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STREAM HABITAT RESTORATION USING SPURS ADDED TO STONE TOE PROTECTION

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ABSTRACT

Longitudinal stone toe is one of the most reliable and economically attractive approaches for stabilizing eroding banks in incised channels. However, aquatic habitat provided by stone toe is inferior to that provided by spur dikes. In order to test a design that combined features of stone toe and spurs, eleven stone spurs were placed perpendicular to 170 m of the existing stone toe in Goodwin Creek, Mississippi. Physical habitat response was evaluated using two experiments: the treated reach and an adjacent comparison reach were monitored over four years, and the treated reach was compared with seven untreated reaches on a single date three years after construction. Overall results indicated that spur addition resulted in modest increases in baseflow stony bankline, water width and pool habitat availability, but had only local effects on depth.

INTRODUCTION

Incised sandbed streams typically contain extremely degraded aquatic habitats. In general, aquatic habitat conditions are characterized by a dominance of shallow, sandy runs, little woody debris, and sparse riparian vegetation (Shields et al., 1994). Pool habitat, in particular, is often in short supply. The overall goal of stream habitat restoration in incising channel systems should be to accelerate natural processes of channel equilibrium recovery, riparian revegetation, and stream-floodplain interaction (Van Haveren and Jackson, 1986; Shields et al., 1992). Habitat structures and plant materials used in these situations must often be maintenance free and durable enough to withstand high energy and elevated sediment transport conditions. Specific objectives for the restoration structure we tested were to increase pool habitat availability and submerged structural cover by using stone to emulate functions of large woody debris formations common in nonincised sandbed streams (Shields and Smith, 1992; Shields et al. 1994).

Incised channels are often stabilized by placing a ridge of stone along the toe of eroding banks. This windrow-like structure, referred to as longitudinal stone toe, is one of the most reliable and economically attractive channel stabilization approaches (Shields et al., 1995a; Spitz et al., 1990). Stone is placed in a ridge with a triangular or trapezoidal cross section with sides at the angle of repose. Crest elevations are not specified, but the rate of application per unit length is normally set between 3,000 and 6,000 kg m^{-1}. Previous studies of warmwater fish populations in incised channels stabilized by stone toe and stone spurs (transverse dikes) have revealed that aquatic habitat provided by stone toe is inferior to that provided by dikes (Knight and Cooper, 1991). Dikes tend to create deeper pools and increase habitat diversity. To test and refine a design with the advantages of both toe and dikes, eleven stone spurs were added to existing longitudinal stone toe in Goodwin Creek, an

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incised channel in northwestern Mississippi. The incremental cost for adding spurs was minimal, requiring only 16% more stone than was used for toe. Variables describing aquatic habitat at baseflow were monitored for four years in reaches containing the toe with spurs and in reference reaches with standard stone toe. This study presents results of one aspect of a multidisciplinary project evaluating the restoration structure design.

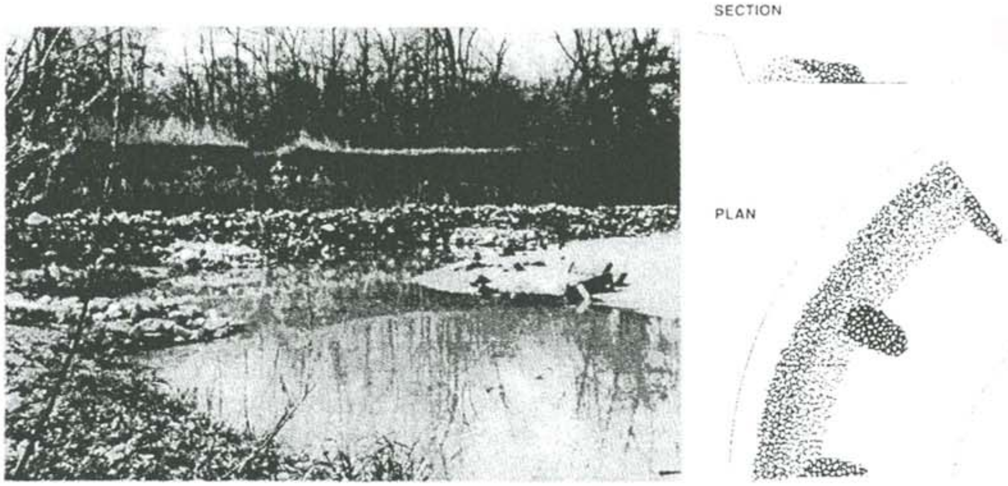

Figure 1. Conceptual drawing of spurs (darker rock) added to toe protection in Goodwin Creek

