipe Culverts
Current Velocity (cm/s)
240
220
200
180
160
140
120
100
80
60
40
20
0
EF1
EF2
EF3
EF4
WF2
MG1
MG3
Box Culverts
Current Velocity (cm/s)
180
160
140
120
100
80
60
40
20
0
EF4
WF1
MG2
MG3
MG4

FIGURE 2.—Current velocities in culverts at each road crossing in the Glover River drainage. The boxes cover the central 50 percent of the observations, the vertical lines extend to the 5th and 95th percentiles, and the open circles represent maximum and minimum values. Abbreviations are as follows: EF indicates crossing in East Fork Glover River, WF indicates those in West Fork Glover River, and MG indicates those in main-stem Glover River.

tances and total distance were reduced in the higher water velocities. In other studies (Jones et al. 1974; Warren and Pardew 1998), water velocities in culverts above 30–40 cm/s limited the passage of most species.

A potential limitation in our study was that the leopard darters were not forced to swim to exhaustion by electrical shock or physical prodding. We were somewhat limited by restrictions in our collecting permit, but we do not feel that the lack of an additional swimming stimulus greatly affected our results. The behaviors observed in the laboratory were nearly identical to those observed in the field. While leopard darters were observed in high current velocities in the field, they were always flat against the substrate. Leopard darters that entered the water column in high-velocity areas were immediately swept downstream. A similar response was noted when fish entered high-current areas in the lower part of riffles.

In addition to the difficulty of swimming against high current velocities, leopard darters are exposed to a variety of other barriers at some road crossings. All of the culverts were longer than the total

distance traversed in our experiment (Table 1). The greatest total distance covered by an individual leopard darter during a 10-min trial was 1.55 m compared with the 4–6-m length of culverts. Mean burst lengths also were considerably shorter. In the 25-cm/s water velocity, three fish had single bursts of 90 cm, nearly the entire length of the swimming chamber. All of the remaining bursts in that velocity (N = 44), however, were less than 20 cm. Except for one box culvert with heavy algal growth, none of the culverts appeared to have water velocity refuges at distances corresponding to mean burst distances. Leopard darters in the laboratory apparatus did not maintain position after a swimming burst and drifted back to the end of the test chamber. In the highest water velocities (42 and 60 cm/s), leopard darters exhibited swimming activity within the first 1–2 min in each trial but spent the remainder of the time flush against the mesh at the back of the chamber. Without current velocity refuges in the culverts, leopard darters would probably have difficulty holding position long enough to traverse a culvert through multiple swimming bursts. In addition, six crossings had additional barriers such as a hydraulic jump at the upstream end, a cascade at the downstream end, or an absence of a refuge pool at one or both ends. The crossing with the highest current velocities (MG1; Figure 2) had all of the additional barriers, including a drop of approximately 0.75 m just downstream from the culverts.

It is unclear whether leopard darters make long-distance movements or even need to move long distances. There is some evidence that leopard darters show migration from pools into riffles associated with spawning (Jones et al. 1984; James and Maughan 1989), although one systematic effort to examine migration of marked individuals was inconclusive (Toepfer et al. 1996). In addition, spawning does not occur in all riffles even though adjacent pools contain leopard darters during the year (James 1989), suggesting that individuals in those locations are required to migrate to other riffles. Because leopard darters have essentially one reproductive season during their estimated life span of 18 months (James et al. 1991), any barrier to migratory movement might be critical to maintaining local populations. During higher flow, when water covers the road, there may be opportunities for darters to move along the edges of the stream, although some darter species appear to move infrequently during high flow events (Freeman 1995). In years such as 1996, however, rainfall during the entire spawning season was low, and all flow at road crossings was through culverts.

Finally, the combination of anthropogenic factors and the leopard darter's limited life span and reproductive opportunities (James et al. 1991) make the species especially vulnerable to localized extirpation. With such a species, recolonization from other areas may be particularly important for the persistence of local populations. For example, in November 1976 a chemical spill extirpated leopard darters from a 16-km reach of the upper Mountain Fork River (Robison 1978), and by 1987 the species had recolonized the area (Zale et al. 1994). Anthropogenic impacts from silviculture, pesticides and fertilizer use, and poultry and swine farming could cause periodic extirpations of local leopard darter populations. Although culverts probably are not long-term barriers to migration or dispersal of leopard darters, their ability to act as barriers during some years may have dramatic effects on populations in areas near road crossings.

Acknowledgments

We thank Tracy Brotherton for her assistance with culvert surveys and measurements. This project was funded by U.S. Fish and Wildlife Service. The Oklahoma Cooperative Fish and Wildlife Research Unit is a cooperative program of the U.S. Geological Survey Biological Resources Division, the Oklahoma Department of Wildlife Conservation, Oklahoma State University, and the Wildlife Management Institute.

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