

Fish Passage in a Western Iowa Stream Modified by Grade Control Structures

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Abstract.—Grade control structures (GCSs) are commonly used in streams of western Iowa to control bank erosion and channel headcutting but may be barriers to fish passage. From May 2002 to May 2006, we used mark–recapture methods to evaluate fish passage over a total of five GCSs, ranging in slope (run : rise) from 13:1 to 18:1 in Turkey Creek, Cass County, Iowa. Three structures, over which limited fish movement was documented from 2002 to 2004, were modified in the winter of 2004–2005 to facilitate fish passage. Before modification, the majority of recaptured fish were recaptured at the station where they were originally marked; only 1% displayed movement between sites and either upstream or downstream over a GCS. After modification fish passage improved, 14% of recaptured fish displayed movement either upstream or downstream over a GCS. Individuals of four target species—channel catfish *Ictalurus punctatus*, yellow bullhead *Ameiurus natalis*, black bullhead *A. melas*, and creek chub *Semotilus atromaculatus*—passed over at least one modified structure. The majority of documented movements over GCSs were in the upstream direction and occurred in late spring and early summer, when streamflow was relatively high. Although we documented low numbers of fish passing both upstream and downstream over GCSs, these structures are probably barriers to fish movement during periods of low flow and when there is a structural failure, such as in-channel movement of riprap. Grade control structures are pervasive in western Iowa streams; nearly every low-order stream contains at least one instream structure. To sustain fish populations, management efforts should focus on constructing or modifying GCSs to allow fish passage.

In rivers around the world, countless instream structures are barriers to fish passage (Porto et al. 1999; Pringle et al. 2000). Movement, whether short distances between habitat patches or long migrations in streams, is vital to survival and reproductive success of many stream fishes (Pringle et al. 2000). Over time, restricted fish passage may result in reduced fish abundance and species richness (Joy and Death 2001), fragmentation of populations and genetic divergence (Pringle et al. 2000; Morita and Yamamoto 2002), shifts in fish assemblages in areas upstream and downstream from impoundments (Taylor et al. 2001;

Gehrke et al. 2002), and possible extirpation of species in reaches upstream from barriers (Winston et al. 1991; Taylor et al. 2001). Although a great deal of past research has investigated fish passage through large barriers (i.e., dams built for hydroelectricity production and reservoir construction) and the corresponding changes in river fish communities resulting from these impoundments, small structures, such as low-head dams and road crossings, also present serious barriers to fish passage that may adversely affect fish populations and communities (Warren and Pardew 1998; Porto et al. 1999; Ovidio and Philippart 2002; Santucci et al. 2005).

In western Iowa, stream networks have been highly fragmented by over 400 grade control structures (GCSs) that have been placed downstream from bridges to control erosion and stabilize channels (Voegelé 1997; Boyken 1998; Gu et al. 1999; Figure 1). In this region, wind-deposited silt (loess) originating

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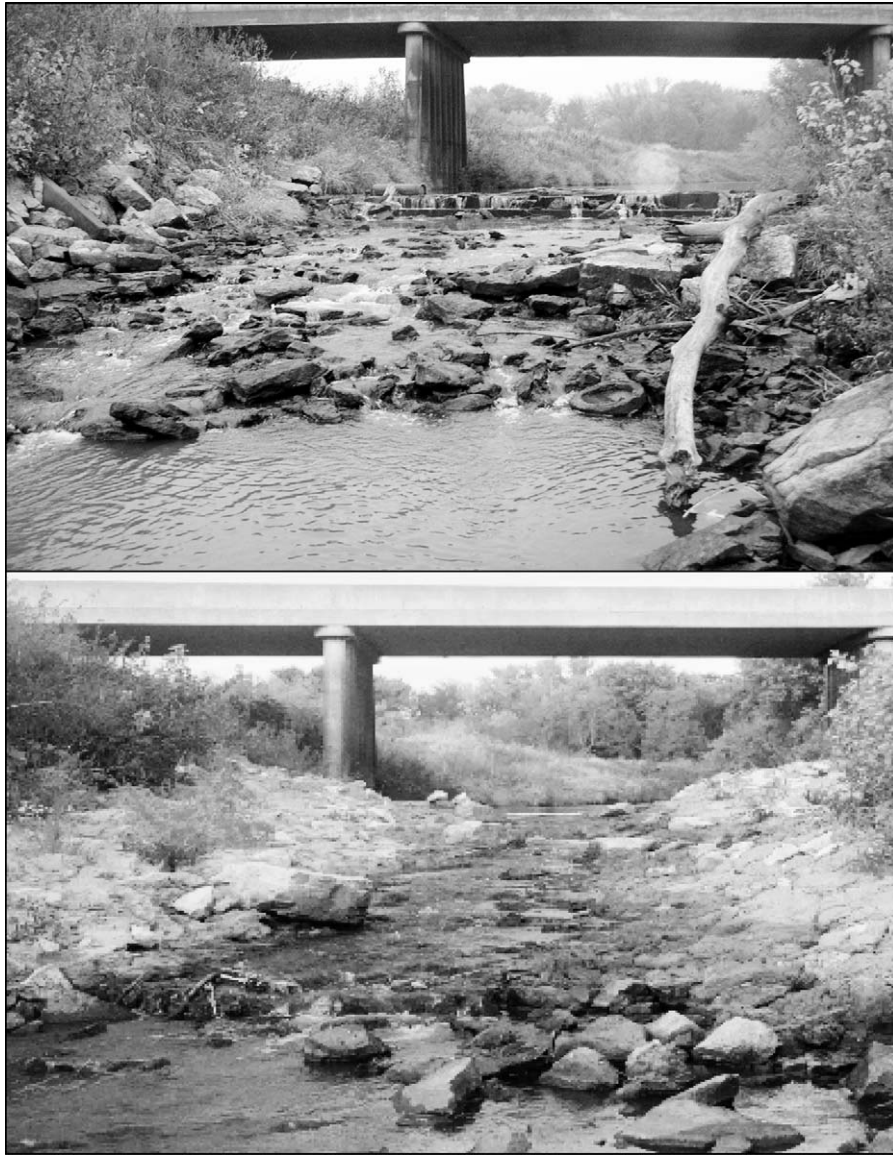


FIGURE 1.—The grade control structure at site G3 on Turkey Creek during the fall of 2004 before modification (top) and during the fall of 2005 after slope modification (bottom). From 2002 to 2004, no fish were documented as passing over this structure. After modification, channel catfish, black bullheads, and creek chub were all documented passing over this structure.

