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Response of fishes and aquatic habitats to sand-bed stream restoration using large woody debris *

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Abstract

Effects of habitat rehabilitation of Little Topashaw Creek, a sinuous, sand-bed stream draining 37 km^2 in northwest Mississippi are described. The rehabilitation project consisted of placing 72 large woody debris structures along eroding concave banks and planting 4000 willow cuttings in sandbars. Response was measured by monitoring flow, channel geometry, physical aquatic habitat, and fish populations. Initially, debris structures reduced high flow velocities at concave bank toes, preventing further erosion and inducing deposition. Physical response during the first year following construction included creation of sand berms along eroding banks and slight increases in base flow water width and depth. Fish collections showed assemblages typical of incising streams within the region, but minor initial responses to debris addition were evident. Progressive failure of the structures and renewed erosion were observed during the second year after construction.

Introduction

Warmwater streams in the Southeastern U.S. have remarkably high levels of biodiversity and are thus important ecological resources. However, many of these streams are severely degraded by erosion and sedimentation linked to human activities. Headward-progressing channel incision in the upper parts of watersheds and attendant downstream sedimentation is endemic within the region. Annual sediment yield is $\sim$1000 t km^{-2}, or about an order of magnitude more than the national average (Shields et al., 1995). Physical aquatic habitat quality is poor in incised reaches, usually exhibiting a surplus of shallow water depths and shifting, sandy substrate and a deficit of woody debris, pool habitats, and stable substrates (Shields et al., 1994). In incising channels, large woody debris (LWD) is input to channels by bank failure processes, and in-channel debris accumulations are associated with sediment retention (Downs & Simon, 2001), in some cases reversing incision (Shields et al., 2000). LWD is an important component of aquatic habitat in warmwater streams, retaining particulate organic matter (Bilby & Likens, 1980), providing substrate for biomass production by benthic macroinvertebrates (Benke et al., 1985), and fostering higher levels of invertebrate species richness and abundance (Cooper & Testa, 1999). LWD creates zones of flow acceleration and deceleration that provide higher levels of physical diversity (Shields & Smith, 1992), which are important to fish (Warren et al., 2002). Native species are likely adapted to high debris densities typical of North American streams prior to European settlement when LWD was abundant due to beaver (*Castor canadensis*) activity and the absence of human actions to remove debris and old-growth forests. We hypothesized that recovery of physical aquatic habitat and fish community structure could be accelerated by placing LWD structures in an incised, warmwater stream.

Study site

A site was selected along 2 km of Little Topashaw Creek, a fourth-order stream (1:24 000 topographic

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Figure 1. Reaches of Little Topashaw Creek, Mississippi sampled for this study. (a) Upstream. (b) Restored reach showing large woody debris structures on outside of bend 1 year after construction. (c) Downstream.

map) in north central Mississippi draining about 37 km^2 (Fig. 1). Criteria used in site selection included rapid bank erosion, an abundant supply of sandy bed material from upstream, nearby sources of native plant and animal colonists, and an advanced stage of incised channel evolution (Simon & Darby, 1999). The single-thread, meandering channel had an average sinuosity of 2.1, an average slope of 0.0025, an average width of 33 m, and an average depth of 3.6 m. Channel bed materials were primarily 0.2–0.3 mm sand. Channel morphology was extremely dynamic, typical of incising channels in the region. Historical air photos suggest mean channel width increased by a factor of 4–5 between 1955 and 1997. Surveys of 14 cross-sections before and after a flow of 55 m^3 s^{-1} (peak stages reached mid-bank elevation) that occurred three months prior to our addition of LWD indicated an average increase in cross-sectional area of 6% (std. dev. = 7%) with bank retreat as great as 7.6 m (mean = 2.0 ± 2.6 m). This event triggered 60 m of upstream migration of a 0.6-m high headcut and produced two chute cutoffs across point bars.

