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EFFECTS OF CHANNEL RESTABILIZATION ON HABITAT DIVERSITY, TWENTYMILE CREEK, MISSISSIPPI

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ABSTRACT

Twentymile Creek, a sand-bed stream draining a 450 km^2 catchment in northeast Mississippi, was channelized prior to 1910, in 1938, and in 1966. Straightening and enlargement in 1966 was followed by channel instability—rapid bed degradation (2–4 m) and cross-section enlargement by 1·4 to 2·7 times. Grade control structures (GCS) (weirs with stone-protected stilling basins) and various types of streambank protection were constructed along the channel in the early 1980s to restore stability. Other investigators have suggested that habitat recovery in incised, channelized streams is facilitated by construction of GCS because they create stable scour holes and promote natural formation of a low-flow channel flanked by vegetated berms. Effects of restabilization of Twentymile Creek on aquatic habitats were assessed in four ways. The fraction of the bank line covered by woody vegetation was mapped from aerial photographs taken in 1981 and 1985; physical habitat (depth, velocity, substrate, and cover) and fishes were sampled at base flow; and the existence and size of a low-flow channel was ascertained from cross-section surveys taken in 1980 and 1989. Woody vegetation, physical aquatic habitat, and fishes were also sampled from Mubby–Chiwapa Creek, a similar-sized unstable channel with no GCS. Physical habitat variables and fishes were sampled concurrently at five stations on Twentymile Creek, and four stations on Mubby–Chiwapa. Four of the five Twentymile stations were either above or below a GCS. Bank-line woody vegetation cover increased 8 per cent between 1981 and 1985 along Twentymile Creek but was stable along Mubby–Chiwapa. Reaches above and below GCS were deeper with slower current velocities than elsewhere. Mean Shannon diversity indices based on physical data were similar for both streams, but were 58 per cent higher for stations immediately above and below GCS than for other stations. Since construction of the GCS and bank protection measures, longitudinal berms have formed within the enlarged Twentymile Creek channel, creating a low-flow channel. Low-flow channel capacity was equivalent to a mean daily discharge equalled or exceeded 30 per cent of the time, and was considerably lower than the effective discharge. Differences in aquatic habitat diversity among the stations sampled were primarily due to the scour holes below the GCS and the low-flow channel. Thirty-nine fish species were collected from Twentymile Creek, but only 22 from Mubby–Chiwapa. Fourteen species were collected exclusively at GCS. Principal component analyses of the abundance of the eight numerically dominant fish species indicated similar faunas at most stations, but Twentymile Creek GCS stations were faunistically distinct. Abundance of several of the numerically dominant species was positively influenced by greater depths and lower velocities found near Twentymile GCS. The mean fish diversity index for Twentymile Creek was 29 per cent higher than for Mubby–Chiwapa, and fish diversity was positively correlated with substrate diversity and mean depth.

KEY WORDS Channel instability Channelization Fish Species diversity Habitat diversity Erosion Rivers Nickpoint Knickpoint-Grade control structure Streambank protection Sedimentation

INTRODUCTION

Straightening and enlarging stream channels to reduce frequency or duration of flooding has been widely practised in the United States, the United Kingdom, and Denmark (Brookes, 1988). Although some

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channelization projects have performed well from a hydraulic standpoint, undesirable channel responses have been reported frequently (Cederholm, 1972; Jahn and Trefethan, 1973; Parker and Andres, 1976; Barnard, 1977; Wilson, 1979; Barclay, 1980; Griggs and Paris, 1982). Typical channel responses include increased velocity upstream and sometimes within the modified reach, with attendant erosion of the upstream bed and banks, and up to 1200 per cent enlargement of the cross-sectional area (Emerson, 1971). Bridge failures have been caused by channel instability when approaches or foundations were destroyed by erosion (Shen *et al.*, 1981). Sediments generated by rapid channel enlargement have resulted in downstream channel widening (Parker and Andres, 1976) and aggradation (Simon and Robbins, 1987), more frequent flooding and overbank deposition (Emerson, 1971; Parker and Andres, 1976). Channel straightening and enlargement reduces heterogeneity of aquatic habitats (Zimmer and Bachman, 1976), which is typically associated with reduced ichthyofaunal richness and diversity (Gorman and Karr, 1978; Karr and Schlosser, 1978; Hortle and Lake, 1983; Foltz, 1982; Swales, 1988). Adverse effects on habitat (loss of cover and habitat heterogeneity, shifting substrate, shallow depths, higher velocities) may be amplified by channel instability (Nunnally, 1978).

Some investigators have suggested that stream reaches destabilized by downstream channelization usually evolve toward more stable and physically diverse conditions. Harvey and Watson (1986) presented a conceptual channel evolution model developed by Schumm *et al.* (1984) for Oaklimiter Creek, Mississippi, and similar incised channels: after initially deepening and widening, the channel experiences deposition of sediments, rather than erosion. These sediments form bars or longitudinal berms composed of sand and mud couplets along the toe of the bank, giving rise to a low-flow channel in the floor of the enlarged section. Woody vegetation becomes established on the berms, which promotes more rapid sediment accretion and bank stability. The channel evolution model consists of five reach types (I to V) describing conditions that occur consecutively at a given location through time or at a given time in a downstream direction along an evolving channel (due to upstream progression of nick points or zones). Type I reaches are upstream of active nick points; Type II reaches are immediately downstream of nick points and are undergoing rapid incision; Type III reaches are rapidly widening; in Type IV reaches, widening continues, but at a reduced rate, and a meandering low-flow channel flanked by alternate bars or berms occurs at low stage; Type V reaches have reached a new state of dynamic equilibrium, and longitudinal berms flanking the low-flow channel are vegetated by perennial woody species. Development of Type IV and V reaches has been observed in several incised streams (Harvey and Watson, 1988; Brookes, 1983; Brookes, 1988).

Peterson, Watson *et al.* (1988) reasoned that installation of grade-control structures (GCS) in unstable, incised channels could promote the formation of a two-stage Type V channel by reducing sediment transport capacity and stabilizing the bed. GCS also promote biological recovery in unstable, channelized streams by providing coarse, stable substrate (riprap), variability in velocity, and relatively deep, permanent scour holes (Cooper and Knight, 1987). Small weirs (similar to small GCS) and jetties have been used to improve fish habitats in channelized streams by increasing habitat diversity and creating scour holes (Swales and O'Hara, 1980; Shields, 1983) with some success, at least in locations where relatively short reaches were channelized (Edwards *et al.*, 1984). Other installations have been only partially effective, possibly because erratic flows limited reproduction (Carline and Klosiewski, 1985).

Two-stage (benched) channels have been recommended by several investigators as an environmentally attractive alternative to more traditional, less complex designs (e.g. prismatic channels with trapezoidal sections) (Hey, 1986; Brookes, 1988; Keller and Brookes, 1984). A stable, slightly sinuous low-flow channel is environmentally superior to shallow flow across the entire bottom width of a flood channel or to a transient low-flow channel defined only by shifting bars in the bed of the flood channel. The low-flow channel provides more natural aquatic habitat (depths, velocities, and bed material), and is less likely to lead to elevated summer water temperatures, because of the greater depths and reduced surface area.

Channel designers who wish to incorporate low-flow channels into their projects must select a flow capacity (discharge) to use as a basis for low-flow channel dimensions. Undersizing the low-flow channel causes berm inundation to occur too frequently. Desirable types of terrestrial vegetation are therefore difficult to establish, and sediment deposits may form on the berms. Oversizing the low-flow channel may lead to deposition (Nunnally and Shields, 1985).

