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RELATIONSHIPS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF CUTOFF BENDS ALONG THE TENNESSEE-TOMBIGBEE WATERWAY

by

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Construction of the Tennessee-Tombigbee Waterway (TTW) involved construction of a navigation channel across the necks of 38 meander bends of the Tombigbee River. The cutoff bends, or bendways, constitute a valuable resource that the Corps of Engineers is committed to maintain. This study was conducted to provide a rational basis for refinement of the management strategy.

Fish and water quality data collected on a semiannual basis over a 3-year period from 12 of the TTW bendways were compared with physical data from aerial photographs and annual hydrographic surveys of 13 of the bendways. To broaden the basis of study findings, similar data for three Upper Mississippi River side channels and 12 Lower Mississippi River floodplain lakes were also examined. Eight of the Lower Mississippi River sites had been

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sampled by other investigators in 1987. One of these lakes and four additional ones had been sampled in 1985 and in 1986.

Important aquatic physical habitat factors for the TTW bendways included current velocity, bendway morphology, and water quality. During the period of this study, current velocities were negligibly small in all of the TTW bendways. Bendway morphology is directly related to the vertical location of the bendway channel relative to normal pool elevation. Bendways in the higher, upstream reaches of navigation lakes tended to be shallower and narrower than those in the middle or lower reaches. Bendways in the downstream portions of the lakes just upstream from the dams tended to resemble deep reservoir embayments.

Based on Kulczynski Type I similarity analyses, fish community composition varied little among the TTW bendways. Electrofishing catch per unit effort and the average number of fish species per electrofishing transect varied inversely with depth and thus was greater for the upper pool bendways. Summer DO levels near the bottom of the water column were lower in the deeper bendways, and Secchi disk depths were higher.

Biological differences among the Upper Mississippi River side channels and the Lower Mississippi river floodplain lakes were related primarily to the relative influence of the main channel rather than depth or shoreline development. However, fish diversity and standing stock reported from the 1987 investigation were inversely related to depth.

PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), in fulfillment of Military Interdepartmental Purchase Request No. FC 89-0031. Mr. Thomas A. Lightcap of the US Army Engineer (USAE) District, Mobile, was the District point of contact. Messrs. Norman Connell and Rick Saucer of the Tennessee-Tombigbee Waterway Management Center, USAE District, Mobile, provided assistance with field inspections. The report was written and prepared by Dr. F. Douglas Shields, Jr., and Messrs. Thomas E. Schaefer and Anthony C. Gibson of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL.

Technician support was provided by Ms. Cheryl M. Lloyd. Assistance with biological and water quality data was provided by Mr. Thomas Thornhill and other personnel of the US Fish and Wildlife Service, Daphne, AL; Dr. Diane Findlay, USAE District, Mobile; Mr. Fred Morris, US Geological Survey, Jackson, MS; and Mr. Garry Lucas, Mississippi Department of Wildlife Conservation, Bureau of Fisheries and Wildlife, Cleveland, MS. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

Technical reviews of the report were provided by Drs. Barry S. Payne and Andrew C. Miller of the Aquatic Habitat Group, Environmental Resources Division, EL, and Dr. Robert H. Kennedy of the Aquatic Processes and Effects Group, Ecosystem Research and Simulation Division, EL.

The work was accomplished under the direct supervision of Dr. John J. Ingram, Chief, WREG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED; Dr. John Keeley, Assistant Chief, EL; and Dr. John Harrison, Chief, EL.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres

RELATIONSHIPS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF CUTOFF BENDS ALONG THE TENNESSEE-TOMBIGBEE WATERWAY

PART I: INTRODUCTION

Background

1. Construction of the River Section of the Tennessee-Tombigbee Waterway (TTW) involved dredging cutoff channels across some 38 meander necks along the Tombigbee River, thereby creating 38 cutoff bends (bendways). Locations of the bendways are shown in Figure 1. Figure 2 depicts two typical bendways. A listing of the TTW bendways, including data on reservoir location, length, cutoff date, and current status, is presented as Table 1.

2. Throughout the development of the TTW project, the US Army Corps of Engineers made commitments to the public and to other agencies that appropriate measures would be taken to maintain the resources of the bendways. These commitments were summarized in the Task Force Phase I Report (US Army Engineer District (USAED), Mobile 1981) and by Shields (1987). To keep these commitments and to address concerns regarding management of the bendways, the Mobile District formed a multidisciplinary task force and conducted a bendway management study (USAED, Mobile 1984). This study resulted in a plan containing specific management recommendations for each of the 30 bendways downstream of Aberdeen Lock and Dam. The bendways located in Aberdeen Lake were not included in the management plan because they were incomplete at the time of the study. The study recommended that the bendway management strategy be flexible due to the rapidly changing nature of the system and the state of knowledge about it. Accordingly, the implemented management measures (shown in Table 1) have differed somewhat from the 1984 recommendations.

3. In addition to management actions, the 1984 study also recommended implementation of a program to monitor fish populations, water quality, and sediment deposition in selected bendways (USAED, Mobile 1984). Accordingly, closely spaced sedimentation ranges were established in 14 of the bendways (indicated by a numeral 1 in the last column of Table 1) at the same time the rest of the reservoir sedimentation ranges were established, and have been surveyed at roughly annual intervals ever since. Furthermore, fish and water

quality of 12 bendways (indicated by numerals 3 and 4 in the last column of Table 1) have been sampled semiannually in the fall and spring by the US Fish and Wildlife (USFWS) with funding provided by the Mobile District. Additional chemical and biological monitoring has been performed by the US Geological Survey (USGS). Bendway monitoring activity is summarized in Table 1.

4. The USAED, Mobile (1984), suggested that review studies be conducted at 3-year intervals after implementation of the management measures to assess the adequacy of the initial study effort and the effectiveness of the management measures. This report represents a part of the suggested review effort and is the third in a series of three that provide technical assistance to the Mobile District in regard to its assigned mission to manage the environmental resources associated with the TTW bendways. The first report (Shields 1987) documented geometric changes that occurred in the bendways between construction of cutoffs and the 1985 survey, and developed and used a technique for predicting future change. Based on this work, prompt blockage of the upstream entrances of most of the bendways was recommended in order to prolong the life of the aquatic resource. The second report (Shields and Gibson 1989) documented physical changes that occurred in the bendways between the initial and the 1987 surveys, and predicted long-term bendway changes based on study of historical aerial photographs of bendways and natural oxbow lakes along the Tombigbee and six other rivers. This study led to the conclusion that, after the TTW bendways are blocked at their upstream entrances to top bank elevation, they are expected to retain fairly constant surface areas and perimeters for periods of time longer than a century unless they receive significant quantities of sediment from their local drainage areas.

Purpose

5. The purpose of this report is to compare and contrast selected TTW bendways based on their physical characteristics and fish communities in order to provide technical support for management decisions. Significant differences among bendway fish communities that are strongly associated with physical factors can be the basis for employing differing management approaches or levels of effort for various bendways. On the other hand, if there are no biologically significant differences in physical habitat

provided by the bendways, management effort should be applied with roughly equal emphasis per unit bendway surface area.

Scope

6. Key descriptors of the physical aquatic habitat provided by the surveyed TTW bendways were calculated based on the 1987 hydrographic survey data. Fish populations of each of the monitored TTW bendways were described by statistics and indices computed from data collected between 1986 and 1988 by the USFWS (1987-1989). These statistics and indices were compared to ascertain the existence of distinctive differences among bendways. The association of these differences with the computed physical habitat descriptors and water quality factors was explored. Similar analyses were performed using data from 12 floodplain lakes along the Lower Mississippi River and three Upper Mississippi River side channels. A discussion of the implications of these findings to management of the TTW bendways concludes this report.

PART II: APPROACH AND METHODS

7. Since the approach of this study is somewhat unorthodox, this part begins with a short review of work done by others in the area of relating physical and biological characteristics of riverine backwaters along shallow-draft waterways. The use of diversity indices and similarity coefficients is described, and study areas for this investigation are identified. The physical and biological variables selected for analysis are then discussed, and data acquisition and analysis methods are presented.

Approach

Aquatic populations and physical habitat

8. Aquatic populations of a given water body, such as the fish community of a bendway or floodplain lake, are a reflection of the physical (morphologic) and chemical (water quality) properties of the water body. This principle is basic to various types of aquatic habitat modeling (Miller et al. 1987). Barring confounding influences such as pollution events, observed differences in communities in different aquatic habitats located along the same river reach may often be explained in terms of differences in physical habitat factors. For example, Beckett and Pennington (1986) found that observed differences in water quality, algal biomass, macroinvertebrate populations, and fish populations among several types of habitat found in and along a 62-mile-long* reach of the Lower Mississippi River were related to physical habitat characteristics, in particular, current. In another case, Castella, Richardot-Coulet, and Richoux (1984) found that macroinvertebrate populations of eight abandoned channels along the French Upper Rhone could be categorized based on whether the channels were permanently connected to the river. Shipp and Hemphill (1974) sampled fish, current, and water quality from five meander bends on the Lower Alabama River, two of which had been recently cut off. Differences in fish habitat and fish communities between

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

the cutoff and unaltered bends were attributed to reduced current velocity in the cutoff bends.

Description of fish communities

9. Results of fish sampling are usually described by species lists and numbers or biomass of each species. Summary or total statistics (number of species, total catch per unit effort, etc.) are typically also presented. Further description often takes the form of length-frequency distributions or condition factors for selected species. Samples are usually replicated in time and space, although the number and frequency of replications vary from study to study.

10. Direct comparison of fishery data from different bendways is difficult due to the temporal variability of many of the reported parameters and the minor differences in sampling technique. Furthermore, the quantity of biological data also complicates comparison. To compare bendways, the entire fish sample taken from each bendway or oxbow lake often must be characterized by a relatively small number of indices or statistics.

11. Diversity indices and binary similarity coefficients, statistics based on species composition and presence or absence, have been used by some investigators to compare fish communities (Polovino, Farrell, and Pennington 1983). Similarity coefficients are preferred over diversity indices because diversity indices tend to be biased when sampling effort is nonuniform across compared habitats and when small sample sizes are used. Furthermore, species diversity is not always lower for degraded systems, nor are diversity indices always consistent indicators of the complexity of community structure. On the other hand, binary similarity coefficients are not influenced by unbalanced sampling designs, if sampling is adequate to generate representative species lists for the communities being compared. They are most attractive for regional assessments of species composition data where very different sampling methods are used. Since binary similarity coefficients do not involve quantitative data, they are therefore exempt from bias caused by the differences in frequency and numbers of dominant species (Polovino, Farrell, and Pennington 1983).

12. Binary similarity coefficients can be awkward for comparing or ranking a large group of communities because the coefficients simply quantify comparison of two fish communities at a time. They do not directly result in the grouping or ranking of a group of more than two communities as to their

relative value or health. The Kulczynski Type I similarity coefficient* was recommended by Polovino, Farrell, and Pennington (1983) over 21 other binary indices.

Previous use of
indices in bendway studies

13. Several investigators have attempted to relate physical characteristics of bendways and oxbow lakes to various types of community indices. Pennington et al. (1981) used the Jaccard and Morisita similarity indices to compare macroinvertebrate communities sampled from four TTW bendways and the adjacent navigation channels (Rattlesnake, Cooks, Big Creek, and Hairston Bends) in 1979 and 1980. The Morisita indices based on the macroinvertebrate collections showed that similarity was related to the time elapsed since cutoff. Fish communities sampled in the same four bendways were compared using the Kulczynski similarity and the Bray-Curtis dissimilarity coefficients. The degree of similarity between communities present in any pair of the four sampled bendways was related to their relative position in the reservoir pool, and thus to current velocity and depth. Kulczynski coefficients from the analysis of fishery data were graphically depicted by Baker and Bond (1982) (Figure 3). The circles in Figure 3 represent the fish communities of the sampled bendways. The similarity between each community pair is directly proportional to the number of connecting lines. Numbers beside the connecting lines are similarity coefficients.