Addition of large woody debris

Large woody debris structures were designed as described by Shields et al. (2001) and constructed on concave, eroding banks using either woody debris (∼10%) or living trees (∼90%). Living trees were ≥0.20 m diameter at breast height, an average of 6.7 ± 3.2 m long, and were harvested with root balls and crowns intact. The finished project consisted of 72 structures built with 1168 trees obtained by clearing 3.4 ha. Placement of structures produced an order of magnitude increase in woody debris loading within the 2-km-long project reach (Fig. 1b). Logs placed perpendicular to the flow direction (‘key members’) were ∼9 m long and were partially buried in trenches excavated into banks when bank slopes were gradual enough to permit trench excavation. About 52% of the logs used had intact rootwads, and about 30% of the rootwads retained a ball of soil. To provide additional structural stability during high flows, metal earth anchors were cabled to 58 (80%) of the completed structures. About 4000 willow (*Salix nigra*) cuttings were planted on point bars and in sediment deposits adjacent to selected debris structures using a water-jetting technique. Including willow planting, costs for construction were approximately US$88 m^{-1} channel treated, roughly 20–50% of costs for recent construction of traditional stone stabilization projects in the region.

Methods

Effects of debris addition on physical habitat quality and fish were quantified by semiannual (June and late September or early October) sampling of selected subreaches at base flow during 1999–2001 inclusive. Although debris structures were constructed during July–August 2000 and willows were planted during January–February 2001, the 1999–2000 data were classified as 'before debris addition,' and the 2001 data, 'after debris addition.' The October 2000 data were influenced only minimally by the debris structures because a prolonged drought prevented the structures from exerting any effects on channel morphology until November 2000.

Five, 150-m-long subreaches were sampled: two were downstream of the modified region in a reach geomorphically similar to the treated reach, two were within the modified reach, and one was in a straight, relatively narrow channel immediately upstream. Within each reach, physical habitat variables were measured along 10 transects placed at 15-m intervals. Along each transect, water depth and substrate were recorded at a point 25 cm from the left bank and at four to six additional points spaced at equal intervals. Water surface width was measured with a tape. Discharge was computed using depth and velocity data collected using a wading rod and an electromagnetic current meter. Fish were sampled concurrently with physical habitat using a backpack-mounted electroshocker as described by Shields et al. (1998).

Effects of debris addition on flow patterns that contribute to retention of fine particulate organic matter were quantified using a tracer dye experiment 9 months after construction. Discharges during the dye experiment ($\sim$0.3 m^3s^{-1}) were above base flow, but well below high flow levels. Slug-injections of Rhodamine WT dye were made upstream and downstream from the treated reach, and passage of the resulting dye cloud was documented by periodically collecting grab samples for several hours 1.3–1.7 km downstream from the injection points. The reach traversed by the downstream dye cloud had similar flow resistance characteristics (bed slope, channel cross-section, bed material size, sinuosity) to the treated reach except for the presence of the debris structures and the attendant features created in the channel bed by scour and deposition adjacent to the structures. The downstream study was completed first to avoid interference from the upstream injection. Time-concentration curves were normalized by dividing concentrations by the mean concentration and the time values by reach length.

Effects of debris on aquatic habitats during high flows were observed using acoustic-Doppler depth-velocity loggers as described by Shields et al. (2001). Loggers were secured above the stream bed along a transect across the channel within a bend where debris structures had been placed on the concave bank and within an unmodified, eroding bend with similar geometry to the modified bend. Depth and velocity measurements were recorded every 5 min during major runoff events. Debris effects on erosion and deposition were quantified using cross-section and thalweg surveys conducted before and during the first year after construction.