The purpose of this study was to investigate effects of channel evolution and GCS installation on aquatic habitat. Evolution of the channel of Twentymile Creek was documented by literature review, visual inspection, sequential aerial photographs and cross-section surveys. The flow capacity of the naturally formed low-flow channel was computed and related to the discharge frequency duration. Effects of GCS and channel evolution on aquatic habitat were investigated by sampling Twentymile Creek and Mubby-Chiwapa Creek, which was destabilized by channelization, but had no GCS or low-flow channel development.

STUDY AREAS AND HISTORY

This study was conducted in 1989 on two unstable, channelized streams in the Upper Tombigbee River Basin on the Black Belt Prairie of northeast Mississippi, U.S.A. (Figure 1). Twentymile Creek and Mubby-Chiwapa Creek drain similar landscapes with areas of 450 and 410 km^2, respectively. Both watersheds are primarily cultivated floodplains bordered by low, steep hills. Both streams are underlain by sands and chalky formations of the Selma Group (Vestal, 1947; Parks, 1960). Annual rainfall averages about 150 cm.

Land use changes following European occupation of northern Mississippi caused rapid erosion of hillslopes, channel and floodplain aggradation, and increased flood frequencies (Happ *et al.*, 1940). Drainage districts and other groups attempted to alleviate flooding by channelizing many of the streams. Drainage districts encompassing the Twentymile Creek watershed were formed by landowners between 1904 and 1911 and at least 19·2 km of drainage ditches were constructed (Water and Engineering Technology Inc., 1988).

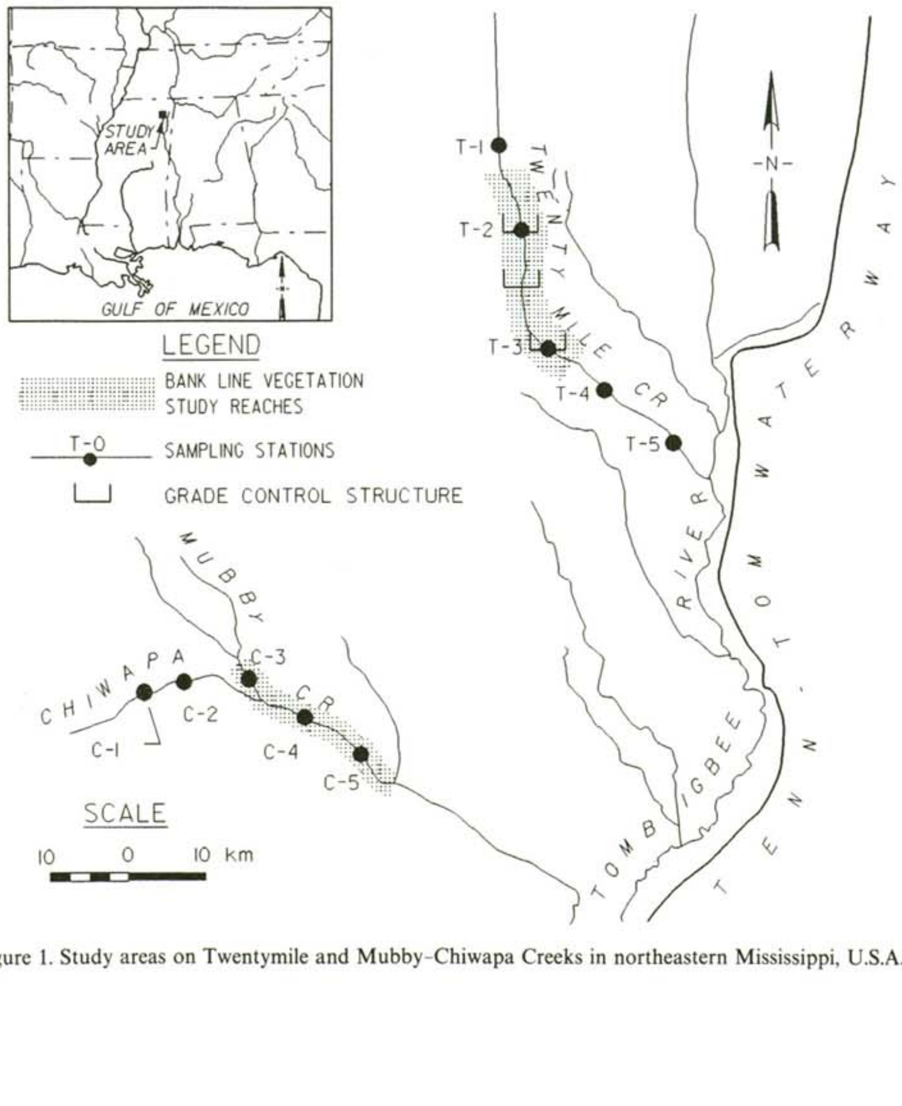

Figure 1. Study areas on Twentymile and Mubby-Chiwapa Creeks in northeastern Mississippi, U.S.A.

Ramser (1930) reported observations of the channel just upstream of river kilometre (RK) 26 where channel top width increased from 10 to 20 m due to erosion between 1910 and 1918. The lower reaches were further enlarged in 1938 and 1966. In 1966 the lower 15-km reach was enlarged to accommodate a discharge of about 110 $m^3 s^{-1}$ and a 4-km reach immediately upstream was cleared and snagged. The design bed slope for the enlarged reach was 0·0004, about twice the estimated slope of the original stream (Neill, 1987).

Chiwapa Creek was also straightened prior to 1913 (Ramser 1930). The lower 17·4-km reach was enlarged and realigned in 1967; by 1977, 114 km of channel within the watershed had been altered. Ramser (1930) reported that the top width of the channel near RK 6·5 increased 5 m between 1913 and 1921. Channel slope was about 0·001 in 1988 (Water and Engineering Technology Inc., 1988).

Twentymile Creek channel response to the 1966 flood control project was dramatic. Channel bed degradation worked its way upstream and propagated up the tributaries. From 1967 to 1980, degradation and subsequent bank failures increased the channel cross-sectional area by factors of 1·4 to 2·7 and channel width by factors of 1·8 to 3·0 between RK 5 and 19 (Neill, 1987). Channel width increased 25 per cent at RK 26 between 1958 and 1988 (Wilson and Turnipseed, 1989). The thalweg was lowered from 2 to 4 m between 1965 and 1989 (Figure 2). Sediments derived from bed degradation and bank failure caused the channel below about RK 9 to aggrade. At least one bridge failure resulted from channel degradation and widening.

In 1982, construction to reestablish channel stability was initiated along the upper reaches of Twentymile Creek. Three GCS (Figure 1) and assorted stream-bank protection measures (concrete jacks, stone revetments, and combinations of structure, grasses, and woody species, primarily *Salix* spp) were installed between RK 18 and RK 35 between 1982 and 1988. GCS consisted of sheet-pile or stone weirs with crests (1·5–2 m) above the stream bed and approach channels and stilling basins lined with stone riprap and graded stone riprap. Structures measured about 45 m long in the streamwise direction. Eroding banks immediately above and below the structures were stabilized with jacks, slotted board fences, and stone training structures.

Chiwapa Creek experienced less instability following channelization than Twentymile Creek, probably because outcrops of erosion-resistant chalk occur more frequently along its length and have retarded bed degradation and degradation-induced bank failure. Some bank erosion did occur, and fields of concrete jacks were installed at several locations prior to 1986 (Water and Engineering Technology Inc., 1988). In October of 1988 the reach of Mubby–Chiwapa Creek including our study area was characterized by caving banks and wide (30–60 m), shallow (10–40 cm) flow (Figure 3). The bed material consisted of fine to medium sand that was moving over frequent outcrops of potholed chalk bed rock. Several nick points (low waterfalls) were observed in the chalk material. Grade control structures were not employed along Mubby–Chiwapa Creek.