14. Lowery et al. (1987) compared fish communities of eight Lower Mississippi River floodplain lakes using Jaccard similarity coefficients. Separate coefficients were computed with data obtained using each of the three gear types: rotenone, gill netting, and electroshocking. The coefficients based on electroshocking data indicated that the two longest lakes (Deer Park and Raccourci) were similar to one another, and dissimilar to the remaining group of six, which were similar to each other. Coefficients based on rotenone data showed seven of the lakes were similar, with only one (Canadian Reach) dissimilar. Canadian Reach had three physical differences from the other seven lakes: (a) the substrate was much coarser, (b) it lacked shallow

* The Kulczynski Type I similarity coefficient is the ratio of the number of species two communities have in common to the number of species found in only one of the two communities.

shoreline habitat, and (c) a solid waste landfill was located on one bank. Coefficients based on gill netting data showed that Deer Park and Canadian Reach comprised one group, with the remaining six lakes in a second group.

15. The USFWS (1987, 1988) reported Shannon-Weiner diversity and Pielou evenness indices for the 10 TTW bendways they sampled. Separate indices were computed for bendways, cut channels, and old river navigation channels. Diversity indices were heavily influenced by large fluctuations in the numbers of shad that were captured. No effort was made to relate variation in the indices to physical characteristics of the areas sampled, but the authors did note that abundance and diversity of fishes in the nonbendway locations appeared to vary with the quantity and quality of shoreline cover.

Study Areas

16. The TTW study bendways were well distributed along the waterway (Figure 1) and were representative of the entire group of 38. Inclusion of TTW bendways in this study was based upon availability of physical and biological data.

17. To verify the utility of the approach used, published data for Mississippi River sites were also examined. Data for three Upper Mississippi River side channels in northeast Missouri (Figure 4) were obtained from Ellis, Farabee, and Reynolds (1979). These side channels, located in navigation impoundments, are similar to TTW bendways in that they are river channel-shaped backwaters connected to run-of-river navigation impoundments. Two of the three are blocked at their upper end.

18. Data were also obtained for 12 Lower Mississippi River floodplain lakes (Lucas and King 1986, Lowery et al. 1987), as shown in Figure 5. All of these lakes are on the river side of the main stem levees, and many are remnants of bendways cut off by man in the 1930s and 1940s.

Selection of Physical Variables

19. Physical variables that may be used to describe bendway habitat include velocity, substrate type, channel width and depth, shoreline development, and cover. Two criteria were used to select specific physical variables for analysis: availability of data and variability among study sites.

If a physical variable was obviously fairly uniform from bendway to bendway, it was not included.

TTW bendways

20. Velocity. During the period of data collection (1985-88), current velocities remained near zero in the TTW bendways; therefore, velocity was an unimportant factor in this analysis. Flow does not occur through the bendways except during floods, and the period of interest was characterized by exceptionally low flow. Limited flow occurs in some bendways due to operation of the locks or tributary inflows, but velocity measurements by the USFWS (1987-1989) concurrent with their fish and water quality sampling showed velocities were generally insignificant.

21. Substrate. Detailed analysis of bendway substrate composition data was beyond the scope of this study. The USGS sampling program has included collection of bed material samples in five of the bendways since 1986. Pennington et al. (1981) found that surficial bottom sediments of three TTW bendways rapidly grew finer after the bendways were cut off. It is probably reasonable to assume that substrates in the bendways were fairly uniform from bendway to bendway during the period when biological data examined herein were collected, due to the uniformity of current velocities. Bendway substrates (surface sediments) were most likely a veneer of unconsolidated silt and clay overlying fine sand (Pennington et al. 1981).

22. Depth. Depth and bendway geometry were the primary measures of physical habitat quality used in this study for comparing bendways. Water surface elevations in the TTW River Section lakes are maintained at normal pool elevations except during high flows. Therefore, depths in the bendways vary little with time during low and moderate flows such as those that persisted during much of the period of data collection. Depth measurements for 14 of the 38 TTW bendways are available from the annual hydrographic surveys, and approximate values for maximum depth are available for nearly all of the other bendways from water quality profiles. Bendway depth and width increased from the upper to the lower ends of the navigation lakes.

23. Length and shoreline development. Bendways such as Big Creek and James Creek, which are located in upper portions of the pools, are shallow, narrow, and sinuous relative to bendways in the lower portions of the pools such as Cooks Bend (Figure 2). Shoreline development indices (SDI) were

computed for the TTW bendways using areas and perimeters measured from aerial photographs and the formula

$$SDI = \frac{P}{2\sqrt{\pi A}}$$

where

P = perimeter, ft

A = surface area, sq ft

The SDI is the ratio of the perimeter to the circumference of a circle with equal perimeter and thus is an indicator of the sinuosity or complexity of the shoreline. The SDI is greater for higher values of shoreline complexity. The SDI of a perfect circle is 1.0. Bendway length probably has little influence on habitat quality, except that shorter bendways may be flushed more readily by transient water-level fluctuations such as those caused by tow passage.

24. Cover. No data were available regarding aquatic cover for any of the bendways, although cover as a percent of water surface area for a given bendway is probably inversely related to mean depth. The bendways are also wider. The wider a bendway is, the less its surface area is influenced by shoreline vegetation and associated snags.

25. Water quality. The USFWS (1987-1989) reported basic water quality measurements (dissolved oxygen (DO), Secchi disk, pH, conductivity) collected at the same times and locations as the fish data. Additional water quality data were available from the files of the USGS. Only DO concentrations and Secchi disk measurements were used in the analyses. Examination of the other data was beyond the scope of this effort.

Mississippi River sites

26. Detailed hydrographic surveys were not available for the Mississippi River sites. Physical descriptors used for those sites were limited to information provided by the original investigators on velocity, substrate, depth, DO, and water transparency. In addition, geometric data (areas and perimeters) were obtained from survey charts. Velocity varied among the three Upper Mississippi River side channels but was uniformly zero for the

Lower Mississippi River sites. Surface area, perimeter, and shoreline development indices were determined for the Mississippi River sites from published survey charts.

Selection of Biological Variables

27. Based on the work by Polovino, Farrell, and Pennington (1983), the Kulczynski Type I similarity index was selected as a key biological variable for this study. Three additional statistics were also computed from electrofishing data for comparison with physical descriptors: the average electrofishing catch per unit effort, the total number of species captured, and the Shannon-Weiner Diversity Index. Rotenone data from Lowery et al. (1987) were also used to tabulate standing crop and total number of species and to calculate diversity indices.

Methods

Physical data

28. Geometric elements for 13 of the 14 surveyed TTW bendways were computed using the Bendway Sedimentation Data (BSD) program described by Shields (1987). Hickelson Lake bendway was not included in the analysis because it was virtually filled with sediment before the period of interest (1986-88). The 1987 survey was used to derive the geometric elements because it represented the midpoint of the biological sampling period (1986-88). Furthermore, dredging and blockage work on surveyed bendways was completed prior to the 1987 survey. Blockage structures were in place in 6 of the 13 bendways prior to the 1987 survey (Big Creek, Hairston, Vinton Creek, Denmon Creek, Cane Creek, and James Creek).

29. Geometric elements that were computed included bendway length, approximate surface area, mean width, and mean depth. The ratio of bendway channel volume below normal pool elevation to total bendway channel volume below top bank elevation was also computed, as was the percent of bendway channel volume below normal pool that was shallower than 3 ft and the percent volume between 3 and 6 ft deep. In addition, to compare the cross-sectional shape of TTW bendways, a dimensionless depth-volume curve was derived for each bendway, and all curves were plotted on a common axis.

30. Less information was available for the Mississippi River sites than for the TTW bendways. Areas and perimeters of the Lower Mississippi River sites were measured from the 1973-75 comprehensive hydrographic surveys published by the USAED, Vicksburg (1977) and the USAED, Memphis (1976). Similar data were obtained from charts published by the US Army Engineer Division, North Central (1982), for the three Upper Mississippi River sites. The shorelines of the lakes depicted on these charts are based on data extracted from aerial photographs using photogrammetric techniques. Measurements were made using a Geographics drafting board digitizer with Measugraph software running on an IBM PC/XT microcomputer with a specified accuracy of 0.00125 in.

31. Ellis, Farabee, and Reynolds (1979) presented average values for width, depth, and surface current velocity for the three Upper Mississippi River side channels they studied. Widths and depths were based on measurements at several transects across each of the side channels. Lowery et al. (1987) presented mean depths and widths for the eight lakes they sampled that were based on a limited number of Fathometer-surveyed cross sections.

Fishery data

32. Fishery data were obtained from four sources:

a. The USFWS conducted semiannual sampling of fish in 12 of the TTW bendways with electrofishing, gill netting, and application of rotenone to 0.012-ha littoral areas from 1986-88.

b. Ellis, Farabee, and Reynolds (1979) compared the limnology and fish communities of three side channels of the Mississippi River in northeast Missouri during 1975-76. Fish were sampled by electrofishing and hoop netting twice each month during June and July and once each month from August through October.

c. The US Army Engineer Division, Lower Mississippi Valley, conducted a study of eight lakes along the Lower Mississippi River in the fall of 1984 (Lowery et al. 1987). Fish populations were sampled by electrofishing, gill netting, and application of rotenone to 0.4-ha plots.

d. The state of Mississippi (Lucas 1985, Lucas and King 1986) conducted electrofishing surveys of five oxbow lakes along the Lower Mississippi River in the fall of 1985. One of the lakes (Lake Whittington) sampled by Lowery et al. (1987) was also sampled by Lucas and King (1986). Information regarding sampling procedures followed in each investigation is presented in Table 2.

Water quality data

33. Water quality data for a few parameters were obtained concomitant with fish sampling by all investigators (Table 2). In addition, the USGS

sampled water quality in selected TTW bendways as shown in Table 1. Standard procedures were used for sample collection, handling, and analysis.

Analysis

34. Descriptive statistics and graphics were used to formulate logical groupings of water bodies in each of the four studies (Table 2) based on physical descriptors. Graphical and correlation analyses were then used to determine if fish community similarity coefficients, species richness, or catch per unit effort was related to physical or elementary water quality factors.

PART III: RESULTS AND DISCUSSION

Physical Data

Tennessee-Tombigbee bendways

35. Key geometric descriptors for the surveyed TTW bendways are presented in Table 3. Values in Table 3 are based on water surface elevation equal to normal pool elevation. Mean depths for New Hamilton and Lockridge Creek bendways were estimated from measured mean depths in the other bendways in the upper portion of Columbus Lake. Physical characteristics tended to display a continuum of values rather than clusters or well-defined groups (Figure 6). However, Big Creek Bend represents one extreme of the observed values (upper pool, shallow, narrow channel), while Rattlesnake and Cooks Bend represent another (lower pool, deep, wide channel). Bendways tended to become wider and deeper from the upper to the lower portions of the navigation pools. Biological data are examined below in light of these physical extremes.