Results and discussion

Physical habitat data collected at similar discharges before (Spring = 0.048 m^3s^{-1}, Fall = 0.018 m^3 s^{-1}) and after (Spring = 0.043 m^3 s^{-1}, Fall = 0.012 m^3 s^{-1}) construction showed that scour adjacent to the woody debris structures and beaver dams resulted in deeper ($\sim 2\times$) and slightly wider aquatic habitats at baseflow relative to pre-construction conditions (Fig. 2). Untreated reaches up- and downstream became shallower or were unchanged. Water depths were greater in the upstream reach than within the treated reach or downstream due to the presence of several upstream-migrating nickpoints. The upstream reach was typical of a transitional phase that is a precursor of the inferior conditions downstream (Shields et al., 1998). The treated reach became significantly deeper following debris addition ($p < 0.003$, Mann–Whitney rank sum test) while Fall depths were shallower in comparison reaches ($p < 0.002$). Trends in water surface width were not as clear (Fig. 2). However, mean water width in the treated reach increased from 3.0 m in Fall 1999 (before addition of woody debris structures) to 5.0 m in the Fall of 2001. The dye experiment showed that debris structures increased flow resistance, moderated velocities and increased retention time (Fig. 3). Mean velocity for the treated reach was 17 cm s^{-1}, but 29 cm s^{-1} for the downstream reach. Although the mean velocity was less in the reach treated with debris, dispersion was nearly the same for both reaches, as evidenced by the width of the dye curves in Fig. 3. Acoustic-Doppler loggers recorded velocity magnitudes within debris structures that were only 50–60% of those measured in the channel adjacent to the structure or in the bend without debris structures (Fig. 4). Velocities within the debris structure were generally less than 30 cm s^{-1}, and usually below 10 cm s^{-1}, even during events that were large enough to produce