In 1989, Twentymile Creek remained a highly altered stream with minimal aquatic habitat heterogeneity. Below RK 15, the channel was straight and approximately 50 m wide and 3 m deep. The steep, uniform banks were regularly mowed and supported forbs and grasses only. At low flow, water depths were extremely shallow. At low flow the stream flowed over a shifting, braided bed of fine sand. Above RK 15 woody vegetation on banks was more common, the channel was more sinuous, and a single-thread low-flow channel about 10 m wide and less than 0·5 m deep was developing. Scour holes were found below the GCS at RK 18·7

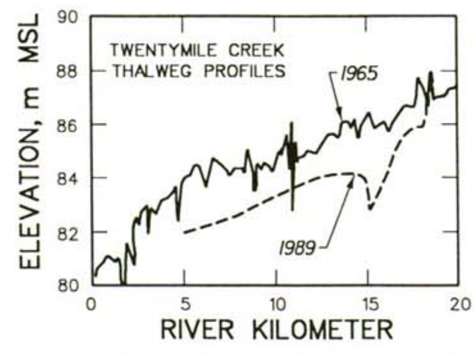

Figure 2. 1965 and 1989 thalweg profiles for Twentymile Creek

Figure 3. Chiwapa Creek RK 6·5, facing upstream, October, 1988

and 31·8 (Figure 4); at low flow the GCS created shallow ($<0·6$ m) backwater pools which extended as far as 300 m upstream. Nick points were not observed, but caving banks were common. The frequency of eroding banks was greatly reduced, however, due to the presence of riprap revetments.

The Twentymile GCS and associated downstream scour holes were distinctive habitat features in an otherwise homogeneous system. The GCS at RK 18·7 was a sheet-pile weir with crest elevation about 1·5 m above the downstream channel bed and an approach channel and stilling basin built of rock riprap. A secondary weir about 1 m high made of graded riprap was located 15 m downstream of the sheet pile weir. The GCS at RK 31·8 (Figures 4 and 5) was a stone weir with riprap protection up- and downstream, but was emplaced on an outcrop of easily crumbled marine shale (a nick point). The shale was subject to erosion, but at a much slower rate than the sand bed located up- and downstream. Accordingly, a large, unprotected scour hole (about 75 m wide by 100 m long) up to 1·5 m deep was located downstream of the shale outcrop even before GCS construction. Use of GCS to prevent upstream migration of nick points is a component of many incised channel stabilization projects (Harvey and Watson, 1986). Concrete jacks were used downstream of both GCS to stabilize eroding banks, and board fences and a stone training structure were also found just downstream of RK 31·8.

METHODS

Sampling stations

Sampling stations were selected along Twentymile Creek to document the biological effects of the GCS (Figure 1 and Table I). Twentymile Creek stations were located immediately up- and downstream of each of the two major GCS (RK 18·7 and RK 31·8); additional stations were located at RK 40·3 and 14·6, and at RK 5·3 in a reach periodically maintained by dredging sediments (fine sand) from the channel and mowing vegetation on the banks. Six stations were located on Chiwapa Creek and its major tributary, Mubby Creek, neither of which contained GCS.

Figure 4. Aerial view of GCS at Twentymile Creek RK 31·8, facing upstream, March 1989

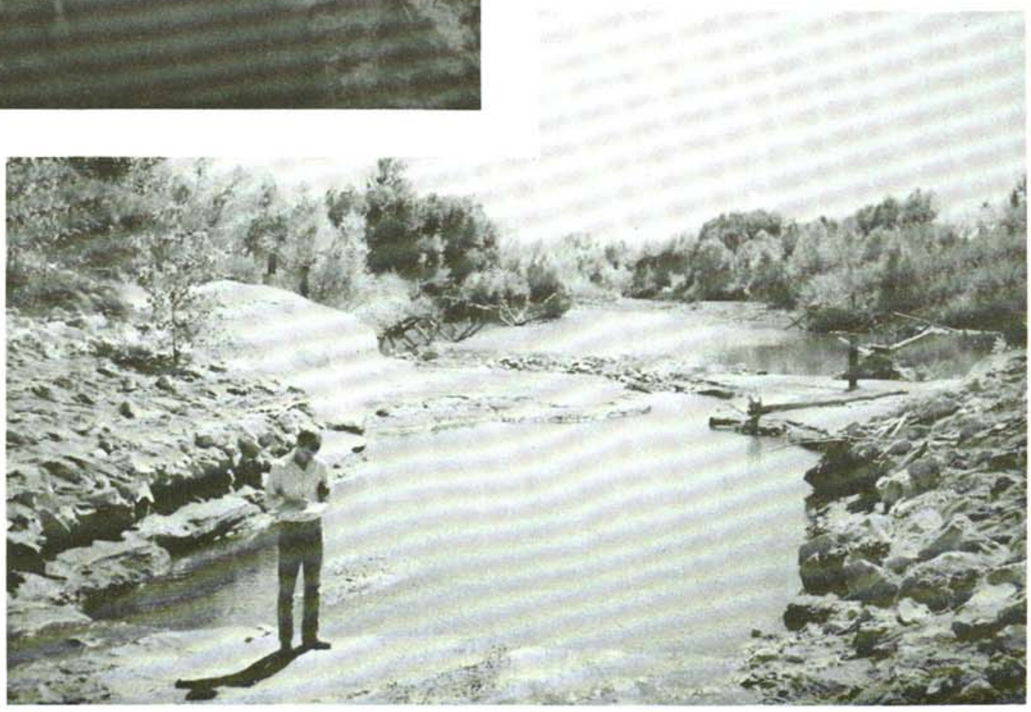

Figure 5. Scour hole below GCS at Twentymile Creek RK 31·8, facing downstream, October 1988

Table I. Sampling station descriptions

Stream	River km	Station	Description	July 1989 Depth (cm) Mean	Std	Velocity (cm s^{-1}) Mean	Std	Substrate	Sampled for Fish May	Fish July	Physical Habitat July
Twentymile	40·3	T-1	Riffles, backwaters	NS	NS	NS	NS	Cut through chalk	×		
Twentymile	31·8	T-2·1	u/s GCS	72	39	3	3	Sand		×	×
Twentymile	31·8	T-2·2	d/s GCS, large scour hole w/eddies	96	86	8	12	Riprap, marine shale	×	×	×
Twentymile	18·7	T-3·1	u/s GCS	93	28	3	2	Sand		×	×
Twentymile	18·7	T-3·2	d/s GCS, smaller scour hole than at RK 31·8	61	33	10	12	Riprap, sand	×	×	×
Twentymile	14·6	T-4	Riffle, deep run, small backwater	NS	NS	NS	NS		×		
Twentymile	5·3	T-5	Mowed banks, no well-defined low-flow channel	30	9	18	6	Sand		×	×
Chiwapa	34·9	C-1	Riffles, runs, nick points	21	23	24	20	Sand	×	×	×
Chiwapa	32·2	C-2	Riffles and runs	NS	NS	NS	NS	Sand	×		
Mubby	2·1	C-3	Riffles, runs, small pools	20	22	18	13	Sand	×	×	×
Chiwapa	20·3	C-4	Riffles and runs	18	14	24	23	Sand	×	×	×
Chiwapa	12·5	C-5	Riffles, runs, pools	24	11	35	16	Sand	×	×	×

u/s = upstream of, d/s = downstream of, NS = not sampled.

