A TALE OF TWO STREAMS: RESTORATION STRATEGIES COMPARED

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__Abstract__: Many stream ecosystems are severely limited by damaged physical habitat. Channelization and associated accelerated erosion is a primary cause of damages in agricultural watersheds. Cost-effective strategies are needed to address erosion problems and restore stream corridor habitats. Detailed studies of restoration outcomes are rare. Herein we present a case study of two small streams (watershed size = 12 and 14 km^2) damaged by channel straightening and incision. One stream was stabilized using a low drop grade control structure and dormant willow post planting, while the other was treated with a stone weir, stone toe bank protection, and willow sprout planting. Effects of restoration were monitored by collecting physical and biological data for one to two years before restoration and two to three years afterward. Following construction, channel planforms were stable, but up to 1 m of deposition and erosion occurred along the thalweg profile. Willow planting was not successful, so canopy, bank vegetation and woody debris density were unchanged. Pool habitat area increased from less than 5% to more than 30%. Fish species richness was unchanged, but species composition shifted away from cyprinids that occur in shallow, sandy runs toward pool-dwelling types (catostomids and centrarchids). Response to restoration was more modest than for two nearby restoration projects. Potential causes include less ambitious restoration design, greater initial degradation, and isolation from less-degraded sites which could serve as sources of colonists.

INTRODUCTION

Ideally, stream corridors in the agricultural landscape are multi-functional components, supplying visual amenities and recreational opportunities, trapping and processing contaminants, providing floral and faunal habitats, and conveying water and sediment downstream. In fact, previous watershed and channel management practices have emphasized conveyance functions at the expense of others, and have frequently accelerated channel erosion. For example, straightened, incised streams draining agricultural watersheds in Mississippi display shortages of pool habitats, stable bed material, woody debris, and woody riparian vegetation (Shields et al., 1994). Flood peaks tend to be sharper than for nonincised channels, and overbank flow, with its ecologically important exchange of nutrients and carbon with the floodplain, occurs rarely or not at all.

Interest in stream restoration, here defined as activities intended to restore lost functional values to stream corridors, has increased in recent years. At least 12 federal agencies administer programs with stream restoration activities (not including research) (Water Policy Branch, 1995) and many state agencies are also involved. Despite a wealth of available restoration techniques (Brookes, 1988), little information is available about the effectiveness of a given technique in a given setting. Scientific studies of warmwater stream restoration projects are scarce. Planning and design of restoration projects often proceeds by guesswork, intuition, political compromise, or with only single functions targeted. Herein we assess short-term effects of two restoration projects on channel stability and on fish and their habitats. The period of observation includes up to two years prior to construction and up to three years following construction of restoration measures. Effects are compared with other stream corridor restoration projects in agricultural watersheds in the same region. The objective of this study is to advance the state of restoration science pertaining to deeply incised, low-order warmwater streams draining agricultural watersheds.

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STUDY SITES

Martin Dale Creek (C) and Martin Dale Tributary (T), are incised streams draining adjacent agricultural watersheds of 12.3 and 13.6 km^2 , respectively, in the upper Yazoo River basin in northwest Mississippi (Figure 1). Watershed relief is 50 to 60 m, and geological conditions are characterized by deep (up to 6 m) loess deposits overlying sand and clay (Simons, Li and Associates, 1987). No bedrock is exposed, and the only geologic controls along channels are outcrops of consolidated clay or cemented sand. During this study, valley bottoms (Falaya or Collins silt loam) were cultivated for cotton and soybeans, while hillslopes (silty and sandy soils) were wooded or in pasture (Huddleston, 1967). Both channels were nearly straight, with depths of about 5 m and top widths of about 20 m, and resembled stage II of the conceptual model of incised channel evolution presented by Schumm et al. (1984). Numerical simulation suggested that the channel capacity of C exceeded the 100-year flow (Simons, Li, and Associates, 1987). Bed material was sand with outcrops of hard clay. Along both channels, left banks were extremely steep, but right banks were benched. Thalweg slopes were about 0.002 to 0.003. At base flow, water widths ranged from about 1 to 7 m and median depths were usually less than 10 cm. Base flows were generally in the range of 0.005 to 0.050 m^3s^{-1}. Woody bank vegetation was scarce, except along the lower reaches of T where there were some large trees on top bank. The exotic vine, kudzu (*Pueraria lobata*) covered much of both banks of both channels. Woody debris was scarce.