from the Missouri River alluvial plain has formed rolling hills that are especially prone to erosion (Prior 1991). Streambank erosion has been exacerbated by stream channelization and alteration of natural flow regimes by landscape and drainage modifications. Most of the landscape has been converted from rolling prairie to row-crop agriculture and grazing pasture, which has led to decreased infiltration of precipitation and increased surface water runoff (Menzel 1983; Prior

1991). In addition, groundwater input to streams has been increased by construction of buried tile lines that transport water from beneath agricultural fields directly into stream channels. Consequently, this increased water delivery to streams, coupled with the shortening and increased slope of channelized reaches, has resulted in extreme incision, erosion, and degradation of stream channels in this region (Daniels 1960; Menzel 1983). In western Iowa, erosion and widening

of streambanks has caused an estimated US\$1.1 billion loss of bridges, roads, and farmland (Baumel et al. 1994). To protect bridge stability and decrease the loss of farmland by erosion, GCSs consisting of a 1.2-m vertical steel sheet piling and a downstream apron of rock riprap (Figure 1) have been placed in streams (Gu et al. 1999). Over 400 GCSs of this design have been constructed in western Iowa streams since the early 1990s, and many more such structures have been proposed or are currently under construction (Larson et al. 2004).

Because of the high cost of riprap material, most GCSs in this region were originally constructed with downstream slopes of 4:1 (run : rise) or steeper (Voegelé 1997; Larson et al. 2004). However, in the late 1990s, concern arose that these steeply sloped GCSs prevented fish passage and that populations of sport fish, specifically channel catfish *Ictalurus punctatus*, were declining in streams with GCSs (Larson et al. 2004). This prompted studies of fish movement over structures and plans to modify some GCSs to more gradual slopes to facilitate fish passage. In 2006, the average 4:1 sloped structure cost approximately US\$78,900 (J. T. Thomas, Hungry Canyons Alliance, personal communication). Because of the additional material needed to construct longer downstream slopes, structures built at a slope of 10:1 would cost approximately 18% (\$14,200) more than a 4:1 structure, a 15:1 structure would cost approximately 33% (\$25,950) more, and a 20:1 structure would cost approximately 48% (\$37,750) more (J. T. Thomas, personal communication).

Although some fish pass designs (e.g., Denil passes) have permissible slopes ranging from 5:1 to 10:1, more gradual slopes ranging from 15:1 to 30:1 are recommended for rock-ramp fishways that are intended to mimic the natural streambed (FAO 2002). Additionally, Newbury and Gaboury (1993a, 1993b) recommend that artificial riffles built for streambed control and habitat restoration have downstream slopes of 20:1. Research conducted on Walnut Creek in Montgomery County, Iowa, from 2001 to 2003 concluded that marked fish species, including channel catfish and flathead chub *Platygobio gracilis*, were capable of bidirectional passage over GCSs with a 20:1 slope and creek chub *Semotilus atromaculatus* were capable of upstream passage over GCSs with that slope (Larson et al. 2004). However, because of high costs associated with construction of 20:1-sloped structures, more research was needed to investigate fish passage over more steeply sloped (and therefore less expensive) structures. In addition, downstream migration of structure riprap and the formation of a vertical obstacle at the structure's upstream metal face is a common

problem of many GCSs in this region (Voegelé 1997). To prevent structural failure and to stabilize riprap, some GCSs are designed with concrete grouting between riprap (Voegelé 1997). Before our study, fish passage over GCSs in western Iowa with grouted downstream slopes had not been investigated, nor had fish passage over GCSs with slopes steeper than 20:1 been studied thoroughly.

Previous studies of GCSs in western Iowa focused on the hydraulic functioning, structural stability, and effectiveness of the structures in providing bank stability (Voegelé 1997; Boyken 1998). However, little research has investigated effects of these structures on aquatic communities. We evaluated fish passage over a total of five instream structures from May 2002 to May 2006. Three of these structures, over which limited fish movement was documented from 2002 to 2004, were modified in the winter of 2004–2005 to facilitate fish passage. The goal of this study was to evaluate fish passage in Turkey Creek; the specific objectives were to (1) determine whether several fish species displayed bidirectional passage over GCSs of various designs and (2) evaluate changes in fish passage after slope modification of three GCSs. In addition, a companion study (Litvan et al. 2008, this issue) investigated fish assemblage structure in this GCS-fragmented stream. Modification of streams with GCSs is widespread in western Iowa; nearly every low-order stream contains at least one instream structure. It is therefore imperative that we understand the effects of GCSs on aquatic communities in these altered stream ecosystems.

Study Area

Turkey Creek, located in the Loess Hills and Rolling Prairies ecoregion of western Iowa, is a tributary of the East Nishnabotna River and part of the Missouri River drainage network (Omernik et al. 1993; Figure 2). Originating in northwestern Adair County, Turkey Creek flows 49 km southwest through Cass County and drains a watershed of 331 km² (Iowa Department of Natural Resources [DNR] Watershed Initiative 2002). Land use in the Turkey Creek watershed is dominated by intensive agriculture, 54% of the landscape being devoted to row crops and an additional 16% to livestock grazing (Iowa DNR Watershed Initiative 2002). Precipitation in the watershed is approximately 80 cm/year. The creek is gently sloping, with a main channel gradient of 1.3 m/km (Iowa DNR Watershed Initiative 2002).

Turkey Creek has been significantly altered by anthropogenic activities, including channelization, removal of riparian vegetation, and placement of GCSs (Bulkley 1975; Larson et al. 2004). Channelization during the late 1800s and more recent projects in 1929

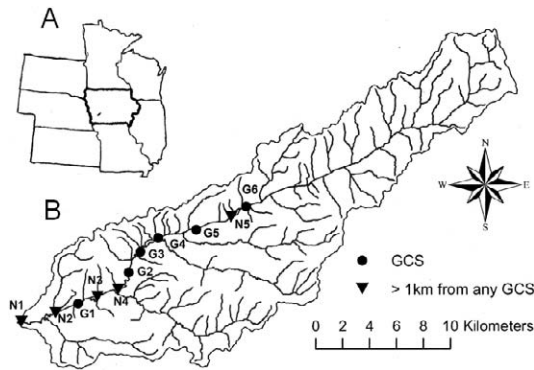


FIGURE 2.—Locations of (A) Turkey Creek and (B) the sampling sites on Turkey Creek at or 1 km from a grade control structure (GCS). Sites G1–G6 and N4 were sampled by means of passive gear and electrofishing, sites N1–N3 and N5 by electrofishing only. At least six additional stream stabilization structures (GCSs or riprap piles) are located upstream from site G6 in the main channel of Turkey Creek and its headwater tributaries.

and 1958 have left 85% of the channel nonmeandering, the sinuosity ratio for a main channel being less than 1.5 (Bulkeley 1975). Turkey Creek has been described as resembling a ditch rather than a natural stream, having nearly vertical banks up to 6 m high (Harlan et al. 1987). Streambank erosion is prevalent and benthic substrates are dominated by silt and sand. Beginning in 1996, nine GCSs have been built downstream of bridges in Turkey Creek to stabilize the stream channel and halt the upstream progression of knickpoints (e.g., Figure 1).