Woody vegetation

Woody vegetation occurring on bank-lines (top banks were pronounced features) or on in-channel berms along reaches containing the sampling stations (Figure 1) was mapped from enlarged, high-altitude black and white aerial photographs (1 : 15 840 scale) taken before and after construction of GCS and bank protection structures (1981 and 1985). Photograph dates were in late winter/early spring (20 Feb–1 Apr) prior to full leaf development. Vegetation on both banks of 22·1 km of the Mubby–Chiwapa channel and 20·1 km of Twentymile Creek was mapped. Streambank vegetation is regularly mowed along the lower 14·6 km of Twentymile Creek, and therefore this reach was not mapped. Mapping was accomplished by tracing woody vegetation seen on the photograph onto Mylar overlays. The length of vegetated and unvegetated bank-line was measured with a digitizer.

Physical aquatic habitat

Physical habitat variables (depth, velocity, substrate, cover (DVSC)) were measured at selected sampling stations (Table I) during base flow (July) conditions using methods similar to those described by Gorman and Karr (1978) and Swales (1988). Depth and velocity were measured, and cover and substrate were visually classified at 1-m intervals along 1 to 10 transects running perpendicular to channel banks at each sampling station. Transects were spread about one channel width apart; more transects were sampled in the more physically heterogeneous reaches. The number of sample points per station ranged from 44 to 206 and averaged 110. Depth was measured using a wading rod, and velocity was measured at the 0·6 depth using a Marsh–McBirney current meter.

Integer values were assigned to each of the four physical variables at each sampled point according to the categories shown in Table II. Ranges for each variable corresponded to habitats and substrates typical of small streams in this region. Backwaters of various depths were characterized by negligible current (<1 cm s^{-1}). Stream margins were very shallow (<5 cm) and slow flowing (1–5 cm s^{-1}). Riffles were shallow (5–20 cm) or moderate in depth (20–50 cm) and were fast flowing (20–40 cm s^{-1}). Typically, raceways, chutes, and torrents were fast flowing (>40 cm s^{-1}) and moderately deep (50–80 cm). Pools were deep (>80 cm) and moderately slow flowing (5–20 cm s^{-1}). Alluvial substrates were classified by size: silt, $<0{\cdot}05$ mm; sand, 0·05–2 mm; gravel, 2–10 mm; cobble, 10–30 mm; boulder, >30 mm. Parent substrate was a chalk–clay bedrock.

Shannon functions (Magurran, 1988) were calculated using all combinations of the four physical variables. The Shannon diversity function H' is given by:

$$H' = -\sum p_i \ln[p_i]$$

where p_i is the proportion of observations in the ith group or category. This index incorporates both richness (i.e. the number of categories present) and equitability (numerical distribution of observations among categories) into a single value. However, it is more responsive to richness than to the abundance within individual categories and consequently is 'sensitive' to the presence of rare categories.

Each unique combination of the integer scores for the four variables in Table II constitutes a category. Although there are 1200 possible combinations of the values in Table II, many of these categories are physically unreasonable. If a reach is completely homogeneous (i.e. all four habitat variables are the same at all points), then $H' = 0$ because $i = 1$ and $p_i = 1$. Diverse streams yield H' values between 3 and 4 (Gorman and Karr, 1978; unpublished data, Shields).

The Pielou evenness index E (Magurran, 1988) was also calculated for each station using all four physical variables. Evenness is defined as the ratio of the calculated Shannon function to its maximum possible value and is calculated by:

$$E = \frac{H'}{\ln(S)}$$

where S = number of categories observed. Evenness ranges from approximately zero (when all points have identical physical habitat characteristics) to approximately one (when no category is numerically dominant). Unlike the Shannon index, though, evenness is primarily responsive to abundances (rather than richness), and consequently, is 'insensitive' to the presence of rare categories.

Fishes

Fish were sampled at moderate discharge (3·5 m^3 s^{-1}) in May and low (base flow) discharge (1·0 m^3 s^{-1}) in July 1989. Fishes were collected with straight seines of 0·64-mm mesh and variable length (1·3, 3·1, 9·2 m).

Table II. Values of variables describing physical habitat

Variable	Values assigned to variable for calculation of diversity* 1	2	3	4	5	6
Depth, cm	0–5	5–20	20–50	50–80	>80	
Velocity, cms^{-1}	<1	1–5	5–20	20–40	>40	
Substrate†	Silt	Sand	Gravel	Cobble	Boulder	Chalk
Cover	None	Small logs	Log jams	Undercut banks and rootwads	Canopy	Other

* Measurements falling on the boundary between two categories were assigned to the higher category.

† Substrates also included vegetation (7) and litter (8)

Sampling encompassed the cross-sectional area of the stream and included all apparent microhabitats; it continued until no new species were observed, and averaged 20 seine hauls per sampling station. A gill net was also used to sample the scour hole T-2·2 in July because that habitat was too deep to seine thoroughly. Small fishes were preserved in formalin and large fishes were released. In the laboratory, fishes were washed and identified according to Douglas (1974) and Suttkus and Boschung (1990).

Analysis of fish community data included rarefaction, principal component analysis, and diversity indices (Ludwig and Reynolds, 1988). May and July collections were pooled to provide a best estimate of species richness for each station; rarefaction was used to compensate for disparate numbers of individuals collected among the 10 stations; and species richness was expressed as the number of species expected for a uniform sample size of 100 individuals. Faunal similarity among stations in July was expressed using principal components analysis (PCA) of abundance of the eight numerically dominant species; sample units were plotted in multivariate species space. The Shannon function and Pielou evenness index were used to quantify species diversity of individual collections using species in place of 'categories' as described above. Coefficients of determination between Shannon indices for fish and Shannon indices for physical habitat were computed.

Low-flow channel

Low-flow channel capacity was determined using methods described by Harvey and Watson (1988). Topographic surveys of cross-sections along Twentymile Creek made in 1989 were visually examined to determine the existence and dimensions of a low-flow channel. Twenty-nine cross-sections were surveyed between RK 14·7 and RK 33·4. Intervals between sections ranged from 0·3 to 1·5 km. Low-flow channel capacity was determined by adjusting discharge supplied as input to a backwater profile computation routine until the simulated water surface profile matched the longitudinal berm crest elevation profile. Friction factors were computed using the method of Brownlie (1983).

RESULTS

Woody vegetation

Woody vegetation (primarily *Salix* spp.) covered 64·1 per cent of Twentymile Creek margins (banks or in-channel berms) in 1981 and 71·7 per cent in 1985. Increased riparian cover was caused by invasion of point bars and protected banks within enlarged cross-sections downstream of the GCS at RK 18·8, 26, and 31·8 (Figure 6). Woody vegetation along Chiwapa Creek was relatively static over the same period, covering 86·0 per cent of the bank line in 1981 and 87·5 per cent in 1985.

Physical habitat

Stations along Mubby–Chiwapa Creeks exhibited smaller ranges of mean depth (18–24 cm), less variability in velocity (C.V. < 95 per cent), and lower substrate diversity ($H < 0{\cdot}75$), than did Twentymile Creek stations which were deeper (30–96 cm) and had more heterogeneous velocities (C.V. < 157 per cent) and substrates ($H' > 0{\cdot}84$ at four of the five stations). Shannon indices based on all four physical variables (DVSC) were generally higher and more variable for Twentymile Creek stations (mean = 2·40, range = 1·22–3·33) than for Mubby–Chiwapa (mean = 2·32, range = 2·18–2·61) and a similar spread was observed in evenness values (0·58–0·89 for Twentymile, 0·31–0·69 for Chiwapa) (Table III). However, neither diversity ($F = 0{\cdot}025$, d.f. $= 1/7$, $p = 0{\cdot}88$) nor evenness ($F = 0{\cdot}004$, d.f. $= 1/7$, $p = 0{\cdot}95$) were significantly different.