Streams C and T were treated using different stabilization measures. A low-drop grade control structure ("drop structure", Little and Murphey, 1982) was constructed on C (Figure 2), while a stone weir was placed in T, and a ridge of stone was placed along the toe of concave banks (Figures 3 and 4). The drop structure and stone weir created pools upstream that were up to 1 m deep. Downstream of the stone weir in T, dumped construction rubble (broken concrete, etc.) created a ~10% slope instead of a scour hole (Figure 3). In addition, about 3,000 willow sprouts (cuttings of no minimum size manually thrust 30 to 36 cm into soil) were planted landward of the stone toe along T, while 4,282 dormant willow posts 1.5 m long by 8-30 cm diameter were planted 1.2 m deep in both banks along 500 m of C (Figure 5). Construction dates were August 1992 through February 1993 and June 1991 through August 1991 for C and T, respectively. Costs for restoration measures are summarized in Table 1.

Table 1. Costs for Restoration Measures

Stream	Components	Cost (1991-1992)[1]	Cost per km^2 of upstream drainage area
C	low drop grade control structure 4,282 dormant willow posts	$178, 467 $17,128	
	TOTAL	$195,595	$15,902
T	stone weir, approximately 700 m of stone toe bank protection, and planting about 3,000 willow sprouts	$165,000	$12,132

[1] Personal communication, Mr. Phil Haskins, U.S. Army Corps of Engineers, Vicksburg, MS.

METHODS

Effects of restoration on channel boundaries were quantified by surveying channel thalwegs and cross-sections during 1991-92 and again in 1995. Bed sediments were grab-sampled at the center and quarterpoints of 12 transects across the baseflow channel of each stream during 1991 and again in 1994. Physical habitat data were measured semiannually (spring and fall) for four years using methods described by Shields et al. (1993b, 1994, 1995a). Counts of living and dead willow posts were made one year after planting. Survival of willow sprouts was assessed visually.

Fish were collected in spring and fall concurrently with physical data using a backpack-mounted electroshocker. Four 100-m stream subreaches within each 1 km study reach were fished for approximately 6 minutes (mean = 388 sec, std dev = 168 sec) of electric field application. Fishes longer than about 15 cm were identified, measured for total length, and released. Smaller fish, and fish that could not be identified in the field were preserved in 10 percent formalin solution and transported to the laboratory for identification and measurement. Water temperature, pH, dissolved oxygen, and conductivity were measured when fish were sampled.