The study area consisted of 11 sampling sites (Figure 2). Site names beginning with the letter *G* were located directly downstream from GCSs, whereas site names beginning with the letter *N* were located at least 1 km from any GCS (Table 1; Figure 2). The most downstream site (N1) was located 0.3 km upstream from the creek's confluence with the East Nishnabotna River, draining a watershed of 331 km²; the most upstream site (G6) was located 23.9 km upstream, draining a watershed of 133 km². Within the study area, Turkey Creek ranges from a third- to fourth-order stream of approximately 3–15 m in wetted width. All sampling sites were accessed at bridge crossings; the six *G* sites were reaches immediately downstream from GCSs, whereas the five *N* sites, which were all located at least 1 km from any GCS, were accessed by bridges without GCSs. None of the bridges in this study were low-water crossings or contained structural elements that could have restricted fish passage. Stretches of stream that appeared to be affected by bridge presence were excluded from sampling reaches.

Methods

GCS modifications and measurements.—Six GCSs are located within the study area of Turkey Creek (Table 1; Figure 2). Structures at sites G2, G3, G4, and G6 were built in 1996 and those at G1 and G5 in 2001. All structures were originally constructed with ungrouted riprap aprons ranging from 4:1 to 10:1 in downstream slope, and all structures except one, site G2, contained a metal sheet-pile dam at the upstream face of the structure. Similar to many GCSs in western

TABLE 1.—Locations of sampling sites (Figure 2) and physical dimensions of grade control structures on Turkey Creek. Structures G1, G3, and G4 were modified during the winter of 2004–2005; there were no structures at sites N1–N5. Fish passage over structure G6 was not evaluated.

Site	Coordinates	Distance upstream ^a (km)	Modification period	Downstream apron slope (run : rise) ^b	Downstream apron length (m)	Apron type	Upstream face vertical height (m)
N1	41°19.47'N, 95°4.28'W	0.3					
N2	41°19.85'N, 95°2.47'W	4.4					
G1	41°20.26'N, 95°1.27'W	6.3	Before After	14.3:1 18.3:1	14.0 19.5	Riprap Grout	0.50 0.43
N3	41°20.55'N, 95°0.25'W	7.9					
N4	41°20.86'N, 94°59.14'W	9.5					
G2	41°21.56'N, 94°58.60'W	11.8		12.6:1	19.2	Riprap	0.10
G3	41°22.41'N, 94°58.01'W	14.1	Before After	12.7:1 17.9:1	14.0 26.2	Riprap Grout	0.47 0.00
G4	41°22.99'N, 94°57.08'W	16.6	Before After	Vertical ^c 15.2:1	13.0 ^c 36.6	Riprap Riprap	1.20 0.56
G5	41°23.35'N, 95°55.07'W	19.5		17.1:1	21.3	Riprap	0.53
N5	41°23.89'N, 94°53.22'W	22.4					
G6	41°24.33'N, 94°52.42'W	23.9		9.6:1	17.1	Riprap	0.33

^a Represents the distance upstream from the confluence of Turkey Creek with the East Nishnabotna River.

^b The premodification slope dimensions of modified structures were measured by the primary author in 2004; the postmodification slope measurements and those of unmodified structures were obtained from 2005 county engineer surveys.

^c The riprap apron of the premodified structure at this site had separated from the face of the metal sheet pile. The structure was a 1.2-m-high vertical dam; riprap extended 13.0 m downstream from the dam but did not form a slope to the top of the structure.

TABLE 2.—Sampling of fish in Turkey Creek by means of passive gear (P) and electrofishing (E) before and after modification of the grade control structures at sites G1, G3, and G4.

Year	Sampling dates	Sites sampled	Type of gear used	Number of 24-hr periods for passive gear
Before modification				
2002	May 27–Aug 13	G1, G3, N4	P	18
	Jul 23–Aug 13	G4	P	6
2003	May 20–Jul 31	G1, G2, G3, G4, G6, N4	P	8
2004	Jun 14–Aug 13	G1, G2, G4, N4	P	25
		G3, G6	P	24
	Jul 12–Aug 13	G5	P	14
	Oct 14–21	All sites except N2	E	
After modification				
2005	Apr 16–Jun 1	All sites except N2	E	
	May 17–Aug 12	G1, G2, G3, N4	P	36
		G4, G5, G6	P	35
	Jul 24–Aug 4	All 11 sites	E	
Sep 30–Oct 16	All 11 sites	E		
2006	May 5–May 14	All 11 sites	E	

Iowa, those in our study area had experienced structural failure; the riprap composing the aprons of these structures had migrated downstream during high-flow events, exposing the metal dam face and causing a vertical drop at the sheet pile of 0.1 to 1.2 m in height as well as an overall structure slope that varied from the original construction design. Three structures (G1, G3, and G4) were modified during the winter of 2004–2005 to have more gradual slopes and thus facilitate fish passage (Table 1; Figure 1). The modifications of the GCSs at sites G1 and G3 consisted of lengthening the downstream apron and grouting the apron with concrete to prevent downstream migration of riprap and reduce the vertical drop at the sheet pile. Before modification at site G4, the downstream apron of the GCS had completely separated from the face of the sheet pile and washed downstream, leaving a greater than 1-m-high low-head dam extending across the stream. This structure was modified by construction of a downstream ungrouted riprap apron, which substantially reduced the vertical incline of the low-head dam.