Four of the five Twentymile Creek stations were immediately adjacent to GCS (T-2·1, T-2·2, T-3·1, 7-3·2); these exhibited lower mean velocities (3–10 cm s^{-1}) and greater mean depths (61–96 cm) than the other stations sampled (Table I and Figure 7). Shannon indices (DVSC) were higher near GCS (Table III). Reaches below GCS (T-2·2 and T-3·2) had DVSC indices of 3·28 and 3·33, while indices for the other seven stations averaged 2·09. Pielou evenness values for stations near GCS were 0·47–0·67, but were only 0·28–0·51 for other stations. Reaches below GCS had evenness values of 0·67 and 0·66.

The lowest observed diversity and evenness on either stream (1·22 and 0·28, respectively) were for station T-5 (Twentymile Creek RK 5·3), which was distant from GCS and was characterized by shallow, braided

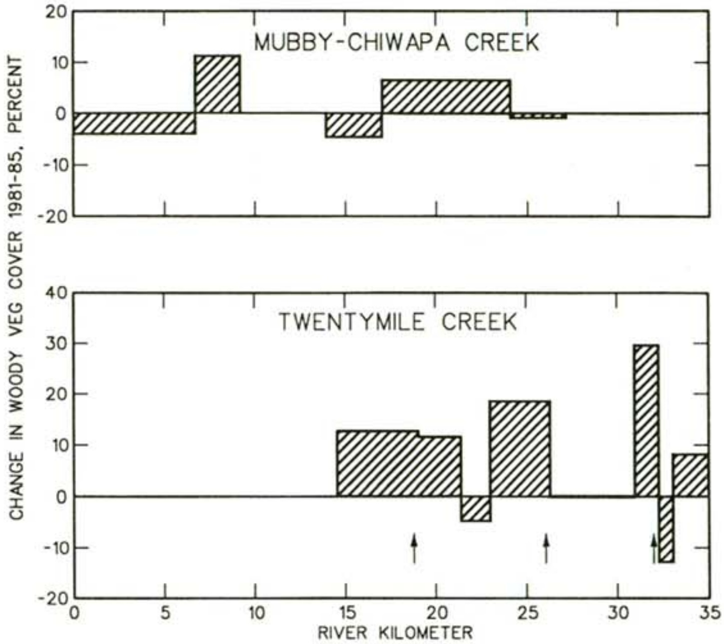

Figure 6. Percent change in woody vegetation cover on banks and in-channel berms, Twentymile and Chiwapa Creeks, 1981–1985. Vegetation was mapped from enlarged (1 : 15, 840) National High Altitude Program photographs. Arrows on lower graph indicate grade control structure locations.

flow, shifting sand substrate, and mowed banks. Physical diversity at other stations on Twentymile Creek were positively influenced by GCS, and even the relatively uniform Chiwapa stations were diversified by naturally occurring potholed chalk outcrops in the bed.

Fishes

Species richness was higher in Twentymile Creek than in Chiwapa Creek (Table IV). A total of 42 species was collected from both systems, 22 from Mubby-Chiwapa and 39 from Twentymile Creek. Longitudinal zonation was not pronounced. Six species (*Hybopsis aestivalis, Notemigonus crysoleucas, Notropis texanus, Gambusia affinis, Menidia beryllina*, and *Ammocrypta meridiana*) occurred only at downstream stations, but only one (*G. affinis*) was ever abundant. Species richness was comparable among eight stations in both systems, ranging from 8–12 species/100 individuals, but collections from Twentymile Creek GCS (stations T-2·1 + T-2·2, and T-3·1 + T-3·2) were more speciose with 15 species/100 individuals. Fourteen species were collected exclusively at GCS.

Eight species were common and abundant in both streams; they occurred at most or all stations and together averaged 86 per cent of all fishes. Four species of cyprinids occurred at all 10 stations (Table IV) and each averaged more than 7 per cent of fishes collected: *Notropis venustus*, 41 per cent, *Pimephales notatus*, 13 per cent, *Notropis ammophilus*, 9 per cent, and *Notropis bellus*, 8 per cent. Another cyprinid, *Notropis stilbius*, occurred only in Twentymile Creek but was frequently abundant. Three noncyprinid species occurred at most of the stations and averaged 3 to 6 per cent of all fishes collected: *Gambusia affinis, Lepomis megalotis*, and *Ictalurus punctatus*.

Principal component analysis identified five species important (loadings $> 0{\cdot}800$) to data set variance (Table V). The first two components, PCI and PCII, together accounted for 78 per cent of data set variance (Table V). PCI was positively associated with the abundance of *N. stilbius, N. venustus*, and *G. affinis*, three species positively intercorrelated in abundance ($r > 0{\cdot}875$, $p < 0{\cdot}01$). PCII was positively associated with the abundance of *L. megalotis* and *P. notatus*, two species significantly correlated in abundance ($r = 0{\cdot}674$, $p < 0{\cdot}05$).

Nine samples plotted in multivariate species space resulted in a cluster of five stations with three outliers

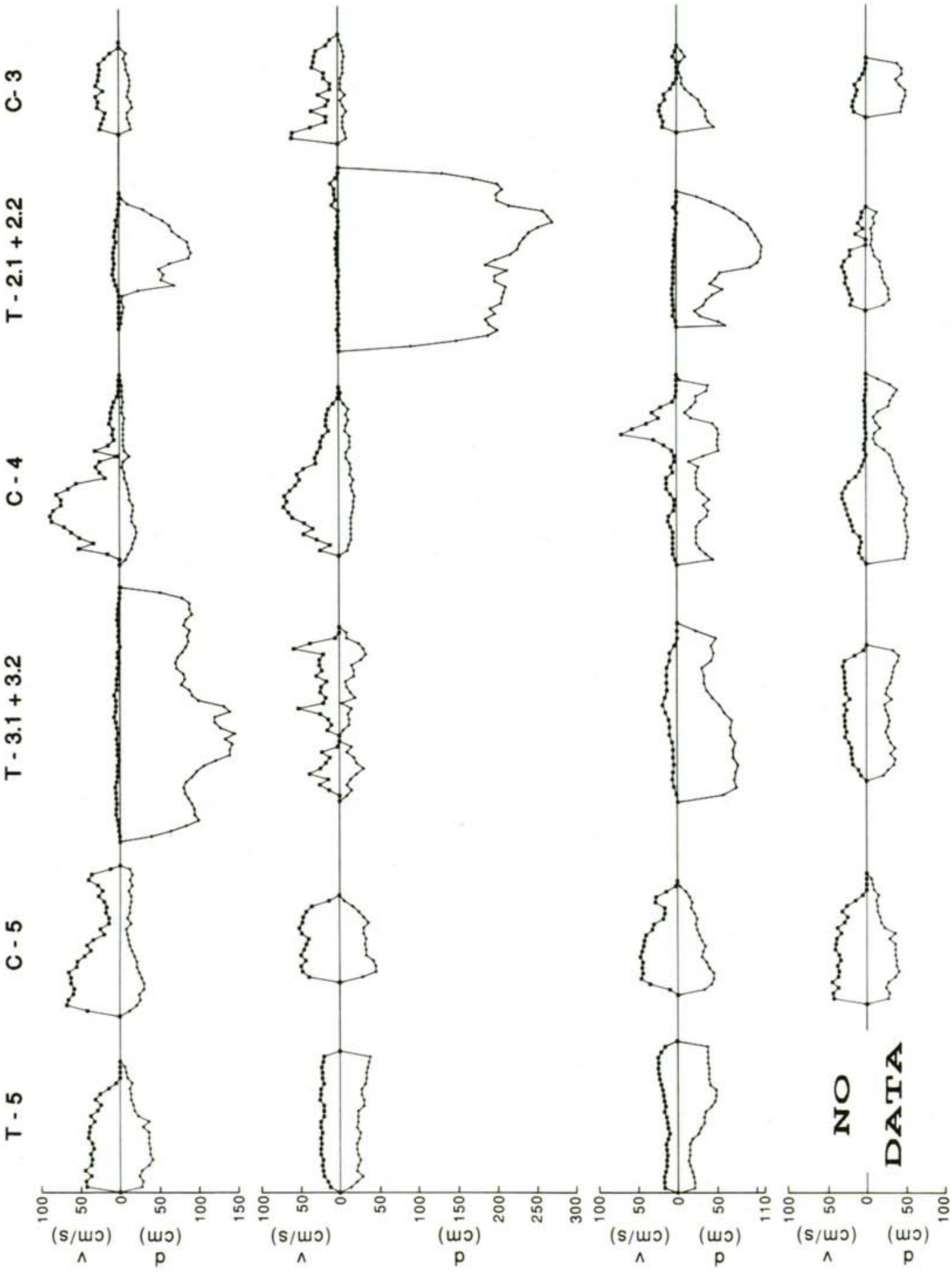

Figure 7. Depths and velocities for selected cross sections at comparable locations along Twentymile and Mubby–Chiwapa Creeks. Station numbers correspond to locations on Figure 1