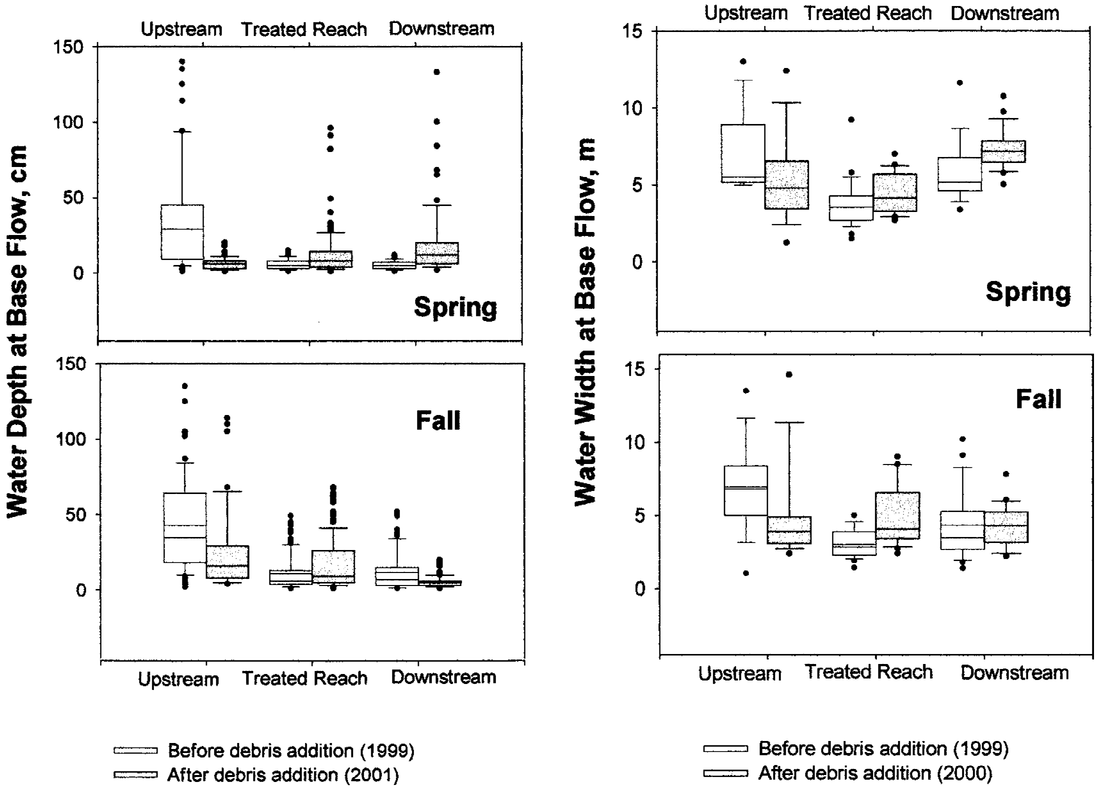

Figure 2. Distribution of water depth and width before and after addition of woody debris to restored reach in late summer 2000. The boundary of each box closest to zero indicates the 25th percentile, horizontal lines within the boxes mark the mean and median, and the boundary of each box farthest from zero indicates the 75th percentile. The error bars above and below the box indicate the 90th and 10th percentiles. Outliers are shown as point symbols.

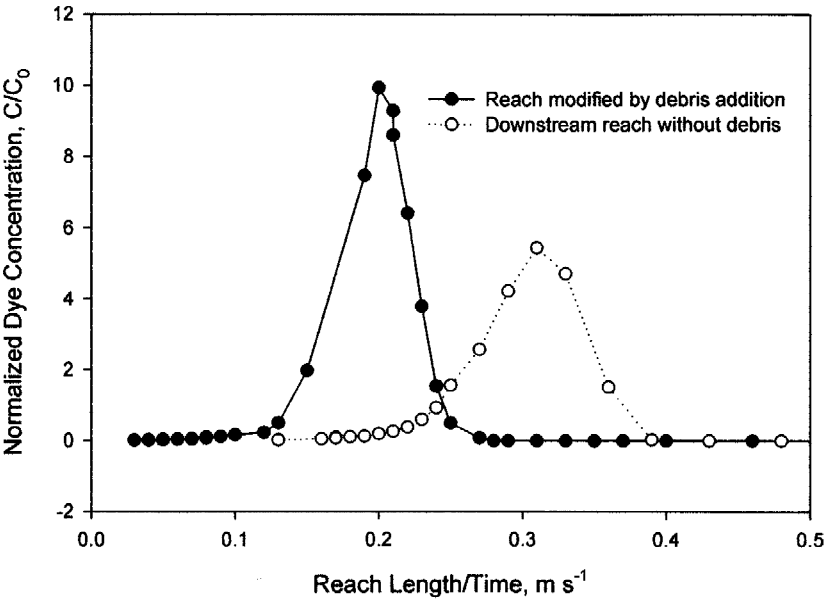

Figure 3. Tracer dye concentration curves following slug injection of fluorescent dye. x-Axis represents reach length divided by time.