Because the six GCSs in our study area varied in length, slope, and vertical drop at the sheet pile, the physical dimensions of each structure were measured under base flow conditions before structure modification (October–November 2004) and after modification (October–November 2005). At each GCS, total structure length was measured to the nearest 0.1 m. A clinometer and a surveying pole were used to determine the drop in elevation from the top of the structure's sheet pile to the end of the structure's downstream apron. Structure slope (run/rise) was then determined by dividing the length of the structure by the change in elevation. To assess the height of the maximum vertical obstacle encountered by a moving

fish, we measured the vertical distance between the stream level above the sheet pile and the stream level below the sheet pile at 1-m intervals across the width of the sheet pile. In addition, county engineers measured slopes of all six structures by standard professional survey methods during the winter of 2005–2006. Because the GCSs in this region are usually built or modified in the fall and winter months, when streamflows are low, these measurements of structure dimensions coincide with the streamflow conditions typical of construction periods.

Fish sampling.—To collect fish data, we used a combination of passive gear sampling and electrofishing surveys. Passive gear were set at sampling sites (G1, N4, G2, G3, G4, G5, and G6) for 24-h periods throughout four summer field seasons (2002–2005; Table 2). To decrease the bias of the mesh size for the size of fish captured, we used two types of passive gear: hoop nets (total net length, 2.6 m; hoop diameter, 61 cm; front throat diameter, 15.2 cm; back throat diameter, 10.2 cm; and mesh size, 1.9 cm) and minnow traps (throat diameter, 2.54 cm; and mesh size, 0.64 cm). At each sampling site one hoop net and one minnow trap baited with soy cake were set on each side of the stream channel, for a total of two hoop nets and two minnow traps at each site. Passive gear were set 50–100 m downstream from GCSs or bridges.

Mark–recapture methods were used to evaluate fish passage. All individuals of four target species—channel catfish, black bullheads, yellow bullheads, and creek chub—captured by passive gear were given a site-specific fin clip or punch. Two sets of fin-clipping sequences were used: one set for fish marked from 2002 to 2004 before structure modification and a different set for fish marked in 2005 after structure

modification. Total length (TL) and wet weight of target fish species were measured to the nearest millimeter and 0.1 g, respectively. In addition to batch-marking fish based on station of capture, individuals meeting size criteria were tagged with individually numbered tags, thus providing individual movement histories for tagged fish. Throughout the study, catfish weighing over 400 g were double-tagged with an individually numbered dorsal dart tag and opercle tag to evaluate tag retention and help prevent loss of information resulting from tag expulsion. Beginning in 2005, all target fish species greater than 170 mm TL but less than 400 g were tagged with individually numbered dorsal t-bar tags. Upon capture, all fish of the four target species were inspected for previous fin clips or tags, marked or tagged if previously unmarked, and released at the station of capture. Three ictalurid species and creek chub were selected for the mark-recapture study because these species are among the most numerous fish in Turkey Creek that reach body sizes sufficient for fin clipping and tagging. In addition, the ictalurid species are popular sport fishes in western Iowa streams, are suspected to make seasonal movements, and probably will be detrimentally affected by barriers to fish passage. All nontarget species caught by passive gear were identified and enumerated.

Additionally, we used hook-and-line sampling during summer field seasons to increase the number of marked and recaptured fish in the stream and to sample deep scour pools below GCSs that were not accessible with electrofishing or passive gear. Target fish species caught by hook and line were inspected for fin clips or tags, measured for TL, weighed (wet weight), marked if previously unmarked, and released at the site of capture.

Five electrofishing surveys were conducted between October 2004 and May 2006 to recapture marked fish and collect fish assemblage data for a companion study (Litvan et al. 2008). The electrofishing survey conducted in October 2004 occurred before GCS modification. After the modification of three GCSs (G1, G3, and G4), electrofishing surveys were conducted in four separate seasons: April–May 2005, July–August 2005, October 2005, and May 2006. The October 2004 and April–May 2005 surveys were conducted at 10 sites (all except N2); the remaining three electrofishing surveys were conducted at all 11 sites. The length of all stream reaches sampled was 280 m, a distance 40 times the mean summer wetted width of all sites (approximately 7.0 m; Lyons 1992). At all non-GCS sites and at GCS sites with deep (>1.5 m) scour pools (G1, G2, and G3), a block net was placed at the upstream boundary of the sampling reach. The upstream endpoints of the sampling reaches at all non-

GCS sites were located at least 20 m downstream from bridges at the point at which bridge-related habitat effects were no longer visible. At GCS sites with nonwadeable scour pools (G1, G2, and G3), the upstream boundary of the sampling reach was the point at which depth became too great to progress when using backpack electrofishing gear. At GCS sites with wadeable scour pools (G4, G5, and G6), the upstream boundary of the sampling reach was located at the base of the GCS apron. Beginning 280 m downstream from the block net or GCS base, two backpack electrofishing units were used to collect fish in a single upstream pass of the sampling reach (Simonson and Lyons 1995). Target fish species collected were inspected for previous fin clips and tags, measured for TL and wet weight, and released at the station of capture. Because of heavy siltation and hazardous conditions for wading at site N1, this site was shifted upstream 200 m in July 2005 before the summer 2005 electrofishing survey.

Throughout this study, our fish sampling efforts at GCS sites focused on reaches immediately downstream from structures but did not sample fish directly upstream from GCSs; upstream from GCSs, water is impounded, forming moderately deep pools that promote siltation and result in hazardous wading conditions. Given the extreme channel incision and lack of boat access points to the stream, we were unable to utilize boat electrofishing gear for these impoundments but were limited to backpack electrofishing in reaches directly downstream from the GCSs.

Physicochemical variables, including water temperature, pH, dissolved oxygen, turbidity, and stream discharge, were measured at each sampling site once a week during summer field seasons and after each electrofishing survey (see Litvan 2006). Water temperature, pH, and dissolved oxygen were measured with electronic probes, and turbidity was measured with a Hach 2100P turbidimeter. Using an electronic flowmeter, we determined stream discharge by taking stream velocity and depth measurements at equally spaced intervals across a designated stream width at each sampling site (Gordon et al. 1992).

Data analysis.—Fish movement was quantified by determining the number and percentage of recaptured fish of each species that displayed movement between sites and upstream or downstream from a GCS. We quantified the proportion of recaptured fish that moved between sites with the ratio M/R , where M is the number of recaptured fish showing movement between sites and R is the total number of recaptures. For each recaptured fish displaying movement, direction of passage, number of structures passed, and distance of movement were determined. Histograms were con-

TABLE 3.—Number of marked and recaptured fish of the four target species in Turkey Creek before and after modification of the grade control structures at sites G1, G3, and G4.