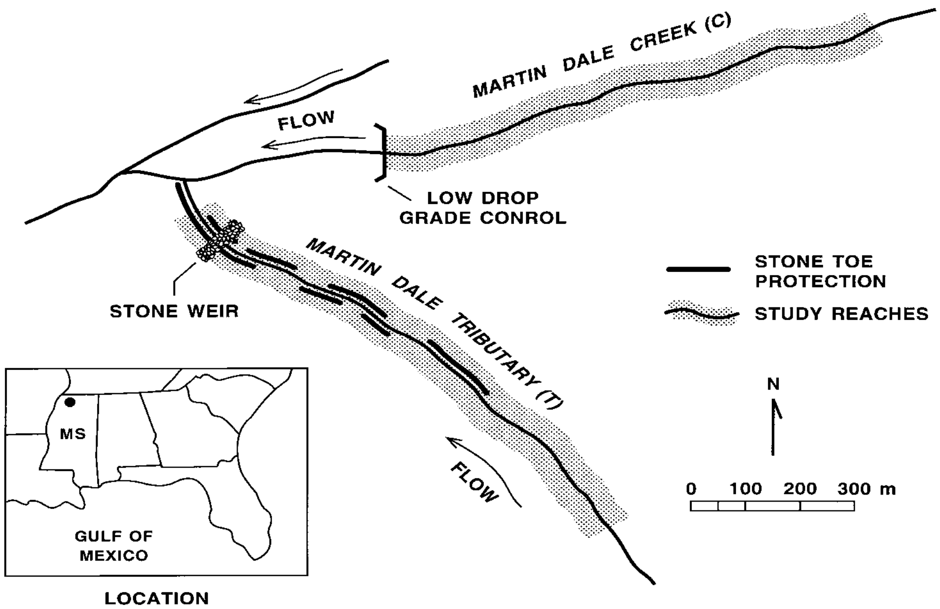

Figure 1. Study site locations.

Figure 2. Drop structure, C.

Figure 3. Stone weir, T.

Figure 4. Stone toe, T.

Figure 5. Willow posts, C.

RESULTS

Thalwegs were horizontally stable during the periods between channel surveys. However, thalweg profiles were dynamic, with up to 1 m of aggradation occurring upstream of the C drop structure (Figure 6). Comparison of 1995 and 1985 (Simons, Li and Associates, 1987) C thalwegs revealed that average slope was reduced from 0.0027 to 0.0021 by deposition above the drop structure and erosion further upstream. Aggradation upstream of the stone weir on T also extended about 400 m upstream, but was less uniform, ranging from 0 to 60 cm (Figure 7). In the aggraded reach, thalweg slope was reduced from about 0.002 to about 0.001, but no change was observed in thalweg elevations or slope upstream of the aggraded reach.

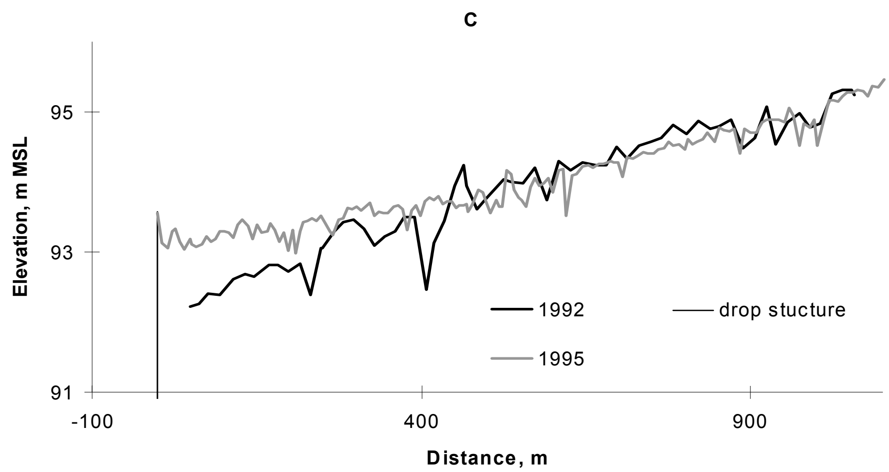

Figure 6. Thalweg profile, site C. Drop structure placed late in 1992.

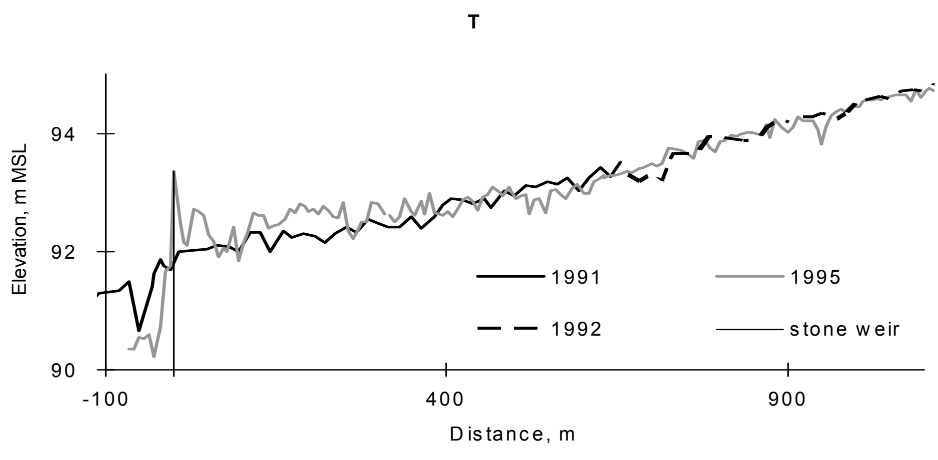

Figure 7. Thalweg profile, site T. Stone weir placed in summer, 1991.