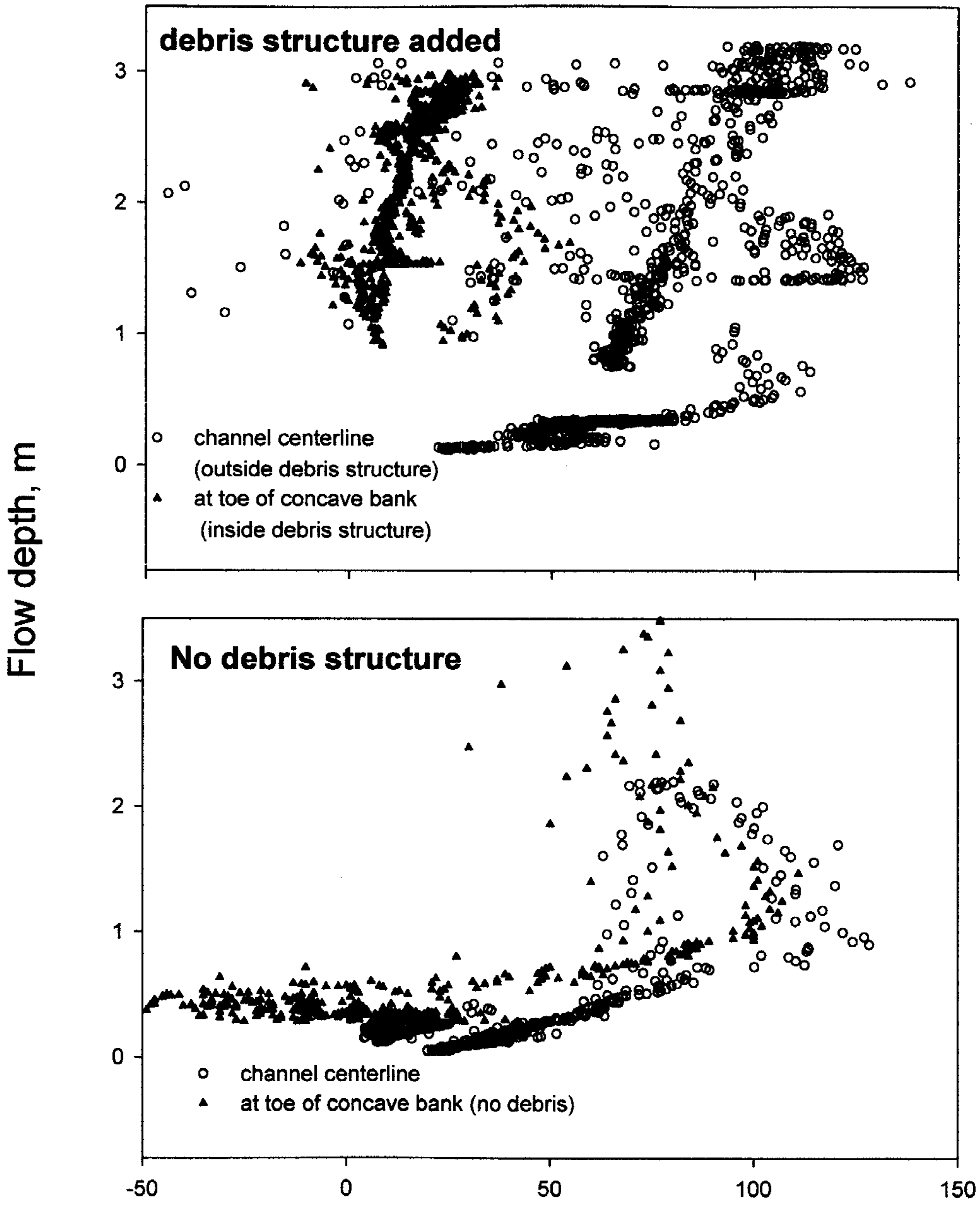

Figure 4. Effect of large woody debris structures on high flow velocities. Velocity measured by acoustic-doppler loggers is plotted on the x-axis against simultaneous records of flow depth plotted on the y-axis for locations within bends with (top) and without (bottom) debris structures along the outside of the bend.

Table 1. Summary of electrofishing catch, Little Topashaw Creek, Mississippi. Boldface values are significantly greater than before construction means for the same reach ($p = 0.05$, two-way ANOVA). Mean values are given ± standard deviation

Quantity	Upstream reach		Reach modified by debris addition and willow planting		Downstream reach	
	Before construction	After construction	Before construction	After construction	Before construction	After construction
Mean no. of fish per sample	74 ± 79	80 ± 20	129 ±72	132 ±106	139 ± 75	213 ± 150
Mean biomass (g per sample)	262 ± 155	280 ± 110	149 ± 78	187 ± 74	166 ± 95	323 ± 208
Total no. of species	12	12	18	16	16	16
Mean no. of species per sample	6.8 ± 0.8	8.0 ± 1.4	6.0 ± 2.7	**9.3± 2.2**	5.4 ± 2.8	**11.0 ±0.0**
Centrarchids (% of total catch by number)	18	16	3	8	6	5
Largest fish (length, cm)	17	17	12	17	20	13

[1] The expression 'sample' here refers to a collection from a 150-m long sampling reach.

flow depths >3 m. Events with depths of only ~1 m produced velocities >100 cm s^{-1}in the bend without debris structures. Habitat preferences of centrarchids and ictalurids generally lie within the 10–50 cm s^{-1} range (e.g., Stuber et al., 1982, McMahon and Terrell 1982).