36. Variation in physical habitat character from one TTW bendway to the next depended almost entirely on the vertical location of the bendway channel with respect to normal pool elevation. For example, Figure 6 shows that the fraction of bendway volume that comprised shallow habitat (3 ft deep or less) was highly* correlated with mean water depth ($r = -0.85$).

37. Figure 7 shows a dimensionless storage curve for all surveyed TTW bendways. The y-axis variable (dimensionless depth) is the ratio of mean water depth to the difference between the top bank and minimum thalweg elevations. Figure 7 shows that, with the exception of Big Creek Bend, all of the bendways had extremely similar cross-sectional shapes. The plotting positions for the points for Big Creek Bend in Figure 7 were no doubt influenced by the considerable sediment deposition that has occurred there.

38. Shoreline development indices tended to increase from upper pool to lower pool (Table 3). Bendways deeper in the pools tended to be longer and to include flooded tributary embayments, which increased shoreline development.

* See Appendix A for detailed tabulation of statistics for correlations presented in this report.

Upper Mississippi River side channels

39. The three Upper Mississippi River side channels studied by Ellis, Farabee, and Reynolds (1979) are morphologically and hydrologically similar to the TTW bendways (Figure 4). All three were located in river reaches controlled by navigation locks and dams constructed in the 1930s. Physical characteristics varied with location in the navigation pools: water-level fluctuations increased in magnitude and frequency from the lower to the upper ends of the pools. Physical data provided by Ellis, Farabee, and Reynolds (1979) for the three study sites are presented in Table 4. Based on physical characteristics, Buzzard and Orton-Fabius side channels would be grouped together, and Cottonwood side channel alone.

Lower Mississippi River floodplain lakes

40. Available physical data for the 12 Lower Mississippi River lakes are presented in Table 5. These water bodies are dissimilar to the TTW and Upper Mississippi River sites in that they are subject to a wider range of more frequent water-surface elevations. Based on velocity measurements and substrate samples, only one of these sites (Canadian Reach) experiences significant velocities and inflow from the river during nonflood periods. Physical habitat characteristics of all of these lakes except for Canadian Reach were similar.

Biological Data

Tennessee-Tombigbee bendways

41. Lists of fish species captured at each sampled bendway were extracted from the USFWS annual reports. Two lists were compiled for each bendway: one consisted of all species sampled on all sampling dates with all gear types; the other was limited to electrofishing data for all dates. These lists were then used to generate corresponding triangular matrices of similarity coefficients. Table 6 presents the matrix of similarity coefficients based on the species list for all gear types. Fewer species were sampled by electrofishing than by using all types of gear, but similarity coefficients based on only electrofishing data were similar.

42. The TTW bendway similarity coefficients were essentially unrelated to differences in physical habitat. Figure 8 presents plots of similarity coefficients versus the ratio of percent of water volume shallower than 3 ft and versus mean depth ratios.* Similarity coefficients for the two most physically dissimilar bendways (Cooks Bend and Big Creek) were used as abscissa and ordinate in the scatter plot shown as Figure 9. If physical differences between Cooks Bend and Big Creek bendways were biologically significant, Figure 9 would display a negative correlation: bendways with species composition most similar to Cooks Bend would be least similar to Big Creek, and vice versa. However, Figure 9 shows that, in general, the more similar the fish community in a bendway was to the Cooks Bend community, the more similar it was to the Big Creek community.

43. Average similarity coefficients between and within the three categories of pool location shown in Table 3 (upper, middle, and lower) were also computed (Table 7). Similarity was related to pool location, with the lower pool sites more similar to middle sites than upper sites. Middle pool sites tended to be more similar to one another than to the other two groups. Results shown in Table 7 must be viewed in light of the fact that the analysis included only one lower pool bendway (Cooks Bend), but six upper pool bendways and five middle pool bendways.

44. Table 8 presents the total number of species and individuals found in each bendway, the number of fish species captured at each bendway that were not found in any of the others, and the maximum similarity coefficient for each bendway. A total of 78 species were captured from the 12 sampled bendways. Columbus Bend yielded the maximum number of species (47). Big Creek Bend and James Creek, upper pool bendways that have experienced rapid sedimentation from tributaries and the main channel, yielded four and one fish species, respectively, not found in any other bendway.

45. A species list for Hairston Bend, which represents preconstruction (preimpoundment and precutoff) conditions, was obtained from Pennington et al. (1981) and used in the analysis for comparison. Seven of the 38 species

* Kulczynski Type I similarity coefficients were computed for each pair of bendways (Table 6). The numbers in Table 6 were then plotted against the ratio of depths for the appropriate pair of bendways (Figure 8). Ratios were computed so that they were always greater than or equal to 1.0. Physical similarity is thus inversely related to the ratio.

captured by Pennington et al. (1981) at Hairston Bend prior to construction were not found at any of the bendways during the USFWS study. The disappearance of these species probably reflects the loss of lotic habitats such as gravel bars.

46. Hairston Bend, from which 41 fish species were captured during the 3 years of sampling, was the most similar bendway to four others (James Creek, Lockridge Creek, Columbus Bend, and Cooks Bend). Hairston Bend contains habitat similar to both lower and upper pool bendways. The upstream entrance resembles middle or upper pool bendways, while the downstream entrance resembles a reservoir embayment, as do the lower pool bendways.

47. Average electrofishing results reported by the USFWS (1987-1989) are presented in Table 9. Electrofishing results were influenced more by physical habitat differences than were similarity coefficients. Average catch per unit effort (CPUE), average number of fish species captured per transect, and species diversity were greater for shallower, narrower bendways in the upper portions of navigation pools (Table 9). Species richness was lower for the two bendways in Aberdeen Lake (Drummond Branch and Roundhouse), possibly because they were only sampled three times, while the other bendways were sampled six times. Conversely, average CPUE was higher at these two bendways, perhaps reflecting the "new reservoir effect." Aberdeen Pool was raised in 1984, while Columbus, Aliceville, and Gainesville were raised in 1981, 1979, and 1978, respectively.

48. Scatter plots and correlation analysis (Figure 10 and Table A1, Appendix A) revealed only one significant correlation between a biological and a physical variable. Average number of fish species per electrofishing transect and mean depth were inversely correlated ($r = -0.62$). Exclusion of data points representing Aberdeen Lake bendways did not significantly improve the statistical strength of the correlations. Evidently, physical conditions in TTW bendways are sufficiently similar that fish communities vary little among the bendways.

49. Electrofishing results were significantly correlated with chemical (water quality) differences among the bendways (Figure 11 and Table A1). Average species richness was inversely related to Secchi disk depth and directly related to bottom DO concentration. Average CPUE was inversely related to Secchi disk depth. As might be expected, the deeper bendways in

the lower portions of the navigation pools tended to have higher Secchi disk readings and lower late-summer bottom DO values (Figure 12 and Table 10).

50. The differences in electrofishing results in Table 9 are due either to electrofishing gear bias toward the shallower upper pool bendways or to real differences in habitat quality. The selectivity of electroshocking for shallower waters and for habitats with more cover is well known. The shallower upper pool bendways experience less thermal stratification and attendant near-bed DO depletion and tend to have more structure per unit area than the deeper bendways. Dissolved oxygen depletion in the lower portion of the water column results from thermal stratification. Lucas (1988) observed a positive association between the degree of thermal stratification and average depth in his study of 15 natural floodplain lakes in Mississippi. Lakes 6 to 12 ft deep were well mixed, while deeper lakes had depressed DO levels near the bottom.

51. Dissolved oxygen depletion reduces habitat suitability for fish and benthos. Harrel (1973) studied a small, deep (18 to 27 ft) meander scar lake in southeast Texas and found that benthic diversity was zero at depths greater than about 9 ft, presumably because all but the upper 6 to 12 ft of the water column was anoxic most of the year. Conversely, healthy aquatic communities have been found in oxbow lakes along the Lower Mississippi River which experience DO depletion at depth (Beckett and Pennington 1986, Wright 1982).

Upper Mississippi
<u>River side channels</u>

52. The species lists provided by Ellis, Farabee, and Reynolds (1979) were used to compute Kulczynski similarity coefficients for the three sampled side channels (Table 11). When compared with the geometric variables shown in Table 4 and the water quality variables shown in Table 12, similarity of side channel fish communities was closely related to mean velocity, Secchi disk depth, and bottom DO, but was evidently unrelated to mean depth and shoreline development (Figure 13). Electrofishing catch per unit effort, species richness, and species diversity were similar for all three sites (Table 12).

53. Relationships between physical and biological variables were not formulated based on this data set because of the low number of sites studied (three). However, qualitative observations reinforce the trends shown in

Figure 13. In particular, Ellis, Farabee, and Reynolds (1979) noted that species composition varied among the three channels in a way that indicated that relative abundance of game and panfish increases and relative abundance of riverine species in the catfish and nongame fish groups decreases as side channels progress from riverine to lacustrine systems. These observations are consistent with the results of the similarity analysis described above. Pennington et al. (1981) noted similar changes in TTW bendways.

Lower Mississippi
River floodplain lakes

54. Separate sets of similarity coefficients were calculated using the data sets from Lowery et al. (1987) and the State of Mississippi (Lucas 1985, Lucas and King 1986). Rotenone data from Lowery et al. (1987) were used for one set of coefficients because rotenone is less selective than electrofishing. The other set of coefficients was based on electroshocking data from Lucas (1985) and Lucas and King (1986), because that was the only gear type they used. Matrices of Kulczynski Type I similarity coefficients for each of these data sets are present in Tables 13 and 14.

55. Seven of the eight lakes sampled by Lowery et al. (1987) were physically and biologically similar; the eighth, Canadian Reach, was distinctive from the other seven because it was more frequently influenced by main channel flow and lacked shallow shoreline habitat. Similarity coefficients are plotted against ratios of several key physical variables in Figure 14. Details of the correlation analysis are presented in Table A1. Similarity was not correlated with mean depth and shoreline development, but was inversely correlated ($r = -0.50$) with the percent sand in bed sediments. Electroshocking catch per unit effort and species richness were not correlated with any of the tabulated physical or water quality variables.

56. One of the main measured physical differences between Canadian Reach and the other lakes sampled by Lowery et al. (1987) was the amount of sand in the substrate. Substrate samples from Canadian Reach averaged 40 percent sand, while substrates in the other lakes tended to be much finer. The influence of percent sand in the substrate on similarity is seen in Figure 14. Figure 15 shows that the benthic biomass and the percent by weight of game fish in rotenone collections were inversely related to the percent of sand in the substrate. The distribution of points in Figure 15 suggests a nonlinear biological response to the amount of noncohesive material (sand) in

the bed; however, use of a nonlinear regression model of the form ae^{-bx} did not increase the coefficients of determination.

57. Shannon-Weiner diversity indices and estimates of standing stock were calculated using rotenone data presented by Lowery et al. (1987) (Table 15). Since many of the collections were dominated by shad, a second set of diversity indices was computed omitting shad. The latter diversity indices tended to be higher for lakes with higher shoreline development, although no such relationship was evident using normally computed indices (Figure 16). Standing stock tended to be lower for lakes with greater mean and maximum depths. Minimum DO levels were also lower in these lakes (Figure 17).

58. Relatively little physical information was available for the oxbow lakes sampled by Lucas and King (1986). Similarity coefficients are plotted against ratios of shoreline development index in Figure 18. No trends or relationships were evident. Although the five lakes were fairly similar physically, Lake Lee was somewhat distinctive. Lake Lee had the lowest shoreline development index of any of the Lower Mississippi River lakes (Table 5), and according to Lucas,* it had less flooded structure (willow mats and snags) at low stage than the others. Furthermore, of the sampled lakes, Lake Lee had the lowest condition factor for white crappie, and no young-of-year bass were captured there (Lucas and King 1986).