STUDY SITE AND SPUR DESIGN

Goodwin Creek drains a fourth-order northwest Mississippi watershed of 21 km^2 located along the bluffline of the Mississippi River Valley. The watershed is hilly, with a total relief of about 60 m. Ridges are capped with loess deposits, and valleys are filled with alluvium derived from post-European settlement erosion overlying a complex of erodible stratigraphic units. The main channel of Goodwin Creek was channelized (straightened) prior to about 1940 and experienced severe incision between 1960 and 1980. Channel width ranged from 20 to 70 m and depth from 4 to 5 m at the time of this study. Bed material was a mixture of sand and gravel; ranges for D_{50} and D_{84} (D_x is the size $\geq$ x% of bed material by weight) were 0.4 to 10 mm and 0.6 to 18 mm, respectively (unpublished data, National Sedimentation Laboratory; Kuhnle, 1996). A grade control structure was placed 1 km downstream of the study reach ca. 1980, and stone toe and groins were placed in a 3 km reach encompassing the study reach during 1990 and 1991. During this work, the study reach was laterally stable and slightly aggradational. Bars and berms appeared to be slowly building to create a two-stage cross section typical of the lower reaches of incising watersheds (Simon, 1989).

Although the study reach was flanked on one side by cotton fields, watershed land use was primarily forest, pasture, and idle lands. Mean annual rainfall during 1982-1991 was 1,460 mm, and mean annual runoff was 537 mm or about 0.4 m^3s^{-1} (Bingner et al., 1996). Available data indicated that water quality was adequate for maintenance of healthy communities of aquatic organisms. However, sediment loads were elevated by erosion of channel beds and banks upstream of the study reach, and flow-weighted mean total sediment load was 110 tons day^{-1}, or about 3,500 mg L^{-1} (1982-1991, Bingner et al., 1996).

Eleven stone spurs were placed perpendicular to 170 m of the existing stone toe (Figure 1). Five were placed in a nearly straight reach (radius = 95 m), and six were placed in a sharp bend (radius = 30 m). Some workers have advocated placing spurs on point bars for habitat enhancement (e.g., Wesche, 1985), but this configuration was avoided due to concern that it might lead to channel instability if the spurs were flanked. Flanking could be avoided by building spurs with long root segments, but this would increase stone volume requirements and cost. Spurs were spaced at roughly twice the average baseflow channel width (~ 7 m) with lengths roughly 40% of the average width. Crests were level, 2 m wide, and 1 m above the bed, or about 60 cm above baseflow water surface elevation. Stone size ranged from 0.2 to 450 kg, with 50 to 85% of the stones weighing less than 36 kg. When spurs were built, dormant black willow (*Salix nigra spp.*) posts, 1.5 m long by 8 to 30 cm diameter, were planted within 5 m of the water's edge on the sandbar opposite the spurs in order to restore woody riparian vegetation.