Table III. Shannon diversity and Pielou evenness indices for various combinations of physical variables, July 1989

Stream	River km	Station	No. of sample transects	No. of sample points	Shannon diversity indices for physical variable combinations* DVSC	DVS	D	V	S	C	Pielou evenness Index†
Twentymile	31·8	T-2·1	4	85	2·08	2·64	1·33	1·08	0·84	0·39	0·42
	31·8	T-2·2	6	142	3·33	3·21	1·32	1·42	1·36	0·30	0·67
	18·7	T-3·1	1	47	2·07	2·08	0·65	0·85	0·98	0·00	0·54
	18·7	T-3·2	5	146	3·28	3·12	1·42	1·36	0·88	0·32	0·66
	5·3	T-5	3	78	1·22	1·18	0·36	0·87	0·12	0·00	0·28
Mubby-Chiwapa	34·9	C-1	10	44	2·18	2·18	1·22	1·38	0·00	0·00	0·58
	2·1	C-3	6	90	2·23	2·19	1·05	1·17	0·68	0·21	0·50
	20·3	C-4	6	206	2·61	2·67	1·12	1·53	0·71	0·11	0·49
	12·5	C-5	4	85	2·27	2·05	0·73	1·19	0·43	0·31	0·51

* D = Depth, V = Velocity, S = Substrate (bed type), and C = Cover.
† Based on DVSC

(Figure 8). The collection immediately upstream of the Twentymile RK 18·7 GCS (station T-3·1) contained only 46 individuals making any interpretation of its position tenuous, but the other eight samples were larger (> 125 individuals). The highest numbers of *N. venustus*, *N. stilbius*, and *G. affinis* were found downstream from the RK 18·7 GCS (station 3·2), the highest numbers of *P. notatus* and *L. megalotis* upstream from the GCS at RK 31·8 (station T-2), with slightly lower numbers downstream. High numbers of *N. venustus* and *G. affinis* were also observed at lower Chiwapa Creek (station C-5), but fewer *P. notatus* and no *L. megalotis* were collected.

Diversity was variable among all stations but was higher in Twentymile Creek, especially at GCS (Table VI), presumably due to higher levels of physical diversity there (Figure 9). The mean Shannon function for Twentymile Creek ($H' = 1{\cdot}84$) was significantly higher than for Mubby-Chiwapa Creeks ($H' = 1{\cdot}43$; $F = 7{\cdot}35$, d.f. = 1/16, $p = 0{\cdot}01$). Five of the 16 station values were high ($H' > 1{\cdot}75$), and four of these were calculated for collections made at GCS in May and July.

The mean evenness value for Twentymile Creek ($E = 0{\cdot}69$) was also significantly higher than for Mubby-Chiwapa Creeks ($E = 0{\cdot}56$; $F = 4{\cdot}86$, d.f. = 1/16, $p = 0{\cdot}04$). Only two evenness values were high ($E > 0{\cdot}80$), and one of these was for a collection made at a GCS. In July, both Shannon function and evenness values were substantially higher downstream from the RK 31·8 GCS (station T-2) ($H' = 2{\cdot}26$, $E = 0{\cdot}72$) than upstream (station T-2) ($H' = 1{\cdot}56$, $E = 0{\cdot}59$). In July, fish diversity was positively correlated with substrate diversity ($r = 0{\cdot}81$, $p = 0{\cdot}006$) and mean depth ($r = 0{\cdot}583$, $p = 0{\cdot}10$). Fish evenness indices were positively correlated with substrate diversity ($r = 0{\cdot}530$, $p = 0{\cdot}02$).

Low-flow channel

A low-flow channel was not generally apparent on cross-sections surveyed along Twentymile Creek in 1980, but a small low-flow channel could be discerned on most of the 1989 survey crosss-section plots. Water surface profiles were computed for a wide range of discharges, and the profile for 2·8 $m^3 s^{-1}$ was judged to best fit the berm crest elevation profile (Figure 10). Thirty per cent of the mean daily discharges recorded between 1983 and 1987 at RK 18·7 equalled or exceeded this value, which represents a specific discharge of 0·009 $m^3 s^{-1} km^{-2}$ of upstream drainage area.

DISCUSSION

Stream channelization and channel destabilization reduce physical aquatic habitat heterogeneity. Although the relationship is complex, stream fish communities respond positively to increasing levels of habitat heterogeneity. For example, the greater availability of deeper water in Twentymile Creek with more variation