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* Personal Communication, 1989, Garry Lucas, Mississippi Department of Wildlife Conservation, Jackson, MS.

PART IV: SUMMARY AND CONCLUSIONS

59. To provide a technical basis for future decisions regarding management of the 38 TTW bendways, biological and physical characteristics of selected bendways were examined and compared. To broaden the basis of study findings, similar data for three Upper Mississippi River side channels and 12 Lower Mississippi River floodplain lakes were also examined. Eight of the Lower Mississippi River sites were sampled by Lowery et al. (1987). One of these lakes and four additional ones were sampled by Lucas (1985) and Lucas and King (1986).

60. Previous investigators suggested that current velocity is often the most important determinant of biological differences among riverine habitats along a given reach. Current velocities were insignificantly small in all of the TTW bendways during this study. However, biological differences among the three Upper Mississippi river side channels were current-related. Current was negligible at all Lower Mississippi River lakes at the time of sampling, but the presence of a larger fraction of sand in the bed sediments of one of the lakes indicated more frequent connection with the main channel. Accordingly, in this study, fish community similarity was found related to percent sand in substrate for the data set presented by Lowery et al. (1987).

61. The influence of morphologic factors, including depth and shoreline development, on community composition and abundance was also studied. Depth was considered because of its interaction with water quality due to thermal stratification. Shoreline development effects are related to the preference of many aquatic species for cover and structure.

62. The morphology of TTW bendways varies with the elevation of the bendway channel relative to normal pool elevation. Bendways tend to become deeper and wider from the upper to the lower end of a navigation lake. Upper pool bendways resemble old river channels with slightly elevated water surface elevations, while lower pool bendways resemble reservoir embayments.

63. Fish community species composition of TTW bendways (as indicated by Kulczynski Type I similarity coefficients) were not related to morphologic differences. Of all biological variables examined, only electrofishing transect average species richness was significantly correlated to a physical variable (mean depth). Average species richness and average catch per unit effort were greater for the six upper pool bendways sampled than for the

single lower pool bendway sampled. It is unknown whether results were due to gear bias toward the shallower bendways or to actual differences in habitat quality. Association was observed between electrofishing results and basic water quality: deeper bendways that had lower species richness and catch per unit effort tended to have lower bottom DO concentrations and higher Secchi disk readings.

64. Biological differences among the three Upper Mississippi River side channels were not related to morphologic factors (mean depth or shoreline development). Kulczynski similarity coefficients for the Lower Mississippi River sites were also not reflective of morphologic differences.

65. Based on the above results, fish habitat quality varies little among the TTW bendways. A previous investigation (Shields and Gibson 1989) showed that the upper pool TTW bendways are under the most immediate threat of conversion to terrestrial habitat by sedimentation. Since the longer upper pool bendways contain a significant acreage of excellent fish habitat, their preservation should receive priority when conducting bendway management activities.

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Table 1

Cutoff Bendways, River Section, Tennessee-Tombigbee Waterway

Reservoir/Bendway	Length ft	Cutoff Date	Current Management Option*	Monitoring**
Demopolis Lake				
Rattlesnake	51,740	1976	1	1
Gainesville Lake				
Pickensville	16,370	1981	1	
Coalfire	7,920	1981	1	
Hairston Bend	29,360	1981	4	1,3,5
Columbus Bend	18,480	1984	1	1,3,5
Aliceville Lake				
Warsaw	4,750	1980	1	
Cooks Bend	19,540	1980	1	1,3,5
Windham Landing	3,700	1979	1	
Cochrane	7,390	1979	1	
Lubbub Creek	21,650	1979	1	
Owl Creek	4,220	1979	2	
Big Creek	15,310	1979	3,2	1,3,5
Columbus Lake				
Waverly Ferry	4,220	1982	1	
Waverly	7,390	1982	1	
Waverly Mansion	3,170	1982	1	
Stinson Creek	10,350	1982	1	1
Town Creek	10,560	1982	1	1
Barton Ferry	5,280	1982	1	
Buttahatchee River	14,573	1982	1	1,3,5
Vinton Creek	8,180	1982	2	1
Denmon Creek	5,068	1982	2	1,3,
Cane Creek	5,810	1982	2	1,3
McKinley Creek	16,160	1982	3	1
Richardson Lake	3,170	1982	2	
New Hamilton	4,220	1982	2	3
Lockridge Creek	4,750	1982	2	3
Hickelson Lake	9,720	1982	1	1
Dead River	5,280	1982	2	
James Creek	19,330	1982	2	1,3
Morgan Landing	4,220	1982	2	
Aberdeen Lake				
Un-named	4,224	1984	1	
Un-named	5,808	1984	1	2
Acker Lake	11,090	1984	1	2
Un-named	3,170	1984	1	2
Drummond Branch	9,500	1984	1	4
Weaver Creek	2,640	1984	1	2
Becker Bottoms	1,580	1984	1	
Roundhouse	3,170	1984	1	4

* Code definitions are: 1 = No action; bendway is either nearly filled by sediment or exhibits no significant deposition above normal water surface elevation. 2 = Top of bank blockage structure made of dredged or excavated sediment placed in upstream bendway entrance. 3 = Upstream portion of bendway was dredged. 4 = Top of bank blockage structure with small boat channel.

** Code definitions are: 1 = Annual hydrographic surveys of three or more ranges. 2 = Annual hydrographic surveys of a single range. 3 = Semiannual sampling of fish and selected water quality variables by USFWS, 1986-88. 4 = Semiannual sampling of fish and selected water quality variables by USFWS, fall 1987-88. 5 = Sampling of water quality, phytoplankton and zooplankton, periphyton, bottom sediments, and benthos by USGS. In addition, USGS collected water quality data from 35 bendways in late July and early August 1985.

Table 2a

Sampling Procedures for Fishery Data

Study	Locations	Sampling Dates and Frequencies	Fish Sampling Gear	Effort
US Fish and Wildlife Service (1987-1989)	12 TTW cutoff bendways	Semiannual sampling--spring (May) and fall (October) 1986, 1987, and 1988	Electrofishing	3 to 5 sample transects per bendway (15 min/transect)
			Gill netting	1 sample transect (45 m) per bendway. Nets set at end of each sampling day, run overnight, and retrieved the following morning
			Rotenone	A 0.12-ha littoral area was sampled for each bendway
Ellis, Farabee, and Reynolds (1979)	3 Upper Mississippi River side channels	Sampled twice monthly June and July and once each month August through October 1975 and 1976	Electrofishing	3 to 4 stations per side channel (30 min/station)
Lowery et al. (1987)	8 Lower Mississippi River floodplain lakes	Sampled once between September 24 and November 8, 1984	Electrofishing	15 transects per lake; 12 were 100 m long; the other 3 were perpendicular to the long axis of each lake and ran across the full width
			Rotenone	Two 0.4-ha samples at each lake. Four samples at Yucatan Lake
Lucas (1985), Lucas and King (1986)	5 Lower Mississippi River oxbow lakes	Beulah and Desoto sampled once in fall 1984; Beulah, Ferguson, Lee, and Whittington sampled once in September and once in November 1985	Electrofishing	3 to 6 samples each sample day at each lake (15- to 45-min runs along the shoreline per sample)

Table 2b

Sampling Procedures for Water Quality Data

Study	Variables	Procedure
US Fish and Wildlife Service (1987-1989)	Dissolved oxygen	Yellow Springs Instrument Co. (Y51) DO meter
	Transparency	Secchi disk
	Velocity	Marsh McBirney Model 201 portable flowmeter
Ellis, Farabee, and Reynolds (1979)	Dissolved oxygen	Unknown
	Transparency	Secchi disk
	Surface velocity	Visual estimate
Lowery et al. (1987)	Dissolved oxygen	Hydrolab Digital System, Model 8000
	Transparency	Secchi disk
Lucas (1985), Lucas and King (1986)	Dissolved oxygen	Yellow Springs Instrument Co. Model 57 DO meter
	Transparency	Secchi disk

Table 3

Physical Characteristics of Monitored TTW Bendways

Bendway	Location in Pool	Approx. Surface Area acres	Mean Depth ft	Percent Channel Volume 3 ft Deep or Shallower	Mean Width ft	Shoreline Development Index*
Rattlesnake Bend	Lower	450	23.5	12	378	7.9
Cooks Bend	Lower	283	16.6	14	616	5.0
Big Creek	Upper	85	4.4	51	229	4.6
Hairston Bend	Middle	420	9.0	28	523	6.5
Columbus Bend	Upper	130	11.9	24	283	4.3
Stinson Creek	Lower	111	11.7	21	436	4.8
Town Creek	Lower	61	14.4	20	274	4.3
Buttahatchee River	Middle	116	11.0	21	256	5.8
Vinton Creek	Middle	28	10.5	27	183	4.0
Denmon Creek	Middle	19	10.9	22	120	3.5
Cane Creek	Middle	19	7.8	32	151	3.5
McKinley Creek	Upper	57	5.0	31	272	6.4
New Hamilton	Upper	5	4.5**			2.8
Lockridge Creek	Upper	12	4.5**			3.5
James Creek	Upper	41	4.8	44	171	5.9
Drummond Branch	Middle	122	10.3	25	238	4.4
Roundhouse	Upper	14				2.2
Mean		116	10.1	27	295	4.7
Mean for upper pool bendways		49	5.9	37	239	4.2
Mean for middle pool bendways		120	9.9	26	245	4.6
Mean for lower pool bendways		226	16.6	17	426	5.5

* Shoreline development index = perimeter ÷ $(2\sqrt{\pi A})$. See paragraph 23 of main text.
** Estimated values (see paragraph 35 of text).

Table 4

Physical Characteristics of Three Upper Mississippi River Side Channels

Name	Character	Location in Pool	Approx. Surface Area acres	Mean Depth ft	Max. Depth ft	Mean Width ft	SDI	Surface Water Velocity Mean fps	Surface Water Velocity Range fps
Buzzard	Riverine	Upper	122	7.5	10.5	460	3.6	0.5	0-1.0
Orton-Fabius	Varied	Middle	156	6.2	16.4	240	4.6	0.5	0-1.3
Cottonwood	Lake-like	Lower	35	5.9	11.8	170	6.4	0.1	0-0.3

Table 5

Physical Characteristics of 12 Lower Mississippi River Floodplain Lakes

Name	Lake Type*	Approx. Surface Area acres	Mean Depth ft	Max. Depth ft	Mean Width ft	Shoreline Development Index	Percent Sand in Bed
Driver Bar	Oxbow	500	13.8	25.3	1,800	3.4	8
Whittington	Oxbow	2,200	8.5	14.1	2,300	5.3	4
Yucatan	Oxbow	1,900	15.4	25.3	2,300	3.3	9
Deer Park	Oxbow	1,700	11.2	21.3	2,300	4.6	6
Raccourci	Oxbow	3,200	6.9	13.1	2,600	3.6	19
Catfish Chute	AC type I	35	5.2	9.2	300	4.3	5
Crutcher	AC type I	46	3.0	4.6	300	3.4	17
Canadian Reach	AC type I	370	7.9	13.1	300	5.3	40
Beulah	Oxbow	1,030				4.0	
Ferguson	Oxbow	1,700				4.7	
Lee	Oxbow	1,990				3.1	
Desoto	Oxbow	1,460				4.0	

* As used here, an oxbow lake is the result of a naturally occurring or man-made neck meander bend cutoff. Oxbow lakes are not generally confluent with the main channel except during higher river stages when they become inundated. However, a deep, narrow channel often is found at the downstream end that connects the lake to the river channel. Abandoned channels (AC) Type I are chute cutoffs or sloughs that remain confluent with the main river channel via an outlet channel throughout most, if not all, of the year; AC Type II are not confluent with the main channel except during period of overbank flow, and are typically much shallower (<10 ft) (Lowery et al. 1987).