Changes in fish population density, average size, and community structure (Table 1) mirrored trends observed in other incised stream ecosystems (Shields et al., 1997, 1998). Collections were dominated by cyprinids (90% of numbers, 64% of biomass) and centrarchids (6% of numbers, 27% of biomass), but the relative dominance of cyprinids was inversely related to the mean water depth ($r^2 = 0.30$, $p = 0.002$) (Fig. 5). Opposite trends were indicated for numbers and biomass of the centrarchids with $r^2 = 0.59$ and 0.54, for the association between percent of numerical and biomass catch, respectively, and mean depth ($p < 0.00005$). Addition of pool habitat following debris addition increased the fraction of numbers and biomass comprised by centrarchids in the treated reach from 3 to 10% and from 13 to 23%, respectively. Species richness was unaffected by debris addition, but the average number of species per 150-m reach increased in all three zones (upstream, within the treated reach, and downstream) following debris addition (Table 1). Relatively large changes in fish numbers, biomass, and species richness observed in the downstream reach (Table 1) may have been due to export of benthic drift and organic matter from the treated reach. Three species typically associated with deeper habitats were captured in the treated reach following debris addition but not before (*Micropterus salmoides*, *Lepomis megalotis*, *Ictalurus punctatus*), and *M. salmoides* was found only in the restored reach. Although changes in the size of centrarchids were not statistically significant ($p > 0.16$, Mann–Whitney rank sum test) in any of the zones, only one of the 27 centrarchids captured in

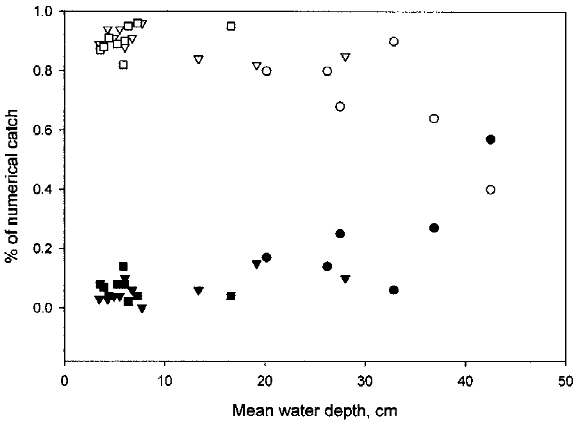

Figure 5. Response of cyprinids (white symbols) and centrarchids (black symbols) to changes in mean water depth. The percent of catch by number for upstream, restored, and downstream reaches are represented by circles, triangles, and squares, respectively. Thus white circles show the percent of numerical catch from the untreated upstream reach comprised by cyprinids, while black circles represent the centrarchids within the same samples.

the two years before debris addition was longer than 10 cm, but four of the 40 captured afterward were longer than 10 cm.

Stream bank erosion was initially checked by placement of the debris structures, and deposition of sand berms adjacent to steep, concave banks was conducive to stability during the first year following construction. However, many of these deposits were scoured away during high flows and attendant bed degradation occurring 16 and 17 months following construction, resulting in progressive failure (loss of woody materials) of ~30% of the structures and renewed erosion of banks.

Conclusions

Addition of LWD in the form of engineered structures produced marginal improvements in physical habitat quality in a rapidly incising sand bed stream. Fish community responses were less pronounced, but were consistent with previous observations of response to addition of pool habitats in incising warmwater streams. Progressive failure of the structures leaves the prospects for long-term ecological recovery in doubt.

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