Year	Status (marked or recaptured)	Channel catfish	Black bullhead	Yellow bullhead	Creek chub	Total
Before modification						
2002	Marked ^a	92	24	2	66	184
	Recaptured ^a	21	2	0	1	24
2003	Marked ^a	318	144	0	160	622
	Recaptured ^a	15	14	0	9	38
2004	Marked ^a	425	52	134	250	861
	Recaptured ^a	103	38	50	96	287
	Recaptured ^b	0	0	1	20	21
After modification						
2005	Marked ^a	359	399	288	298	1,344
	Recaptured ^a	60	198	84	66	408
	Recaptured ^{a,c}	10	2	7	11	30
	Recaptured ^b	6	5	4	28	43
	Recaptured ^{b,c}	2	0	0	4	6
2006	Recaptured ^b	0	1	0	0	1
	All					
	Marked	1,194	619	424	774	3,011
	Recaptured	217	260	146	235	858

^a Sampled by passive gear and hook and line during summer field seasons.

^b Recaptured during seasonal electrofishing surveys.

^c Recaptured after modification of grade control structures but marked before modification.

structured to illustrate (1) the number of recaptured fish that displayed movements of various magnitudes of upstream or downstream distance traveled and (2) the number of recaptures that displayed movement between sites over various numbers of GCSs. For each instream structure over which fish passage was evaluated, the species, range of fish total length, and direction of fish passage were summarized for the premodification and postmodification periods. Also, to determine whether there was a significant relationship between fish size and distance traveled or number of GCSs passed, we conducted correlation analyses to investigate the following relationships: (1) length of fish at recapture and distance traveled upstream and (2) length of fish at recapture and number of GCSs passed in the upstream direction.

Results

GCS Modifications and Measurements

The GCSs over which fish passage was evaluated ranged in slope from 12.6:1 to 18.3:1 (Table 1). Before modification, the structure at site G4 was essentially a 1.2-m-high low-head dam with a sheer vertical incline. Fish passage over the GCS at site G6 was not evaluated, this site being the most upstream mark-recapture station. Modifications of the GCSs at sites G1, G3, and G4 resulted in increased length of the downstream apron, decrease of structure slope, and reduction of mean vertical height at the sheet-pile (Table 1). Based on the premodification slope measurements, modification of the GCSs at sites G1 and G3 resulted in 22% and 29% reductions in

structure slope, respectively. At site G4, the vertical low-head dam was modified through addition of a downstream apron (Table 1). The modified downstream aprons at sites G1 and G3 consisted of concrete grouting between riprap, whereas the modified downstream apron at site G4 consisted of ungrouted riprap (Table 1). All unmodified structures (G2, G5, and G6) contained ungrouted riprap aprons (Table 1).

Fish Movement

In the 4-year duration of this study, 3,011 fish of the four target species were marked, of which 858 were recaptured (Table 3). The majority of recaptured fish ($n = 771$) were recaptured at the same station where they had been originally marked; only 10% displayed movement between sampling locations, and 8% of the recaptured fish displayed movement either upstream or downstream over a GCS (Table 4). A total of 87 movements between sampling sites were documented (Figure 3). Seventy-two (83%) of these movements were over GCSs, and 15 (17%) were between sites not fragmented by GCSs (Figure 3). Overall, 87% of all documented movements by marked fish were in the upstream direction. For fish moving over GCSs, 92% of passages were in the upstream direction, occurring mostly in late May or early June when streamflow was relatively high. At least one fish of all four target species, including channel catfish, black bullheads, yellow bullheads, and creek chub, moved both upstream and downstream over at least one GCS (Table 5; Figure 3). The GCSs over which at least one species moved ranged in slope from 12.6:1 to 18.3:1

TABLE 4.—Percentages of recaptured fish that displayed movement over grade control structures in either the upstream or downstream direction in Turkey Creek. Thirty-six fish marked before structure modification were recaptured after structure modification, and six of them displayed movement over a structure; however, these fish are included only in the all-years-combined percentages because of uncertainty whether they moved during the pre- or postmodification periods.

Year	Direction of movement	Channel catfish	Black bullhead	Yellow bullhead	Creek chub	Total
Before modification						
2002	Upstream	0	0	0	0	0
	Downstream	0	0	0	0	0
2003	Upstream	0	0	0	0	0
	Downstream	0	0	0	0	0
2004	Upstream	1.9	0	0	0	0.6
	Downstream	1.0	0	2.0	0	0.6
After modification						
2005	Upstream	13.6	20.6	8.0	1.1	13.1
	Downstream	3.0	0	0	1.1	0.7
All years combined	Upstream	6.0	16.2	5.5	1.3	7.7
	Downstream	1.4	0.4	0.7	0.4	0.7

(Table 5). The total length of fish showing passage over structures ranged from 149 to 433 mm (Table 5). Overall, tag retention in our study was good during the tag evaluation period (2004–2006); in fact, 75% of recaptured channel catfish larger than 400 g retained both tags. All other fish were marked with fin clips, which were easily visible throughout summer sampling seasons.

A total of 1,667 fish of the four target species were marked during the summers of 2002–2004 (i.e., before the modification of the GCSs); there were 370 recapture events during this period (Table 3). From 2002 to 2004 (before GCS modification), the majority of recaptured fish (98%) were recaptured at the same station at which they were originally marked; only 2% displayed movement between sampling sites, and only 1% displayed movement between sites and either upstream or downstream over a GCS (Table 4). From 2002 to 2003, none of the recaptured fish displayed passage over any GCS. In the summer of 2004, only four recaptured fish (1.4% of all fish recaptured in summer 2004) were documented moving over GCSs, including three channel catfish (2.9% of recaptured channel catfish) and one yellow bullhead (2.0% of recaptured yellow bullheads; Table 5). In addition, two creek chubs recaptured during the October 2004 electrofishing survey moved downstream from site G6 to N5, a distance of 1.5 km, but did not pass over any GCS. From 2002 to 2004, no fish passage was documented over the GCSs at sites G3 and G4.