Table IV. Fishes collected from two stream systems in northeastern Mississippi

	Mubby–Chiwapa Creek					Twentymile Creek				
	1	2	3	4	5	1	2·1 + 2·2	3·1 + 3·2	4	5
Lepisosteidae										
Lepisosteus oculatus, spotted gar	○	○	○	○	○	○	○	×	○	○
L. osseus, longnose gar	○	○	○	○	○	○	○	×	○	○
Clupeidae										
Dorosoma cepedianum, gizzard shad	×	×	×	×	○	○	×	×	○	○
Cyprinidae										
Cyprinus carpio, carp	○	○	○	○	○	○	×	×	○	○
Hybopsis aestivalis, speckled chub	○	○	○	○	×	○	○	○	○	○
Hybognathus hayi, cypress minnow	○	○	○	○	○	○	○	×	○	○
Notemigonus crysoleucas, golden shiner	○	○	○	○	○	○	○	×	○	×
Notropis ammophilus, orangefin shiner	×	×	×	×	×	×	×	×	×	×
N. bellus, pretty shiner	×	×	×	×	×	×	×	×	×	×
N. emiliae, pugnose minnow	○	○	○	○	○	○	○	×	○	○
N. stilbius, silverstripe shiner	○	○	○	○	○	○	×	×	×	×
N. texanus, weed shiner	○	○	○	○	○	○	○	×	○	×
N. venustus, blacktail shiner	×	×	×	×	×	×	×	×	×	×
N. volucellus, mimic shiner	○	○	○	○	○	○	○	×	○	○
Pimephales notatus, bluntnose minnow	×	×	×	×	×	×	×	×	×	×
P. vigilax, bullhead minnow	○	×	×	×	×	○	×	×	×	○
Semotilus atromaculatus, creek chub	○	○	○	○	○	×	○	○	○	○
Catostomidae										
Carpiodes velifer, highfin carpsucker	×	×	×	×	×	○	×	×	○	○
Ictiobus niger, black buffalo	○	○	○	○	○	○	×	○	○	○
Moxostoma poecilurum, blacktail redhorse	○	○	○	○	○	○	×	○	○	○
Ictaluridae										
Ictalurus natalis, yellow bullhead	○	○	○	○	○	○	×	○	○	○
I. punctatus, channel catfish	×	×	×	×	×	○	×	×	○	×
Cyprinodontidae										
Fundulus notatus, blackstripe topminnow	○	○	×	×	×	○	○	○	○	○
F. olivaceus, blackspotted topminnow	×	○	○	○	○	○	×	×	○	○
Poeciliidae										
Gambusia affinis, mosquitofish	○	○	○	×	×	○	×	×	×	×
Atherinidae										
Menidia beryllina, inland silverside	○	○	○	○	○	○	○	○	○	×
Centrarchidae										
Lepomis cyanellus, green sunfish	×	○	×	×	×	×	×	×	×	×
L. humilis, orangespotted sunfish	○	○	×	○	○	○	○	○	○	○
L. macrochirus, bluegill	×	×	×	×	×	○	×	×	×	×
L. megalotis, longear sunfish	×	×	×	×	×	×	×	×	×	×
L. microlophus, redear sunfish	○	×	×	×	×	○	×	×	×	○
Micropterus salmoides, largemouth bass	×	○	×	×	×	○	×	×	×	×
M. punctulatus, spotted bass	○	○	○	○	○	○	○	×	○	×
Pomoxis annularis, white crappie	○	○	○	○	×	○	×	×	○	○
P. nigromaculatus, black crappie	○	○	○	○	○	○	○	×	○	○
Percidae										
Ammocrypta meridiana, southern sand darter	○	○	○	○	×	○	○	×	×	×
Etheostoma chlorosomum, bluntnose darter	○	○	○	○	○	○	×	×	○	×
E. nigrum, johnny darter	○	○	○	○	○	○	×	○	○	○
E. rupestre, rock darter	○	○	○	○	○	○	○	×	○	○
E. stigmaeum, speckled darter	○	○	○	×	○	○	○	×	○	○
E. whipplei, redfin darter	○	○	×	×	○	×	×	×	○	×
Percina sciera, dusky darter	○	○	○	○	○	○	○	×	○	○
Total number of individuals	518	324	912	702	943	143	1109	2370	815	138
Total number of species	12	11	16	17	17	8	24	33	13	18
Number of species/100 individuals	8	9	10	12	9	8	15	15	9	—

Table V. Principal components analysis of fish collections: per cent variance accounted for by the first three principal components (PCs) and species correlations (loadings) on those components

	PCI	PCII	PCIII
Per cent variance	52·8%	25·6%	10·4%
Species correlations			
Notropis ammophilus	0·750	−0·331	0·377
N. bellus	0·674	0·379	0·540
N. stilbius	0·949	−0·013	−0·144
N. venustus	0·917	−0·342	−0·034
Pimephales notatus	0·080	0·809	−0·342
Ictalurus punctatus	0·752	0·341	−0·337
Gambusia affinis	0·902	−0·287	−0·293
Lepomis megalotis	0·282	0·909	0·236

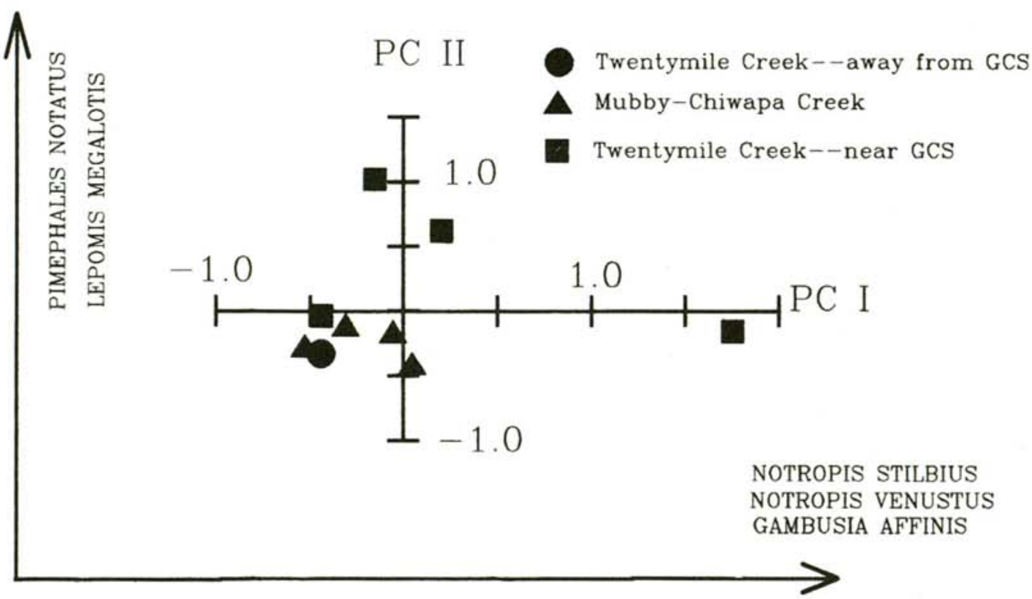

Figure 8. Principal components analysis of fish collections from Twentymile Creek and Mubby-Chiwapa Creek: position of sampling units (stations) in multivariate (fish) species space. Species that were significantly intercorrelated in abundance and strongly associated with PCs (loadings > 0·800) are indicated

in current and substrate type was reflected in species richness, relative abundances, and species diversity. Maximum species richness occurred at GCS where some swift water species (e.g. *Notropis volucellus*, *Etheostoma rupestre*) and slackwater species (e.g. *Hybognathus hayi*, *Notropis emiliae*, *Etheostoma nigrum*) were collected exclusively (Table IV).

Relative abundance of more common species was also positively influenced by conditions at GCS. *N. venustus*, *N. stilbius*, *P. notatus*, and *L. megalotis* are typical of pools and depths greater than 1 m (Pflieger, 1975; Baker and Ross, 1981; N. H. Douglas, personal communication); all four species were collected in large numbers around GCS (stations T-2 and T-3) where mean depths were ≥ 60 cm and in low numbers at other stations where mean depth was ≤30 cm, suggesting that depth was positively, albeit indirectly, associated with PCs I and II (Figure 8). Large numbers of the slackwater species, *P. notatus* and *L. megalotis*, were collected at the station with lowest velocity (2·7 cm s^{-1}) (T-2·2), reduced numbers in slightly faster water

Table VI. Species diversity of fish collections: Shannon function (H') and Pielou evenness index (E)

Stream	River km	Station	May 1989 H'	May 1989 E	July 1989 H'	July 1989 E
Twentymile	40·3	T-1	1·82	0·87		
	31·8	T-2·1 + T-2·2	2·09	0·84	2·06	0·65
	18·7	T-3·1 + T-3·2	1·75	0·58	2·05	0·60
	14·6	T-4	1·44	0·56		
	5·3	T-5			1·69	0·58
Chiwapa	34·9	C-1	1·22	0·49	0·61	0·31
	32·2	C-2	1·32	0·53		
Mubby	2·1	C-3	1.65	0.62	1·59	0·62
	20·3	C-4	1·61	0·61	1·92	0·69
	12·5	C-5	1·51	0·57	1·46	0·59

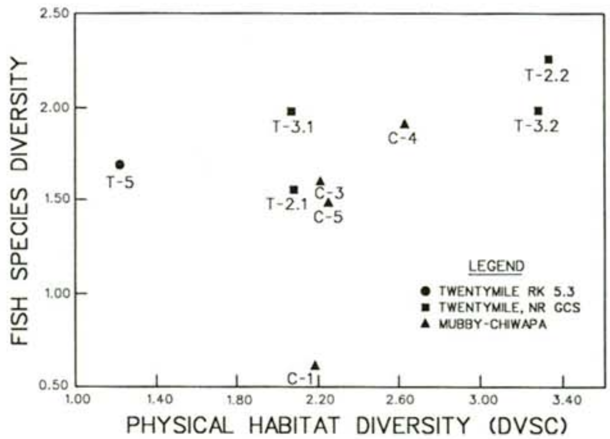

Figure 9. Fish species diversity and physical habitat diversity. Station numbers correspond to locations shown in Figure 1. Note that highest levels of physical and ichthyofaunal diversity were observed at stations below GCS