Bed material size was unchanged following restoration: in both streams, median size ranged from about 0.1 to 0.8 mm, and hard clay outcrops were common. Gravel was absent.

Seven of the eight measured baseflows in T were greater (3 to 32 times) than those in C. Discharges in T ranged from 0.025 to 0.060 $m^3\ s^{-1}$, while those in C were only 0.002 to 0.056 $m^3\ s^{-1}$. Water width, depth, and velocity measurements were not normally distributed, so median values for each site were compared using a Kruskal-Wallis one way ANOVA on ranks. Time was used as the independent variable, and differences in medians were found to be significant in all cases ($p < 0.0001$) except for T width ($p = 0.53$). Median water surface widths increased from 4.5 m to 6 m for C but fluctuated from 3 m to 6 m without apparent trend along T. Water depths in both channels were extremely shallow, but median values generally increased over the period of observation from less than 10 cm to more than 20 cm. Velocities declined over the same period, with median values decreasing from about 4 to 6 cm s^{-1} to 2 to 3 cm s^{-1}. T velocities were always greater than C velocities, as would be expected from the differences in discharge. The percent of habitat classified as "pool" (arbitrarily defined as depth > 30 cm and velocity < 10 cm s^{-1}) increased from less than 5% to more than 30%, with the greatest increase along T (Figure 8). Most pool additions occurred upstream of the weirs and adjacent to stone toe.

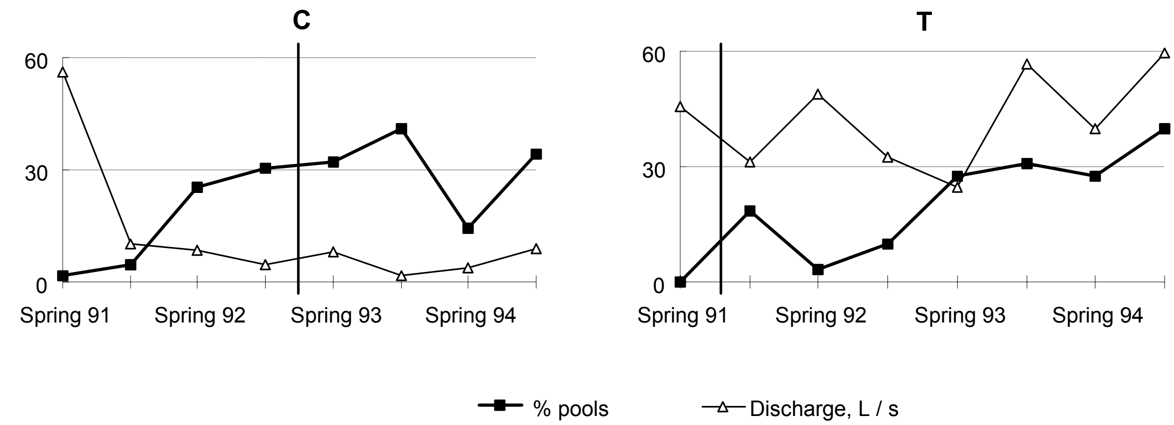

Figure 8. Discharge and availability of pool habitat versus time. Vertical lines indicate dates construction was completed. Fall 92 pool data for C reflect influence of temporary diversion dam placed during construction.