Table 6

Kulczynski Type I Similarity Coefficients for Fish Populations of TTW Bendways (Based on All Gear Types)

Bendway	James Creek	Lock-ridge Creek	New Hamilton	Cane Creek	Denmon Creek	Butta-hatchee River	Columbus Bend	Hairston Bend	Big Creek	Cooks Bend	Round-house	Drummond Branch
James Creek												
Lockridge Creek	1.94											
New Hamilton	1.56	1.18										
Cane Creek	2.14	1.81	2.00									
Denmon Creek	2.21	1.61	2.50	5.50								
Buttahatchee River	2.36	1.50	1.23	2.67	2.75							
Columbus Bend	1.65	1.65	1.78	2.06	2.50	1.70						
Hairston Bend	2.36	2.00	2.21	2.67	2.75	2.06	3.17					
Big Creek	1.68	1.48	1.22	1.82	1.43	1.35	2.53	2.77				
Cooks Bend	2.14	1.81	1.44	2.42	2.07	1.88	2.06	2.67	1.82			
Roundhouse	1.28	1.28	1.17	1.64	1.44	1.15	1.14	1.33	1.00	1.33		
Drummond Branch	1.86	1.33	1.71	1.44	1.79	1.05	1.35	1.63	1.19	1.71	1.36	
Average	1.93	1.60	1.64	2.38	2.41	1.79	1.96	2.33	1.30	1.95	1.29	1.49

Table 7

Similarity Among and Between Pool Location Categories, TTW Bendways (All Gear Types)

Location in Navigation Pool	Upper	Middle	Lower
Upper	1.50	1.85	1.78
Middle	1.85	2.43	2.15
Lower	1.78	2.15	*

* Only one bendway.

Table 8

Species Richness and Maximum Similarity Coefficient, TTW Bendways (All Gear Types)

Bendway	Number of Species	Number of Individuals	Number of Species Not Found Elsewhere	Maximum Kulczynski Similarity Coefficient	Most Similar Bendway
Cooks Bend	35	1,711	1	2.67	Hairston Bend
Big Creek	44	2,109	4	2.77	Hairston Bend
Hairston Bend	41	2,716	1	3.17	Columbus Bend
Columbus Bend	47	3,365	3	3.17	Hairston Bend
Buttahatchee River	41	3,068	3	2.75	Denmon Creek
Denmon Creek	37	2,577	0	5.50	Cane Creek
Cane Creek	35	2,241	0	5.50	Denmon Creek
New Hamilton	35	1,206	2	2.50	Denmon Creek
Lockridge Creek	39	2,164	3	2.00	Hairston Bend
James Creek	39	2,455	1	2.36	Hairston Bend and Butta-hatchee River (tie)
Drummond Branch	27	1,976	0	1.86	James Creek
Roundhouse	25	1,175	0	1.64	Cane Creek

Table 9

Summary of Electrofishing and Water Quality Results, TTW Bendways (USFWS 1987-1989)

Bendway	Location in Pool	Average per Transect: CPUE* kg	Average per Transect: Number of Fish Species	Total Number of Fish Species	Number of Individuals	Average: Minimum DO mg/ℓ	Average: Secchi Depth in.
Cooks Bend	Lower	7.1	8.3	30	2,511	5.0	24
Big Creek	Upper	15.4	12.4	35	1,704	7.0	14
Hairston Bend	Middle	12.4	10.7	35	2,583	2.9	19
Columbus Bend	Upper	15.0	11.9	35	2,394	6.8	15
Buttahatchee River	Middle	9.4	10.8	30	2,401	5.2	16
Denmon Creek	Middle	11.0	13.1	30	1,827	4.6	19
Cane Creek	Middle	10.7	12.0	27	1,640	4.6	17
New Hamilton	Upper	11.9	13.3	23	873	6.1	13
Lockridge Creek	Upper	10.5	11.9	30	1,614	6.8	14
James Creek	Upper	11.9	16.1	34	2,286	4.5	13
Drummond Branch**	Middle	20.7	14.2	22	1,872	5.7	14
Roundhouse**	Upper	25.9	11.3	17	983	6.4	14
Mean for upper pool bendways		15.1	12.8	29	1,642	6.3	14
Mean for middle pool bendways		12.8	12.2	29	2,065	4.6	17
Mean for lower pool bendways		7.1	8.3	30	2,511	5.0	24

* Catch per unit effort.

** Sampled only three times. Other bendways sampled six times.

Table 10

Selected Fish and Water Quality Data for TTW

Bendways, 1985-88*

Bendway	Date	Catch per Unit Effort (No./ Transect)	Average No. of Fish Species/ Transect	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Depth in.
Rattlesnake	15-Jun-86					
Rattlesnake Warsaw	08-Aug-85				25.8	5.2
Cooks Bend	07-Aug-85				26.4	6.4
Cooks Bend	12-May-87				22.5	6.4
Cooks Bend	14-Jul-87				32.5	0.8
Cooks Bend	25-Mar-86				8.8	9.8
Cooks Bend	15-May-86	2.9	7.4	2.06	17.9	5.4
Cooks Bend	16-Jul-86				20.5	
Cooks Bend	15-Oct-88	7.9	10.0	2.24		
Cooks Bend	15-Oct-86	3.6	7.2	1.99	38.8	4.0
Cooks Bend	06-Aug-85				25.8	6.4
Cooks Bend	15-Aug-86				20.5	
Cooks Bend	15-Oct-87	7.3	8.0	1.75	23.4	6.5
Cooks Bend	15-May-88	10.6	9.0	1.74	24.4	3.4
Cooks Bend	12-Jul-88				18.5	4.3
Cooks Bend	19-Apr-88				14.7	9.2
Cooks Bend	15-May-87	10.3	8.0	2.12	14.0	5.8
Windham Landing	06-Aug-85				22.2	5.7
Cochrane	06-Aug-85				20.1	6.8
Lubbub Creek	06-Aug-85				21.6	5.4
Owl Creek	05-Aug-85				21.3	3.1
Big Creek	15-Oct-86	7.1	9.3	2.41	23.8	5.8
Big Creek	15-Jul-86				10.2	4.3
Big Creek	15-Oct-88	4.0	13.0	2.43	14.6	8.8
Big Creek	14-Jul-87				12.5	6.4
Big Creek	25-Mar-86				8.0	8.1
Big Creek	02-Aug-85				15.0	7.8
Big Creek	15-Oct-87	24.5	16.0	2.24	9.1	7.8
Big Creek	19-Apr-88				18.5	7.5
Big Creek	15-May-88	21.9	13.0	2.01	15.0	7.4
Big Creek	12-May-87				10.5	6.3

(Continued)

* Electrofishing catch per unit effort and average number of fish species are from USFWS (1987-1989). Water quality data not associated with fish data are from files of the USGS.

Table 10 (Continued)

Bendway	Date	Catch per Unit Effort (No./ Transect)	Average No. of Fish Species/ Transect	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Depth in.
Big Creek	12-Jul-88				12.5	6.3
Big Creek	15-May-87	22.0	14.0	0.86	5.5	5.4
Big Creek	15-May-86	2.9	9.0	2.10	16.3	6.6
Pickens- ville	02-Aug-85				28.8	3.4
Coalfire Creek	02-Aug-85				30.9	4.6
Hairston Bend	14-Jul-86				28.0	0.4
Hairston Bend	18-Apr-88				19.0	5.7
Hairston Bend	24-Mar-86				9.3	9.4
Hairston Bend	11-Jul-88				31.5	0.6
Hairston Bend	13-Jul-87				31.5	
Hairston Bend	01-Aug-85				37.8	1.3
Hairston Bend	15-Oct-86	6.7	7.3	2.11	25.4	3.0
Hairston Bend	15-May-86	5.6	9.8	2.11	21.3	2.7
Hairston Bend	15-Oct-88	16.5	11.0	2.10	19.5	5.0
Hairston Bend	15-May-88	14.1	11.0	1.84	27.6	0.6
Hairston Bend	15-Aug-86				28.0	
Hairston Bend	15-May-87	15.9	13.0	2.20	10.0	0.1
Hairston Bend	15-Oct-87	15.3	12.0	2.31	12.6	5.8
Hairston Bend	12-May-87				26.2	0.9
Columbus	15-May-88	13.0	10.0	1.60	15.0	6.6
Columbus	24-Mar-86				10.0	11.7
Columbus	18-Apr-88				16.5	9.1
Columbus	14-Jul-86				18.5	5.5
Columbus	15-Oct-87	20.8	13.0	2.09	13.4	8.0
Columbus	15-May-86	8.7	11.4	2.11	17.3	6.2
Columbus	15-May-87	22.2	12.0	1.91		6.4

(Continued)

Table 10 (Continued)

Bendway	Date	Catch per Unit Effort (No./Transect)	Average No. of Fish Species/Transect	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Depth in.
Columbus	01-Aug-85				23.7	8.0
Columbus	11-May-87				18.7	6.5
Columbus	11-Jul-88				20.0	5.6
Columbus	15-Oct-86	10.2	9.2	1.86	25.8	5.3
Columbus	13-Jul-87				26.2	2.9
Columbus	15-Oct-88	15.1	16.0	2.43	5.7	8.2
Columbus	15-Aug-86				18.5	
Waverly Ferry	02-Aug-85				19.2	6.2
Waverly	02-Aug-85				19.2	5.4
Waverly Mansion	02-Aug-85				20.4	6.2
Stinson Creek	02-Aug-85				20.4	6.3
Stinson Creek	15-Sep-86					
Town Creek	02-Aug-85				19.2	3.8
Town Creek	15-Sep-86					
Barton Ferry	02-Aug-85				18.0	5.5
Buttahat-chee	15-May-86	4.0	7.2	1.94	18.5	5.9
Buttahat-chee	06-May-87				23.0	4.3
Buttahat-chee	02-Aug-85				21.6	5.0
Buttahat-chee	22-Jul-87				30.0	3.2
Buttahat-chee	15-May-88	12.6	9.0	1.81	19.1	4.2
Buttahat-chee	29-Jun-88				36.0	4.4
Buttahat-chee	15-May-87	9.0	9.0	1.83		5.0
Buttahat-chee	15-Oct-86	5.1	7.0	2.15	23.8	4.0
Buttahat-chee	15-Oct-87	17.8	12.0	2.04	7.9	5.0
Buttahat-chee	09-Jul-86				26.2	2.0

(Continued)

Table 10 (Continued)