METHODS

Physical habitat variables (baseflow width, depth, velocity, and bed type) were monitored before and after toe addition. Two experiments were conducted:

1. Habitat in 100-m segments of the treated reach and a comparison reach 200 m upstream were sampled ten times over 4 years (1992-1995) at base flow. Concave banks of both reaches were protected with stone toe placed in 1991, and spurs were added to the treated reach in 1993. The comparison reach was not sampled prior to spur construction. Data were collected from at least 25 points along five transects from each reach at baseflow during Spring (April-early June) or Autumn (September-early October). Water surface width was measured with a tape at each transect. Transects were 20 m apart, and measuring points were located at intervals equal to 0.2 times the water surface width along each transect. At each point, water depth was measured with a wading rod, velocity was measured at 0.6 depth using a Marsh-McBirney current meter (brand names provided for information only), and bed type was visually classified. Depth and velocity measurements were used to compute pool habitat availability (percent of measurement points with depth > 30 cm and velocity < 10 cm s^{-1}). Discharges were measured using wading rod and current meter. Fish and benthic macroinvertebrates were sampled concurrently with physical habitat, but data analysis is presently incomplete. The effect of spurs on shoreline length was determined using survey data collected with a total station one year after spur placement.
2. On April 26, 1996, physical habitat variables were measured adjacent to two stone toe structures with added spurs and seven stone toes without spurs located just upstream. All structures were within a 1-km stretch. The treated and comparison reaches from experiment one were located within this stretch. Stone toe was placed in 1991, and spurs were added in 1993. At each structure, water surface widths were measured at 6 transects spaced 10 m apart, and depths were measured along each transect at points 50 cm from each water's edge and at one-third, one-half, and two-thirds of the water width from the left bank. Four months later, the thalweg was surveyed in the stretch containing the 9 sampled structures, and local slopes were computed. Bend radii and top bank widths were measured from a detailed topographic map produced for construction plans.

RESULTS

Mean water width and pool habitat availability increased by 16% and 10% in the treated reach following spur addition, but mean depth and velocity showed little change (Table 1). Changes were greater in the immediate vicinity of the spurs, with mean depth increasing from 30 cm before toe addition to 49 cm two years later, and maximum depth increasing from about 72 cm to 100 cm. Patterns of scour and deposition following spur addition indicated that the bed reached an equilibrium condition within no more than two years. Depths, widths, and pool availability in the comparison reach were inferior to the treated reach, both in terms of means and in terms of the diversity of available habitats. Great changes in physical habitat characteristics occurred in the autumn each year due to backwater effects of beaver dams downstream (Figure 2), and data from these periods were excluded when calculating means shown in Table 1. Habitat conditions in the comparison reach were relatively static during the study (Figure 2). Spurs increased the length of stable, stony shoreline in the treated reach by 24% . Little permanent change in substrate character occurred during the study, but dense carpet-like growths of periphyton were common in both reaches each year during autumn. Gravel was more common in the comparison reach, where bed slope was greater. Willow posts planted in the point bar opposite the spurs suffered ~50% mortality during the first two growing seasons, but surviving posts produced dense foliage and increased the fraction of sandbar margin supporting vegetation from 0 to 80%.

Table 1. Physical aquatic habitat conditions at similar discharges before and after stone spur addition based on data collected once each Spring and Autumn 1992-1995.

	Before Spur Addition	After Spur Addition	
	Treated Reach	Treated Reach	Comparison Reach
Mean Instantaneous Discharge during data collection, L s^{-1}	43	49	49
Mean (std) water depth, cm	40 ± 21	41 ± 23	20 ± 15
Mean (std) water width, m	6.9 ± 1.2	8.0 ± 2.5	6.2 ± 7.8
Mean (std) velocity, cm s^{-1}	2 ± 2	2 ± 2	5 ± 2
Percent pools	58	64	18%
Percent bed covered with sand:gravel	32:24	38:37	24:54
Length of riprap bankline, m	100	124	60

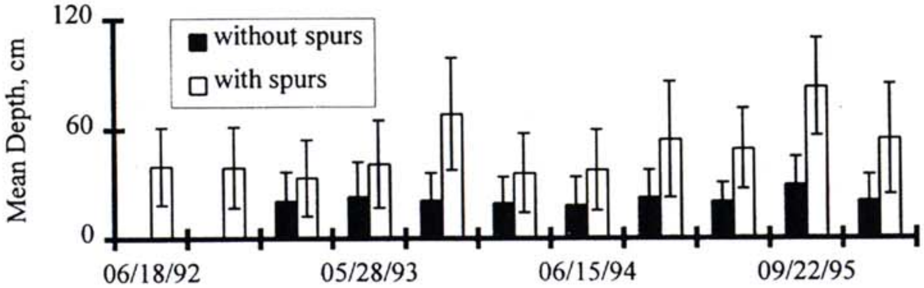

Figure 2. Mean and standard deviation (error bars) of water depth adjacent to stone toe with and without spurs. Toe was constructed in 1991 and spurs were placed in March, 1993.