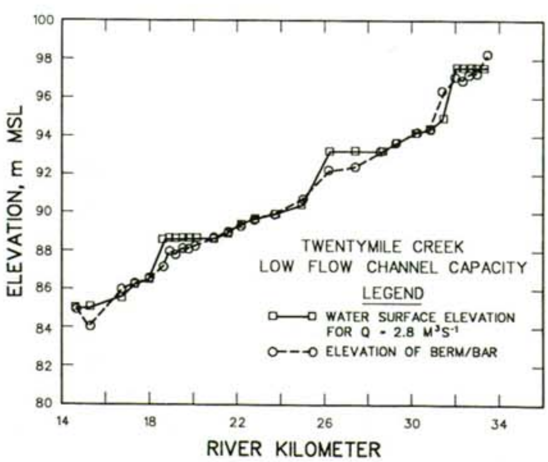

Figure 10. Longitudinal within-channel berm crest profile and low water surface profile, Twentymile Creek

(7·4 cm s^{-1}), moderate numbers at moderate velocities (9·5–24 cm s^{-1}), and lowest numbers at the station with the highest velocity (35 cm s^{-1}) (C-5), suggesting that mean velocity was negatively associated with PC II. Concomitant variation in species richness and relative abundance of common species with certain physical parameters resulted in significant positive correlations between those variables (mean depth, variation in velocity, substrate diversity) and fish diversity indices. Such correlations have been documented previously (Sheldon, 1968; Gorman and Karr, 1978; Evans and Noble, 1979; Foltz, 1982), but would not necessarily be expected for disturbed environments.

Poor water quality and habitat alterations could obscure relationships between physical habitats and fish assemblages. Tramer and Rogers (1973) surveyed streams degraded by agricultural runoff, sediment, and organic nutrients and, despite high variability, found no relationship between habitat complexity and fish diversity. Scarnecchia (1988) observed that fish diversity was not significantly different between channelized and unchannelized sections of a stream. In the latter study, however, species richness was substantially greater in the unchannelized section, and fish diversity was associated with higher mean velocity and substrate diversity. These findings suggest that small-scale variations in flow provide important microhabitats for rare and uncommon species.

Hillslope cultivation and a series of channel modification projects have damaged aquatic habitats throughout the Twentymile Creek watershed. Although recovery of aquatic habitats and communities may be slow and ultimately incomplete, the process of recovery may be facilitated by construction of GCS and development of a low-flow channel flanked by vegetated berms. Scour holes below GCS weirs and low-flow channels immediately downstream were superior habitat to reaches without deep holes or low-flow channels; however, we did not evaluate habitats provided by channel reaches distant from GCS.

GCS and bank protection structures facilitate habitat recovery in two ways. By promoting overall channel stability, they encourage evolution of a two-stage channel with vegetated berms, and they serve as major habitat features by providing relatively large, permanent scour holes, regions of accelerated and reduced velocity, and coarse, stable substrate. Even though the Twentymile Creek GCS directly influence only short reaches of stream, the GCS scour holes provided habitat for several species absent from shallow reaches (e.g. suckers and gars). Riffles, runs, and rocky substrates near the GCS were utilized by minnows and darters absent at other stations (Table IV). Such habitats in small streams are increasingly important for many fishes of the Tombigbee drainage, especially those that are endemic or inhabit larger streams. *Etheostoma rupestre*, for example, is endemic to the Mobile basin and has recently experienced substantial fragmentation of its range through habitat alterations (Kuehne and Barbour, 1983). *Hybognathus hayi*, once common in pools and backwaters of medium and large streams of the southeastern U.S. coastal plain, has declined substantially throughout much of its range (Pflieger, 1975; Robison and Buchanan, 1988). Both species have disappeared throughout much of the upper Tombigbee River, and isolated populations in small tributaries are increasingly important to the species (Boschung, 1987; Boschung, 1989). The presence of these two species, and a dozen others, at the Twentymile Creek GCS underscores the importance of habitats provided by stabilization structures as refugia for fishes experiencing reductions in available habitat. On the other hand, channel evolution and restabilization depends upon stable conditions upstream and downstream (Harvey and Watson, 1986). If channel baselevel or watershed land use are changed, a new episode of instability may ensue, disrupting the habitats associated with GCS.

Channel modification projects would be less detrimental to aquatic ecosystems if they were designed and constructed with two-stage cross-sections that included low-flow channels. Design criteria for low-flow channel dimensions might be based on dimensions of naturally-formed low-flow channels in enlarged cross-sections. Apparently main channels of stable, unaltered streams are sized to convey the effective discharge—the increment of discharge that transports the largest fraction of the annual sediment load over a period of years (Wolman and Miller, 1960; Pickup and Warner, 1976; Andrews, 1980). Reported recurrence intervals for effective discharges vary widely, but frequently are 1–2 years (Williams, 1978). A dichotomy of thought exists regarding the capacity of low-flow channels. Some investigators (Watson *et al.*, 1988) report low-flow channel capacities equal to the effective discharge, while others (Harvey and Watson, 1988) have identified low flow channels sized to convey much smaller, more frequent events. For example, Harvey and Watson (1988) reported a low-flow capacity for Muddy Creek that was equal to base flow, which was only 12 per cent of the 1 year recurrence-interval event. Osterkamp and Hupp (1984) reported that elevations of depositional bars in northern Virginia streams (defined as the lowest prominent in-channel features above the channel bed) corresponded to the water surface elevation for the 40-per cent duration discharge. Nunnally (1990) reported low-flow channel capacities equivalent to 16, 26, and 41 per cent duration discharges for three streams in the Eastern U.S.A.

Our finding that the Twentymile Creek low-flow channel capacity was equivalent to the 30 per cent duration flow seems to support the second position; the effective discharge for Twentymile Creek was much larger than the 'bermfull' discharge (Shields *et al*., 1990). However, prediction of the shape and size of low-flow channels is probably more complex than can be expressed by a simple empirical relationship. Immature low flow channels are likely quite dynamic, reflecting flow variability and antecedent conditions (Yu and Wolman, 1987) as well as sediment load and size. Formation of the low flow channel within the Type V configuration described by Harvey and Watson (1986) occurs only if sediment supply and channel hydraulics combine to produce transport of sand as dune bedforms during higher flows and formation of drapes of cohesive fine sediments over channel margin bedforms during falling stages. Sediment supply and channel hydraulics reflect site-specific conditions that relate to the magnitude of channel incision at the location in question and upstream as well as other factors such as watershed land use.

CONCLUSIONS

Stream channel modifications, particularly those that cause widespread bed degradation, can have extreme consequences for the entire watershed. Within and upstream from the modified reach, rapid channel enlargement, destruction of bridges and other riparian structures, and gullying occur, while sediment deposition occurs downstream of the modified reach. Rapid scour and deposition can be detrimental to aquatic and terrestrial habitats along the stream. Incised channels of modified streams in northern Mississippi can evolve into potentially more heterogeneous two-stage configuration if baselevels and watershed hydrology remain stable. This evolution may be facilitated by construction of GCS and bank stabilization measures. Species diversity and richness of fish communities in channelized streams are positively associated with structures which increase depth, decrease velocity, and increase physical heterogeneity at low flow. Simple design criteria for sizing low flow channels within two-stage flood control channels are unlikely to be developed.

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