Bendway	Date	Catch per Unit Effort (No./ Transect)	Average No. of Fish Species/ Transect	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Depth in.
Buttahat-chee	13-Apr-88				24.0	10.2
Buttahat-chee	15-Oct-88	16.0	12.0	1.90	11.4	7.3
Buttahat-chee	20-Mar-86				6.0	8.6
Vinton	01-Aug-85				31.2	2.5
Vinton	15-Sep-86					
Denmon Creek	01-Aug-85				46.2	1.5
Denmon Creek	15-Oct-86	9.9	9.0	1.96	23.4	6.0
Denmon Creek	15-May-87	10.1	10.0	1.85	11.4	5.5
Denmon Creek	15-Oct-88	17.7	14.0	1.81	11.0	7.6
Denmon Creek	15-May-86	8.1	9.7	2.14	21.1	0.8
Denmon Creek	15-May-88	12.5	11.0	2.20	21.5	1.5
Denmon Creek	15-Oct-87	20.4	12.0	2.28	23.0	6.0
Cane Creek	15-Oct-88	17.5	13.0	1.90	12.0	7.6
Cane Creek	15-May-88	16.3	11.0	2.18	16.9	3.3
Cane Creek	15-Oct-86	10.7	9.3	2.24	21.5	6.3
Cane Creek	15-Oct-87	11.5	13.0	2.04	20.1	6.4
Cane Creek	15-May-86	8.2	9.0	2.11	19.9	4.0
Cane Creek	01-Aug-85				43.2	3.4
Cane Creek	15-May-87	7.5	9.0	1.84	13.0	0.2
McKinley Creek	15-Sep-86					
McKinley Creek	01-Aug-85				46.2	0.7
Richardson	01-Aug-85				14.4	11.6
New Hamilton	15-May-87	17.3	10.0	2.07	7.9	3.6
New Hamilton	15-Oct-88	10.6	10.0	1.78	12.0	8.6
New Hamilton	01-Aug-85				12.6	10.7
New Hamilton	15-Oct-86	8.2	12.0	2.22	23.8	5.0
New Hamilton	15-May-88	14.3	14.0	2.06	17.5	5.4
New Hamilton	15-May-86	7.7	9.5	2.14	14.0	7.0
New Hamilton	15-Oct-87	21.8	16.0	1.84	4.9	6.8
Lockridge	15-Oct-86	6.5	7.5	1.99	20.7	7.9

(Continued)

Table 10 (Concluded)

Bendway	Date	Catch per Unit Effort (No./ Transect)	Average No. of Fish Species/ Transect	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Depth in.
Lockridge	15-May-87	12.8	12.0	2.27	10.8	6.1
Lockridge	15-Oct-87	12.9	12.0	2.20	6.1	5.8
Lockridge	15-Oct-88	25.2	13.0	2.06	10.4	7.9
Lockridge	01-Aug-85				21.6	2.0
Lockridge	15-May-88	10.4	12.0	2.19	18.5	7.5
Lockridge	15-May-86	3.4	6.3	1.78	15.8	5.4
Hickelson Lake	15-Dec-86					
Hickelson Lake	15-Jun-85					
Dead River	01-Aug-85				19.2	7.4
James Creek	15-May-86	7.3	8.8	2.30	13.2	3.5
James Creek	15-Oct-87	17.3	13.0	1.90	10.4	5.8
James Creek	15-Oct-88	21.8	11.0	2.04	13.6	5.8
James Creek	15-May-87	21.4	16.0	2.18	6.9	2.0
James Creek	15-Oct-86	10.3	8.3	2.23	14.8	5.4
James Creek	01-Aug-85				19.8	2.0
James Creek	15-May-88	18.5	14.0	1.90	16.5	4.3
Morgan Landing	01-Aug-85				16.2	8.2
Acker Lake	31-Jul-85				20.4	3.6
Drummond	31-Jul-85				16.8	3.3
Weaver Creek	31-Jul-85				16.8	5.8
Drummond Branch	31-Jul-85				15.6	4.0
Drummond Branch	15-Oct-88	27.1	12.0	1.92	14.0	7.4
Drummond Branch	15-May-88	20.2	10.0	1.96	16.9	3.6
Drummond Branch	15-Oct-87	30.3	12.0	2.18	9.8	6.0
Roundhouse	15-Oct-88	25.2	15.0	2.13	13.2	8.0
Roundhouse	15-Oct-87	11.3	14.7	2.36	8.9	6.9
Roundhouse	31-Jul-85				16.8	0.9
Roundhouse	15-May-88	25.5	13.0	1.91	19.5	4.3

Table 11

Kulczynski Type I Similarity Coefficients for Fish Populations of Three Upper Mississippi River Side Channels

	Buzzard	Orton-Fabius
Orton-Fabius	4.86	
Cottonwood	3.44	3.10

Table 12

Summary of Electrofishing and Water Quality Results, Mississippi River Sites

Water Body	Catch per Unit Effort (no./min)*	No. of Fish Species	No. of Individuals	Shannon-Weiner Diversity Index	Bottom DO mg/ℓ	Secchi Disk Depth, in.
			Upper Mississippi River Side Channels (Ellis, Farabee, and Reynolds 1979)			
Buzzard	1.5	36	2,716	2.24	7.9	14.2
Orton-Fabius	1.6	38	2,645	2.33	8.2	8.3
Cottonwood	1.8	34	2,670	2.22	5.2	10.2
			Lower Mississippi River Floodplain Lakes (Lowery et al. 1987)			
Driver Bar	56.6	14	1,127	0.4	29	
Whittington	66.5	14	7,927	2.4	13	
Yucatan	23.9	13	800	0.2	27	
Deer Park	2.1	2	180	1.0	26	
Raccourci	1.7	6	22	0.2	27	
Catfish Chute	44.3	14	616	1.0	22	
Crutcher	119.7	17	2,279	4.2	16	
Canadian Reach	10.5	11	177	0.5	17	
			Lucas (1985) and Lucas and King (1986)			
Whittington	1.9	22	408	2.19	21	
Beulah	5.2	26	1,048	2.21	15	
Ferguson	2.9	24	845	2.05	33	
Lee	1.9	19	381	2.48	22	
Desoto (1984)	1.8	9	247	0.37	40	

* Catch per unit effort from Lowery et al. (1987) is in units of kilograms per 100-m transect.

Table 13

Kulczynski Type I Similarity Coefficients for Fish Populations of Lower Mississippi River Floodplain Lakes, Based on Rotenone Data*

Floodplain Lake	Raccourci Old River	Deer Park	Yucatan Lake	Catfish Chute	Lake Whittington	Crutcher Lake	Driver Bar	Canadian Reach
Raccourci Old River								
Deer Park	1.21							
Yucatan Lake	1.55	0.96						
Catfish Chute	1.30	1.18	1.81					
Lake Whittington	1.72	1.41	1.78	1.50				
Crutcher Lake	1.25	1.00	1.04	1.40	1.25			
Driver Bar	1.00	1.69	1.18	1.10	1.14	1.23		
Canadian Reach	0.53	0.71	0.50	0.35	0.68	0.59	0.62	—
Average	1.22	1.17	1.26	1.23	1.35	1.11	1.14	0.57
Average								
All lakes except Canadian Reach	1.32							
Canadian Reach only	0.57							

* Coefficients based on data from Lowery et al. (1987).

Table 14

Kulczynski Type I Similarity Coefficients for Fish Populations of Lower Mississippi River Floodplain Lakes, Based on Electrofishing Data*

Floodplain Lake	Beulah	Ferguson	Lee	Desoto 1984	Whittington
Beulah					
Ferguson	2.22				
Lee	1.33	0.93			
Desoto 1984	0.35	0.37	0.38		
Whittington	1.64	1.42	0.87	0.53	
Average	1.39	1.23	0.88	0.41	1.12

* Coefficients based on data from Lucas (1985) and Lucas and King (1986).

Table 15

Summary of Rotenone Sampling Results, Lower Mississippi River Floodplain Lakes (Lowery et al. 1987)

Lake	Standing Stock kg/ha	Number of Fish Species (Rotenone)	No. of Individuals	Shannon-Weiner Diversity Index w/Shad	Shannon-Weiner Diversity Index w/o Shad
Driver Bar	594	32	7,412	1.78	1.66
Whittington	1,008	40	11,113	1.63	2.17
Yucatan	169	42	18,739	1.30	1.61
Deer Park	331	25	15,014	1.24	2.02
Raccourci	534	40	15,065	1.80	2.07
Catfish Chute	423	32	4,692	1.99	1.80
Crutcher	939	44	92,096	0.81	1.74
Canadian Reach	145	26	3,190	0.95	2.15

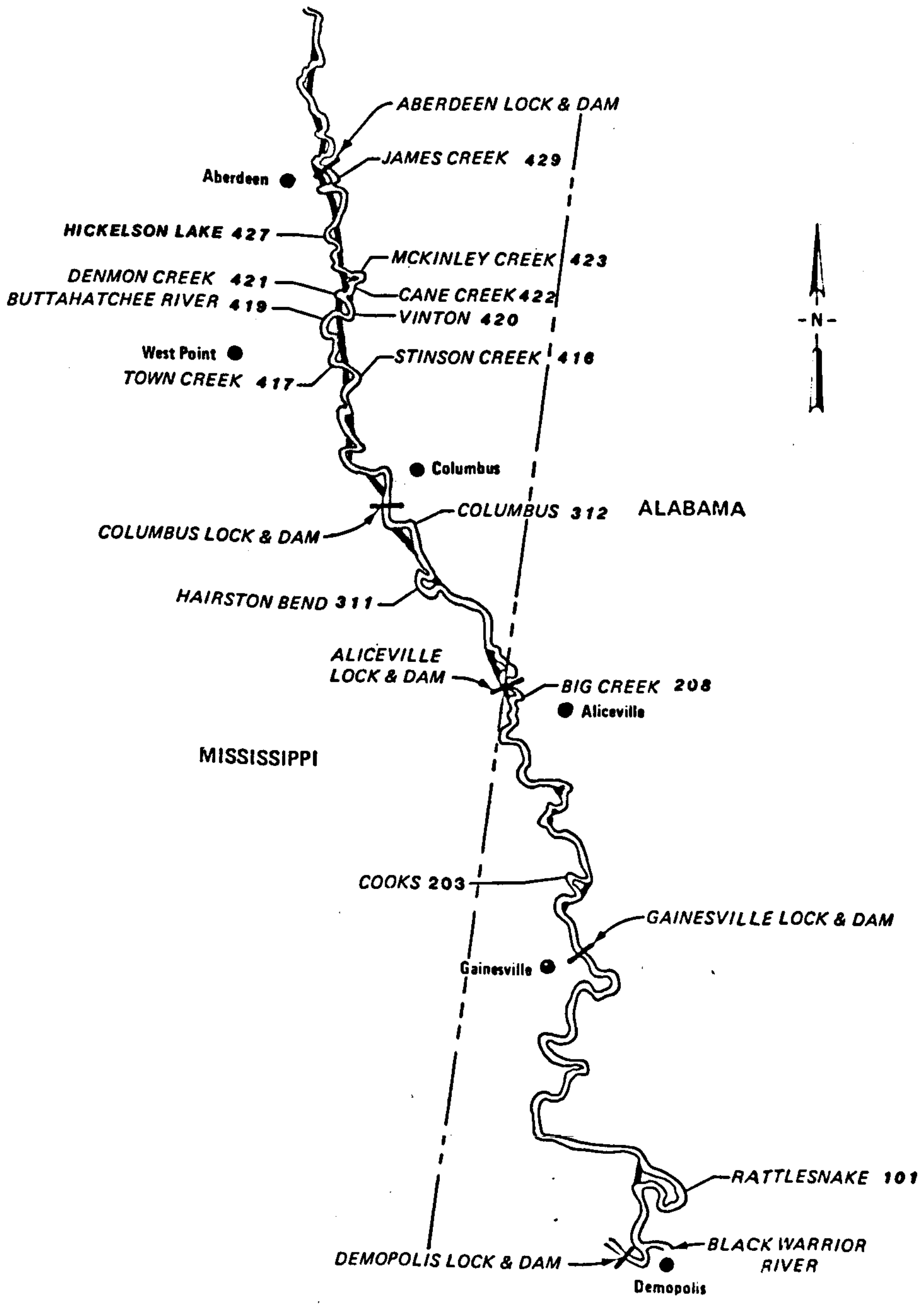


Figure 1. Locations of study bendways, River Section, Tennessee-Tombigbee Waterway (TTW)

a. James Creek Bendway, Columbus Lake, an example of an upper pool bendway. The navigation channel is shown at the bottom of the picture. Flow is from left to right

b. Stinson Creek Bendway, Columbus Lake, an example of a lower pool bendway. The navigation channel is shown at the bottom of the picture. Flow is from left to right