Three years after spur placement, means of water width and depth at baseflow adjacent to toe with spurs were roughly twice as great as the means for seven toe structures with no spurs.

However, thalweg slope adjacent to structures with spurs was five times less than the mean of slopes adjacent to toe structures without spurs(Table 2 and Figure 3). Pearson correlation coefficients indicated that mean water width and depth were not significantly correlated ($r^2 < 0.48$, $p \geq 0.04$) with thalweg slope or with bend radius divided by top bank width (Figure 3).

Table 2. Mean (standard deviation) values for April 26, 1996 (Discharge = 116 L s^{-1})

Variable	Two stone toe segments with spurs added	Seven segments of standard stone toe
Water depth, cm	54.6 ± 30.2	24.6 ± 18.9
Water width, m	10.8 ± 2.5	5.7 ± 1.8
Bed slope	0.001	0.005 ± 0.003
Bend radius/top bank width	2.8 and 0.6	2.2 ± 1.6

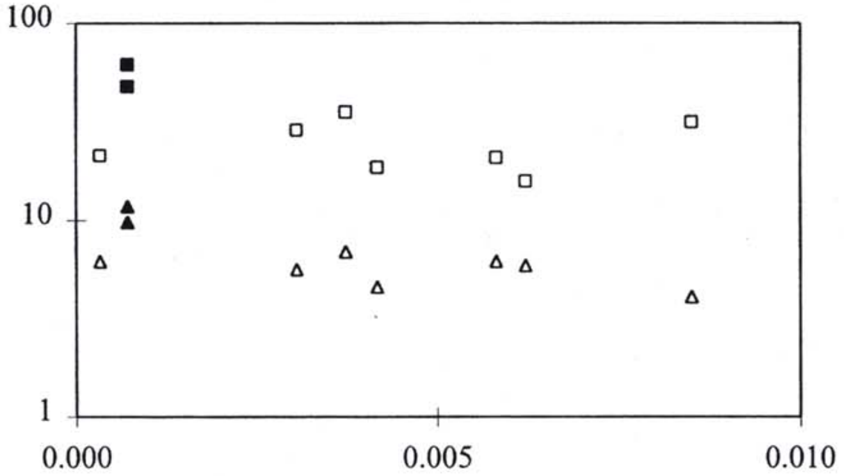

Figure 3. Mean water depth in cm (squares) and water width in m (triangles) versus thalweg slope adjacent to stone toe with (dark symbols) and without (open symbols) spurs in 1996.

DISCUSSION AND CONCLUSIONS

Stone toe is often selected as a bank stabilization alternative for reasons of economy, efficiency, and reliability. However, discontinuous forms of protection have much to offer with respect to restoring more natural physical conditions. The design tested here is an attempt to obtain the best features of both types of structure. Physical response to addition of spurs to toe was modest, consisting primarily of increased water surface width and pool habitat availability. However, the benefits of adding complex structure in the form of the spurs and willow posts which furnished hiding cover and shelter from high velocities should not be overlooked. As the baseflow channel widened, it migrated into the posts planted closest to the stream, creating a small (0.1-1.0-m-wide) aquatic zone featuring structural and overhanging cover.

Three years after construction, the deep pool habitat adjacent to the spurs contrasted strongly with shallow conditions found along stone toe without spurs (Table 2). The lower bed slopes adjacent to the toes with spurs make it difficult to attribute the differences in flow width, depth, and velocity solely to spur addition. Full evaluation of the spurs should include consideration of biological response, which will be possible once ongoing laboratory and data analyses are complete

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