A total of 1,344 fish of the four target species were marked during the 2005 summer field season (after the modification of the GCSs), and 488 were recaptured from 2005 to 2006 (Table 3). From 2005 to 2006, the majority of fish marked and recaptured after GCS modification (83%) were recaptured at the same station

at which they were originally marked; 17% of fish displayed movement between sampling sites, and 14% displayed movement either upstream or downstream over a GCS (Table 4). During the summer of 2005, after modification of three of the five GCSs being evaluated for fish passage, passive gear and hook-and-line sampling documented 69 movements (16.9% of recaptures) among fish that had been marked after GCS modification (Tables 4, 5). Ten of these movements were between sites not fragmented by a GCS; the remaining 59 movements showed passage between sites and over at least one GCS. Most summer movements over GCSs (98%) were upstream movements; only 2% of summer movements over GCSs were downstream. At least one fish moved over each of the five GCSs within the study area. Autumn and spring electrofishing surveys conducted after GCS modification documented six movements by marked fish, three of which were over GCSs.

Overall, most ictalurid fish passing over GCSs were recaptured one site upstream from their original marking site, displaying movement over only one GCS (Figure 3). Channel catfish were documented moving upstream a maximum distance of 7.9 km over a maximum of two GCSs; their maximum distance downstream was 13.8 km, passing over a maximum of three GCSs (Figure 3A, B). Black bullheads were documented moving upstream a maximum distance of 13.3 km over a maximum of four GCSs and downstream a maximum 7.9 km over a maximum of two GCSs (Figure 3C, D). Yellow bullheads were documented moving upstream a maximum distance of 5.4 km over a maximum of two GCSs and downstream a maximum distance of 4.4 km over a maximum of one GCS (Figure 3E, F). Ninety-one percent of all ictalurid movements were in the upstream direction (Figure 3).

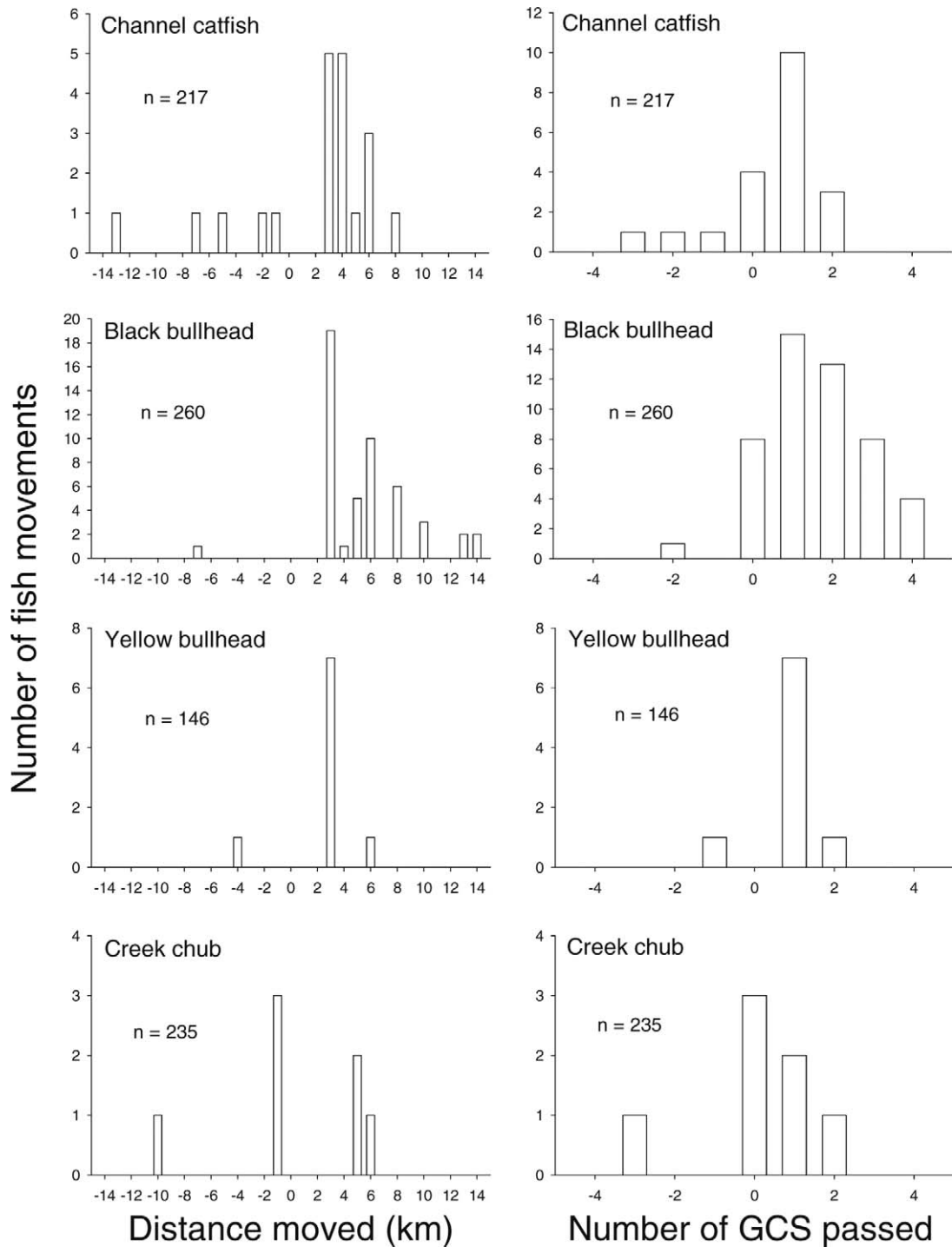


FIGURE 3.—Histograms of documented movements of marked channel catfish, black bullheads, yellow bullheads, and creek chub in Turkey Creek from May 2002 to May 2006 (n = the total number of recaptures). Downstream movements are indicated by negative values, upstream movements by positive values. These histograms show a total of 85 movements; four upstream movements of black bullheads were treated as two recorded movements because they involved the same fish moving upstream twice.

TABLE 5.—Numbers and total lengths (mm [parentheses]) of fish passing over grade control structures (GCSs) in Turkey Creek from June 2004 to May 2006. Structures at sites G1, G3, and G4 were modified during the winter of 2004–2005; structures G2 and G5 were not modified during this study. No passage over structures was documented in 2002 or 2003.