Figure 2. Aerial photos of typical TTW bendways

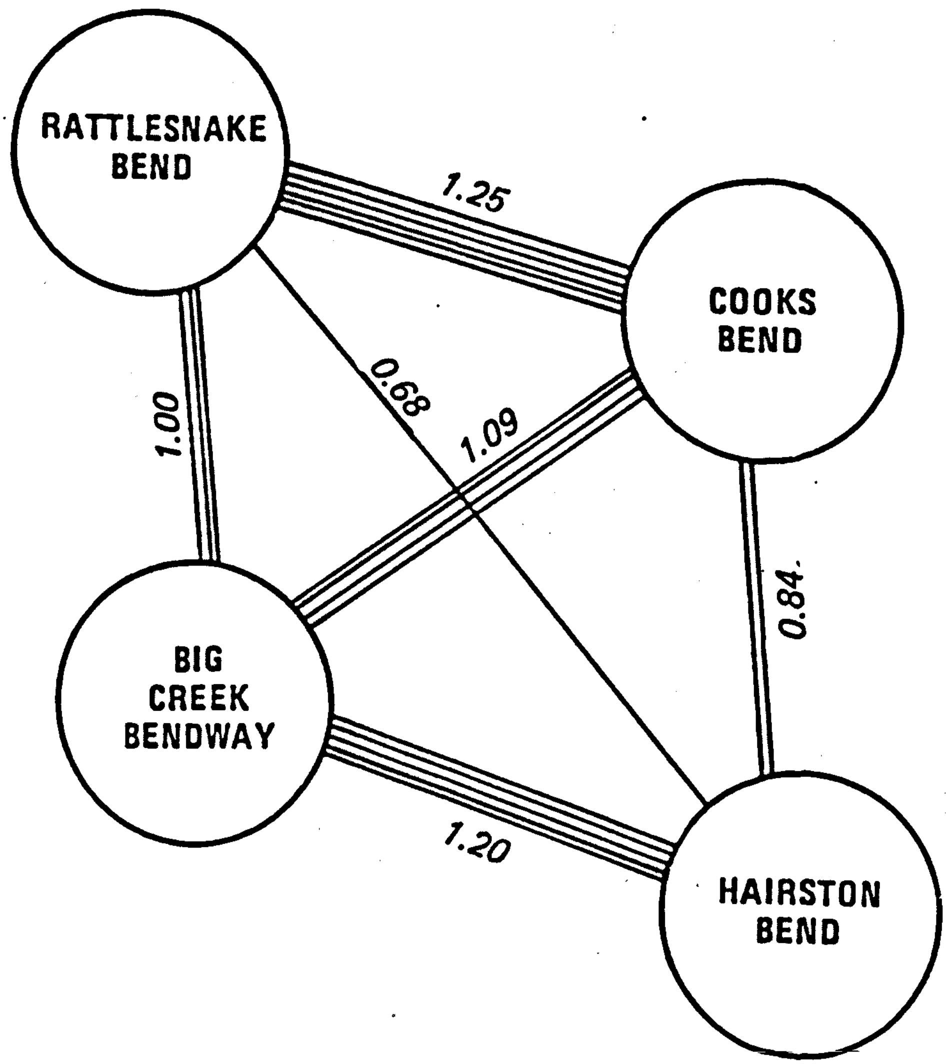


Figure 3. Graphical depiction of Kulczynski coefficients (from Baker and Bond 1982) (see discussion, paragraph 13 of main text)

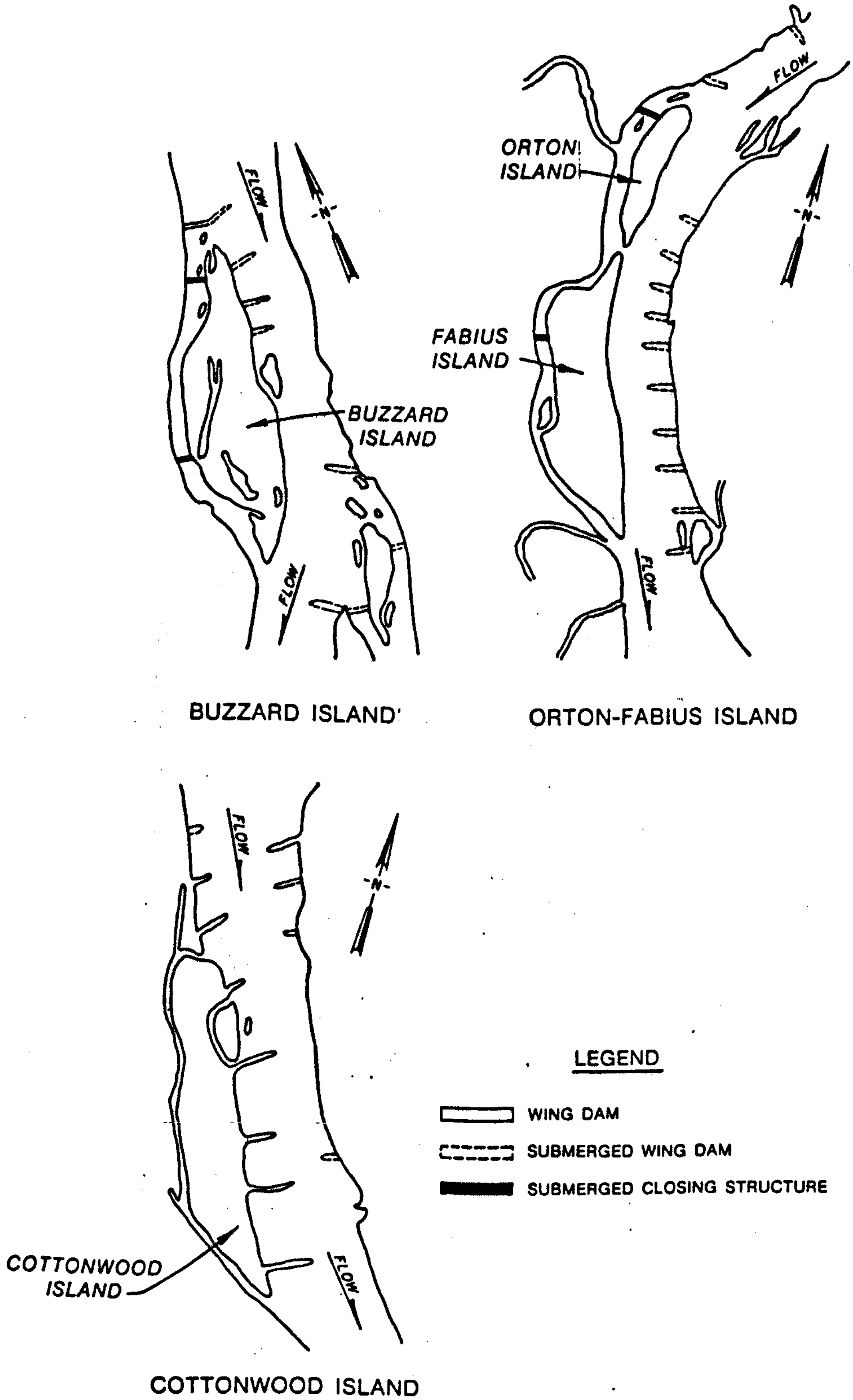
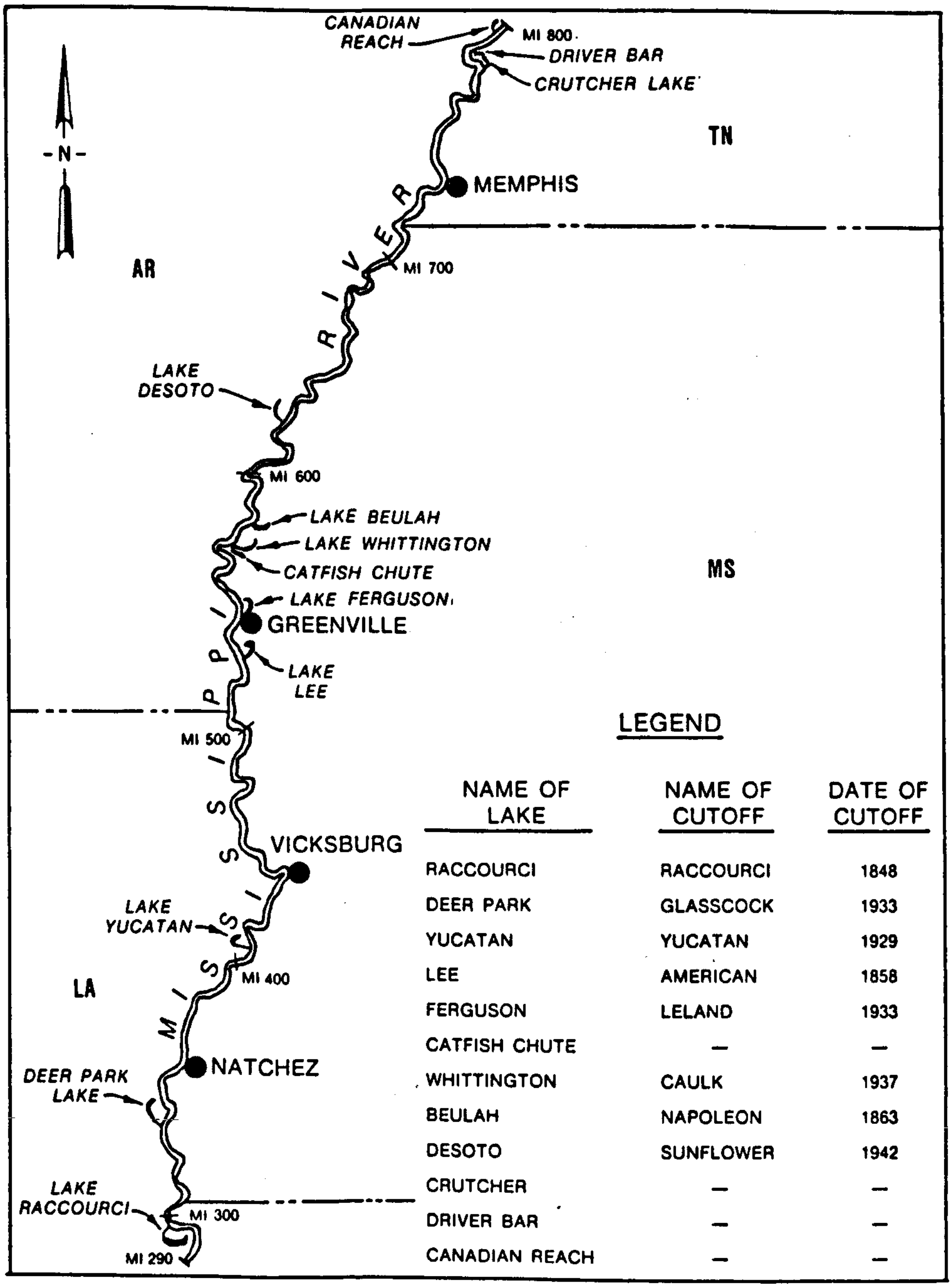