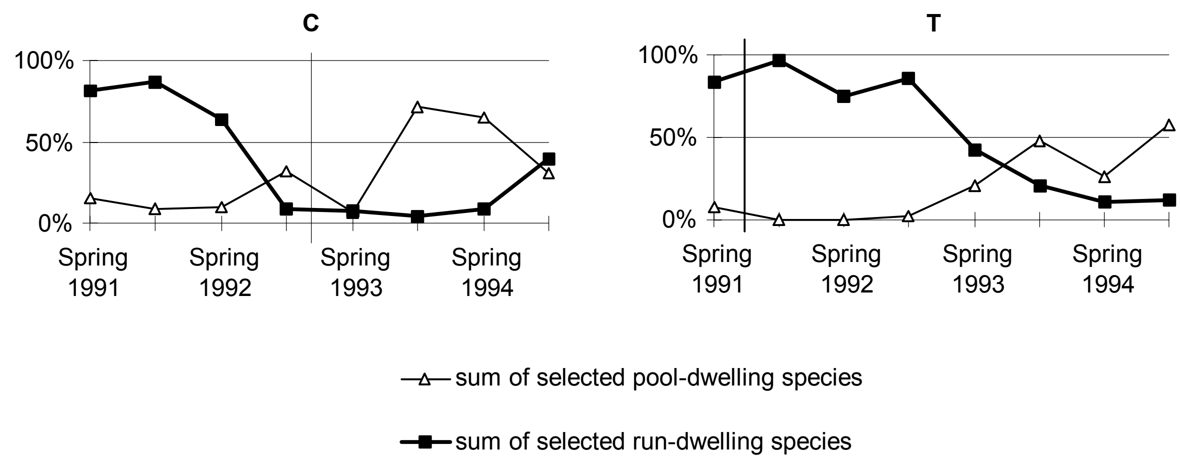

Figure 9. Relative abundance of selected fish species versus time. Pool species are bluegill (*L. macrochirus*), green sunfish (*L. cyanellus*), creek chubsucker (*E. oblongus*), and yellow bullhead (*A. natalis*). Run species are Yazoo shiner (*N. rafinesquei*), blacktail shiner (*C. venusta*), and bluntface shiner (*C. camura*). Vertical lines indicate dates construction was completed.

The frequency distribution of bed types varied with current and antecedent conditions throughout the period of observation but was always dominated by sand (~50 to 70%). Clay comprised ~30 to 40% of the bed surface. However, following restoration, stone riprap comprised 2 to 10% of the subaqueous bed along T, and detritus increased from about 1% to a range of 3 to 7%. Detritus and woody debris became slightly more common along T. Changes were less pronounced along C, with sand becoming slightly more common (increasing from about 60% to 65%) and clay less common (declining from 39% to 31%).

Woody debris was scarce along both streams, but increased along C after placement of willow posts. The row of posts closest to the stream was quickly surrounded by water as the base flow channel migrated, and the posts furnished limited debris habitat. Fewer than 10% of posts survived 12 months due to infertile soils and competition by kudzu. Survival of willow sprouts on T was even lower, perhaps because they were planted during the summer. One to two beaver dams 50-75 cm high were found along both channels during periods of prolonged low flow. Shade canopy was nearly absent along C during the entire study, and declined slightly along T where trees were removed from the top of about 200 m of bankline prior to stone toe emplacement. Water quality data indicated conditions were suitable for aquatic life. Stream C tended to be about 2 Centigrade degrees warmer than T.

During the study, 10,056 fishes representing 23 species and six families were collected. Biomass ranged from about 0.4 to 4 kg per collection and averaged about 2 kg. Smaller fishes dominated all collections, with no individual longer than 24 cm or weighing more than 107 gm. Catch per unit effort (CPUE) declined from about 30 to 80 fish min^{-1} the first year to 10 to 20 fish min^{-1} the fourth year, reflecting reduced sampling efficiency as depths increased, and a shift in community structure away from large numbers of cyprinids. However, correlations of CPUE with median depth were not statistically significant ($p > 0.14$). The variance in CPUE between streams was not significant, but variance with time was significant ($p = 0.01$, two-way ANOVA). Biomass per unit effort did not vary significantly between streams or through time.