Site	Year	Modification period	Direction of movement	Channel catfish	Black bullhead	Yellow bullhead	Creek chub
Modified GCSs							
G1	2004	Before	Upstream	2 (260–433)	0	0	0
			Downstream	0	0	0	0
	2005	After	Upstream	5 (193–412)	5 (170–192)	0	0
			Downstream	1 (220)	0	0	0
G3	2004	Before	Upstream	0	0	0	0
			Downstream	0	0	0	0
	2005	After	Upstream	3 (200–280)	26 (150–256)	0	1 (180)
			Downstream	1 (399)	0	0	1 (185)
G4	2004	Before	Upstream	0	0	0	0
			Downstream	0	0	0	0
	2005	After	Upstream	1 (280)	21 (150–256)	6 (149–210)	1 (180)
			Downstream	1 (399)	0	0	1 (185)
Unmodified GCSs							
G2	2004		Upstream	0	0	0	0
			Downstream	1 (415)	0	0	0
	2005		Upstream	3 (200–296)	24 (150–254)	1 (174)	0
			Downstream	2 (220–399)	1 (222)	0	1 (185)
G5	2004		Upstream	0	0	0	0
			Downstream	0	0	1 (149)	0
	2005		Upstream	0	6 (173–249)	0	2 (189–190)
			Downstream	0	0	0	0

Most of the creek chub displaying movement between sites moved downstream from site G6 to N5, a distance of 1.5 km, but they did not pass over any GCS (Figure 3G, H).

From 2002 to 2004, we documented limited fish passage over the premodified GCSs at G1 and no fish passage over the premodified structures at G3 and G4 (Table 5). After these structures were modified, we documented both upstream and downstream passage of marked fish (Table 5). Eleven fish, including channel catfish and black bullheads, moved over the modified structure at G1. At site G3, 32 total fish, including channel catfish, black bullheads, and creek chub moved over the modified structure. All four target species (a total of 31 fish) moved over the modified structure at site G4. Channel catfish and creek chub were documented moving both upstream and downstream over grouted structures, whereas black bullheads were documented moving just upstream over the grouted structures. No yellow bullheads were documented moving either upstream or downstream over grouted structures. At least one fish of all four target species was documented moving both upstream and downstream over ungrouted riprap aprons.

Our correlation analyses using the individual lengths of fish with numbered tags revealed no statistically significant relationships. For each marked species, there was no significant correlation between fish length and distance traveled upstream or between fish length

and the number of GCSs passed in the upstream direction ($r < 0.15$, $P > 0.300$).

Discussion

Before our study, fish passage over GCSs in western Iowa with grouted downstream slopes had not been investigated, nor had fish passage over GCSs in western Iowa with slopes steeper than 20:1 been thoroughly studied. Our results indicate that three ictalurid species and one cyprinid species are capable of passage over GCSs with slopes steeper than 20:1 and that channel catfish, black bullheads, and creek chub are capable of passage over structures with grouted downstream aprons. However, given the limited scope of our study, precautions should be taken when applying these results to other stream systems or fish species not included in this study. The majority of our sampling effort and documented fish movements occurred during late spring and early summer, when typical velocities of water flowing over the GCSs in Turkey Creek ranged from 0.3 to 2.1 m/s. However, water flow over the GCSs in western Iowa varies greatly with season; structures become nearly dry in late fall and winter and are inundated in the spring, maintaining a steady flow until early fall. Our mark–recapture methods did not allow us to determine the exact time and flow condition at which structures were passed. Future studies evaluating fish passage over instream barriers should consider using passive integrated transponder tags and real-time stream

discharge data to obtain exact time and flow velocity measurements for fish passage (Zydlewski et al. 2006).

In addition, because there is no suitable control stream within this region, we were unable to determine differences in fish movement in streams with GCSs and streams without GCSs. Also, our mark–recapture study was limited to four species and did not adequately evaluate passage for young-of-year fish. At least 29 species and 8 families of fish reside in Turkey Creek, either as year-round residents or temporary migrants (Litvan et al. 2008). Furthermore, the smallest fish documented moving over any GCS was 149 mm. Very few young-of-year fish were captured and marked during this study, and none of these fish were recaptured after passing a GCS upstream or downstream. The effects of GCSs on the passage of the remaining species and juveniles of all species are unknown at this time.

Despite these limitations, our research provides valuable insight into the passage capabilities and movements of four fish species that are widespread and relatively abundant in streams across western Iowa, virtually all of which are impacted by GCSs. Previous studies indicate that channel catfish migrate downstream from tributaries to larger rivers during the autumn, move upstream from larger rivers to tributaries during the spring, and have relatively small home ranges within summer months (Dames et al. 1989; Pellett et al. 1998). Sakaris et al. (2005) found that brown bullhead *A. nebulosus* travel upstream during the spring after an increase in water temperature and have relatively small home ranges (<0.5 km) during the summer. In our study, ictalurid fish displayed an upstream bias in movement direction during the late spring and early summer that was probably associated with spawning. In Iowa rivers, black and yellow bullheads spawn in late April, May, or early June, whereas channel catfish typically spawn somewhat later, from May through July, when water temperatures reach approximately 24°C (Harlan et al. 1987). In our study, the majority of fish passing over GCSs in Turkey Creek were channel catfish and black bullheads that moved upstream from mid-May to mid-July, when flows were relatively high and water temperatures ranged from 18°C to 25°C.

In Turkey Creek, few yellow bullheads and creek chub were seen at downstream sampling locations (i.e., N1, N2, and G1) during the spring, summer, and autumn sampling periods (Litvan et al. 2008), suggesting that these species are year-round residents of upstream reaches of Turkey Creek. Studies by Pezold et al. (1997) and Butler and Fairchild (2005) concluded that creek chub were year-round residents of small temperate streams, and Skalski and Gilliam (2000) found that

creek chub do not display directional bias of movement during spring and summer months. The results of these studies coincide with our findings: marked creek chub were repeatedly captured at their station of original marking during the spring, summer, and autumn sampling periods; for creek chub displaying movement between sites, the numbers of upstream (three fish) and downstream (four fish) movements were comparable. In Turkey Creek and similar streams in western Iowa, a substantial portion of creek chub populations appear to be year-round residents of their particular stream. Our study documented both upstream and downstream movements of creek chub over GCSs, indicating that even species generally considered nonmigratory move within their resident stream and may be deleteriously affected if unable to pass a GCS barrier.