Species richness (number of species per collection) varied from 8 to 11 for T and from 5 to 11 for C without any trend. Differences between streams and sampling dates were not significant ($p > 0.56$). However, pronounced trends were observed in relative abundance at the family level. Cyprinids, principally the Yazoo shiner (*Notropis rafinesquei*) which prefers shallow, sandy habitats (Suttkus, 1991) dominated all collections, but became much less dominant in later years. Pool-dwelling catostomids and centrarchids increased in relative abundance as run-dwelling cyprinids declined (Figure 9). These changes were more pronounced for T than C. Median lengths of selected species known to grow longer than 10 cm were plotted versus time; no trends were evident.

DISCUSSION AND CONCLUSIONS

The difference in base flows and temperatures for C and T reflects greater groundwater inflows to T, where artesian inflows (“sand boils”) were often observed in the bed. Aquicludes underlying many northwest Mississippi watersheds are not conformable with surface topography, leading to groundwater transfer and widely varying baseflows between adjacent watersheds (Grissinger et al. 1982). The similarity of the geometry of the two channels confirms that channel shape and size are defined by geomorphic and hydraulic factors independent of groundwater contributions.

The development of pool habitats along both streams is a positive sign, and attendant shifts in fish species composition may presage more positive biological developments. On the other hand, more than half of the increase in pool habitat occurred immediately upstream of the weirs, and these pools are rapidly being eliminated by sedimentation.

Previous restoration studies of warmwater streams damaged by channel incision have illustrated the positive effects of increasing pool habitat availability, riparian vegetation, and stony substrates (Shields et al. 1995a, 1995b, 1993a, 1993b). Results of these efforts are encapsulated in Table 2, and results of this study are presented in parallel form. The project described above was less successful than the others. We hypothesize that this was due to a combination of factors. First, initial habitat conditions at C and T were worse than for the other sites, as was evidenced by the low fish species richness and the dominance of Yazoo shiners (Shields et al., In Press). The absence of gravel substrate and the scarcity of woody riparian vegetation, woody debris, and stream-floodplain interaction evidently created stressful habitat conditions. Second, the study reaches are distant from habitats that could provide colonizing organisms. Third, restoration efforts were primarily standard channel stabilization practices applied without consideration of habitat goals. The primary habitat feature, planting willow posts along C, was limited to a

500 m reach and was unsuccessful. Previous studies have highlighted the superiority of discrete structures like spur dikes over continuous structures like stone toe for aquatic habitat restoration (Shields et al., 1995c, but see Shields et al. 1995d). Recovery of habitat resources in deeply incised low-order warmwater streams draining agricultural watersheds is likely to be slow and minimal without a more aggressive approach to addressing environmental goals in channel stabilization design. Bed stabilization using standard approaches does not yield dramatic improvements in upstream habitat quality.

Table 2. Results of Restoration of One km Reaches of Incised, Warmwater Streams in Northwest Mississippi

Stream	H	G	T	C
Reference	(Shields et al., 1993a, 1995a)	(Shields et al., 1995b)	this study	this study
Watershed, km^2	91	21	14	12
Restoration measures	16 stone spur dikes, 3,400 willow posts [1]	18 stone weirs, 1,400 willow posts [1]	1 stone weir, stone toe protection, 3,000 willow sprouts	1 drop structure, 4,300 willow posts
length of observation before/after restoration (yr)	1/2	2/<1	1/3	2/2
Physical response, change in pool habitat[2]	increased from 3 to 14%	increased from 11 to 61%	increased from 0 to 40%	increased from 5 to 34%
Biological (fish) response	species richness increased from 14 to 19, median fish length (all species) increased from 3.6 to 5.5 cm	Cyprinids declined from 74% to 32% of numerical catch, median length of five selected species increased	Cyprinids declined from >90% to <50% of numerical catch.[3]	Cyprinids declined from >80% to <60% of numerical catch. [3]

[1] Study areas were immediately upstream from low drop structures placed prior to restoration.
[2]Arbitrarily defined as all area with depth >30 cm (> 20 cm for H) and velocity < 10 cm s^{-1}
[3]Species richness, abundance, and fish size apparently unaffected

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