Although our study documented low numbers of four common fish species passing both upstream and downstream GCSs in Turkey Creek during the flow conditions present in late spring and early summer, we observed multiple structural problems with the GCSs in Turkey Creek (regardless of structure slope) that are probably causing these structures to act as barriers to fish passage during periods of extremely low or high flows or that will alter further structural deterioration. These structural problems are typical of the GCSs in streams across western Iowa and include in-channel movement of riprap, resulting in vertical obstacles at the upstream face of the structure; flow velocities and depths that do not meet designated passage criteria; collection of debris at the upstream end of the structure; and local scouring downstream of GCSs (Voegelé 1997; Papanicolaou and Dermisis 2006). In our study, all five of the GCSs over which fish passage was evaluated had experienced some degree of structural failure (including in-channel movement of riprap and separation of riprap from the metal sheet pile dam) before GCS modification. This created a vertical incline at the upstream face of the structure that posed an obstacle to upstream fish movement, regardless of the overall slope of the structure, and probably was responsible for the low number of recaptured fish moving over premodified and unmodified GCSs. Reduction of the vertical height at the upstream face of modified structures (G1, G3, and G4) and restoration of the downstream aprons of these structures probably account for the apparent increase in fish passage after structural modification.

Management Implications

The factors affecting the ability of fish to pass over a barrier include the water velocity over the structure, the height of the structure, the water depth immediately below and throughout the length of the obstacle, and

the swimming and jumping capabilities of the fish attempting passage (FAO 2002; Ovidio and Philippart 2002; Peake 2004). In this study, our measurements of the physical dimensions of GCSs focused on structure slope because the slope design of the structure in turn affects water velocity and depth throughout the structure, the amount of building material needed to construct the desired length of the structure apron, and ultimately the monetary cost of the structure. Our research documented limited passage of four species over GCSs with slopes ranging from 13:1 to 18:1. Design recommendations for artificial riffles and rock-ramp fishways generally include a slope recommendation of 20:1 (Newbury and Gaboury 1993a, 1993b), although some designs range in slope from 15:1 to 30:1 (FAO 2002). The agencies responsible for the construction of artificial riffles, GCSs, and other instream structures will need to balance the trade-off between economic costs and stream rehabilitation goals, realizing that constructing instream structures with steeper slopes may compromise the passage of some species within the fish assemblage.

In our study and those of others (Harris et al. 1998; Papanicolaou and Dermisis 2006), in-channel movement of the riprap composing GCSs and rock-ramp fishways is a common form of structural failure. In a study of 43 GCSs in western Iowa, Voegelé (1997) found that 72% of the structures with riprap aprons had failed to some degree because of in-channel movement of riprap. The movement was attributed to underestimating stream velocities when the required rock size was calculated and consequently using rocks too small to remain stable in high flows (Voegelé 1997). Preventing separation of riprap from the upstream face of the structure would require the placement of Geotextile material or larger rock across the upstream crest of the structure (Harris et al. 1998). In addition, the toe (downstream end) of the structure should be stabilized to prevent the downstream migration of riprap (FAO 2002). Because of the scarcity of large rock building material in western Iowa and the history of instability of ungrouted structures, newly constructed and modified GCSs will probably contain some grout in the downstream apron. However, if the grouted slope settles and sinks over time, this might cause structural failure and thus possibly create a barrier to fish passage. As general recommendations for fish passes, the bottom of the pass should be constructed with substrate that closely mimics natural substrate, and large boulders and constructed pools can be placed within the downstream ramp to provide surface roughness and resting places for fishes (FAO 2002).

We observed structures that were becoming dry (i.e., with little to no surface flow over them) in late fall and

winter, indicating that water was seeping through the face of the structure and flow occurring underneath it (FAO 2002; Papanicolaou and Dermisis 2006). To allow fish passage, the minimum depth of water throughout a fishway should be no less than 0.3–0.4 m (FAO 2002). In addition, periods of high flows may produce flow velocities over GCSs that exceed the maximum velocity criteria for fish passage (Papanicolaou and Dermisis 2006). A study of the hydraulic properties of 22 GCSs in western Iowa found that all structures violated a selected maximum-velocity criterion of 1.2 m/s during the discharge conditions predicted to occur on a yearly interval (Papanicolaou and Dermisis 2006). During periods of extremely low or high flows, the GCSs in western Iowa probably act as barriers to fish passage and should be designed to allow conditions favorable to fish passage under a wider range of flow conditions. Furthermore, we have observed the collection of debris (corn stalks, tree limbs, and in some cases beaver dams) at the upstream faces of GCSs that block the flow of water over the top and may present an additional barrier to fish passage, regardless of the overall design of the structure. Finally, large scour pools have formed downstream from the GCSs in Turkey Creek (Litvan et al. 2008). Scouring downstream from a GCS jeopardizes the stability of the structure and may eventually undermine it; therefore, the area downstream from the structure should be stabilized (FAO 2002).

Fragmentation of flow in rivers is harmful to the sustainability of fish populations and aquatic communities, including both vertebrates and invertebrates (Dynesius and Nilsson 1994; Watters 1996; Pringle et al. 2000). In Iowa, nearly one-fifth of fishing trips are to interior streams, and channel catfish are one of the state's most popular sport fishes (Harlan et al. 1987). Restriction of the movement of channel catfish between the Missouri River and tributary streams will probably lead to a decrease in channel catfish populations because of decreased access to spawning areas, food resources, and overwintering habitat. Instream barriers may also lead to upstream extirpation of nongame fishes (Winston et al. 1991; Taylor et al. 2001). Without GCSs, the stream channels in western Iowa would continue to incise, widen, and eventually reach a stable condition over many decades. However, before stream channels cease to degrade, hundreds of acres of farmland would be lost to erosion and millions of dollars would be spent replacing transportation and communication infrastructure. Therefore, the presence of GCSs in western Iowa is certain, and the ability of fish to pass over them will be important for the long-term sustainability and integrity of aquatic communities in this region.

Currently the Iowa DNR is working with agencies

that fund GCS construction to develop fish-friendly design criteria for newly built structures. In addition, in an attempt to reconnect the largest amount of previously fragmented reaches, structures are being given priority for modification based on their proximity to free-flowing habitat. Poor maintenance of structures has been cited as the chief cause of functional failure of fish passes (FAO 2002). The agencies funding and constructing instream structures such as GCSs must consider the expected lifetimes of the structures and plan for maintaining and replacing them so that future generations are not left with the task of ameliorating problems caused by past rehabilitation practices (Thompson 2002). The impact of the GCSs in the streams of western Iowa on normal fish movements and the long-term effect of these structures on stream fish communities are largely unknown. Future research should continue to investigate the impacts of GCSs on aquatic communities and attempt to minimize the deleterious affects of these structures while providing for bank stabilization and infrastructure protection. In a companion article (Litvan et al. 2008), we examine the fish assemblages in Turkey Creek in light of the fragmentation by GCSs.

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