Figure 4. Upper Mississippi River side channels



NAME OF LAKE	NAME OF CUTOFF	DATE OF CUTOFF
RACCOURCI	RACCOURCI	1848
DEER PARK	GLASSCOCK	1933
YUCATAN	YUCATAN	1929
LEE	AMERICAN	1858
FERGUSON	LELAND	1933
CATFISH CHUTE	—	—
WHITTINGTON	CAULK	1937
BEULAH	NAPOLEON	1863
DESOTO	SUNFLOWER	1942
CRUTCHER	—	—
DRIVER BAR	—	—
CANADIAN REACH	—	—

Figure 5. Lower Mississippi River study sites

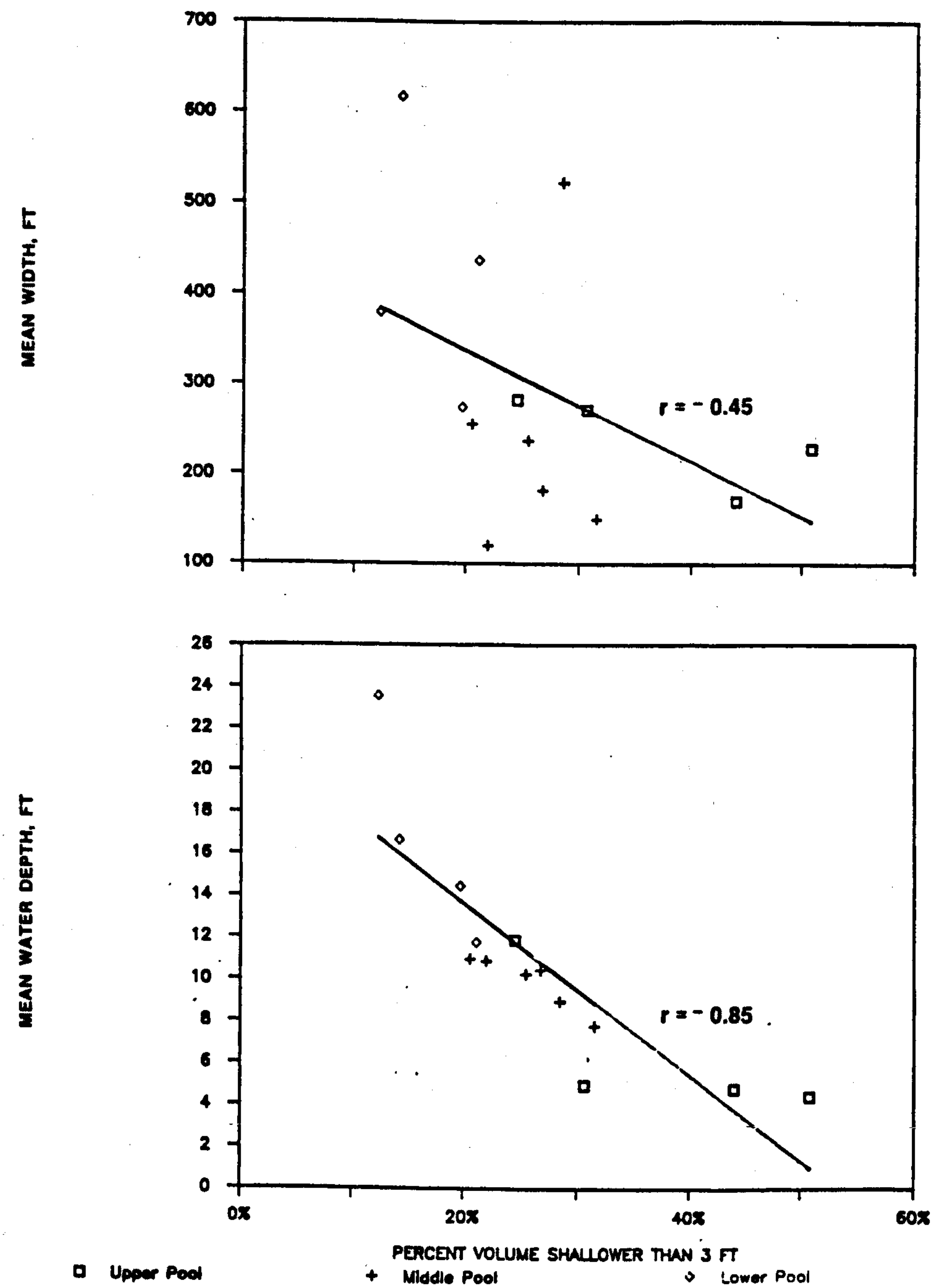


Figure 6. Mean water depth and width versus percent volume shallower than 3 ft, TTW bendways

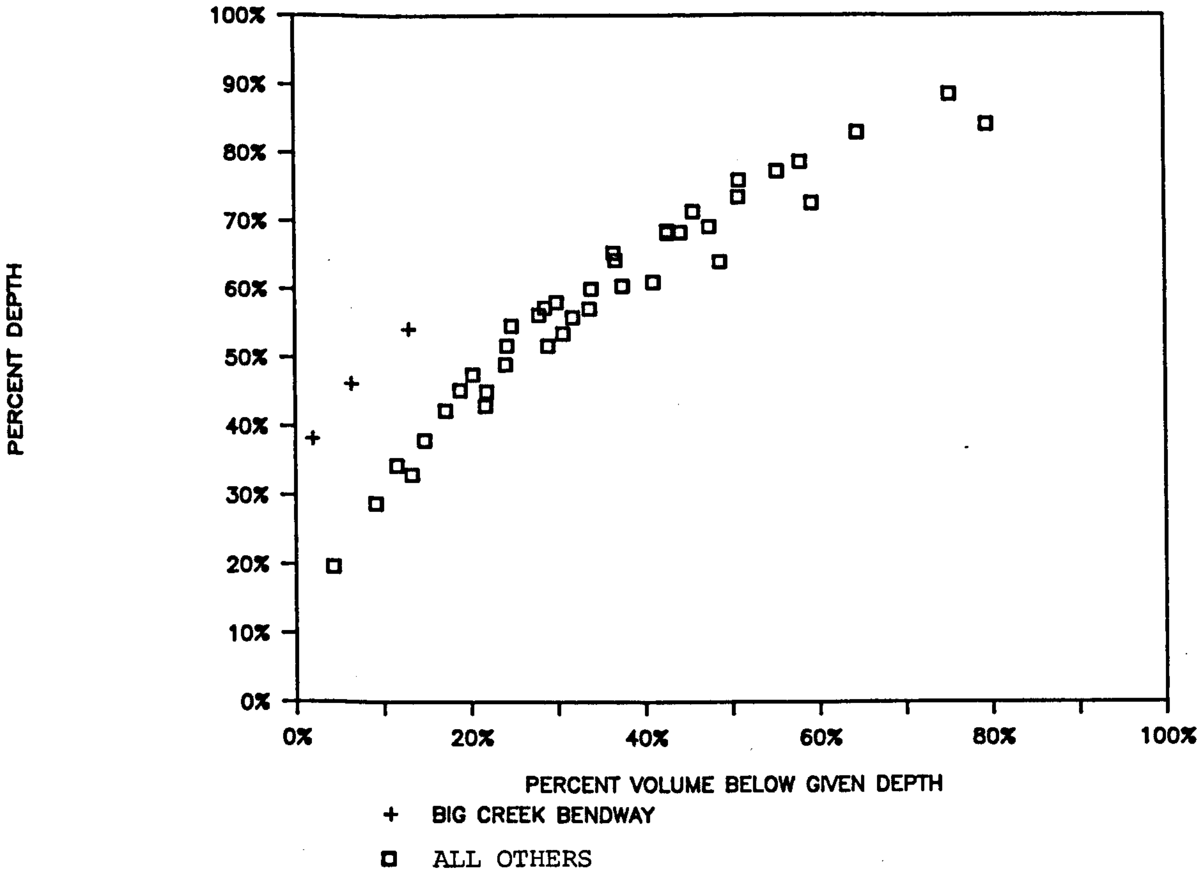


Figure 7. Dimensionless depth-storage curve for TTW bendways

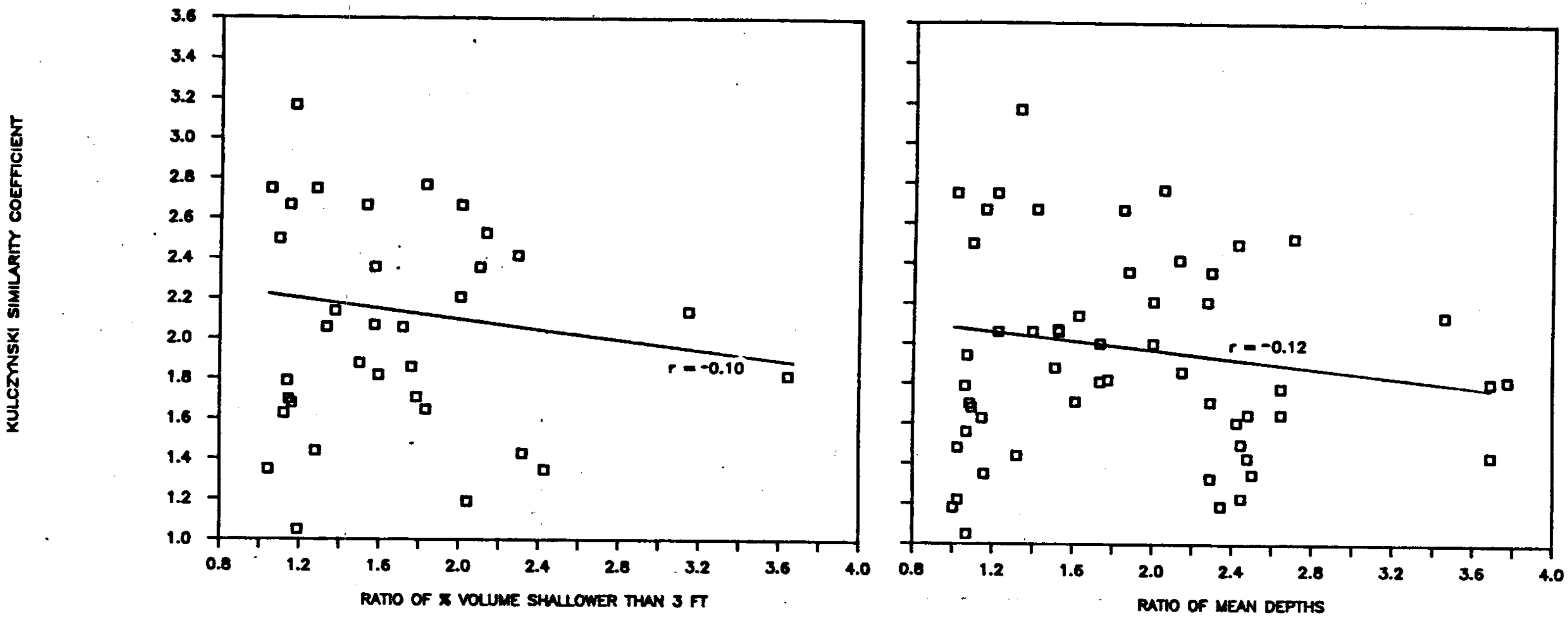


Figure 8. Similarity coefficients versus key physical variables, TTW bendways

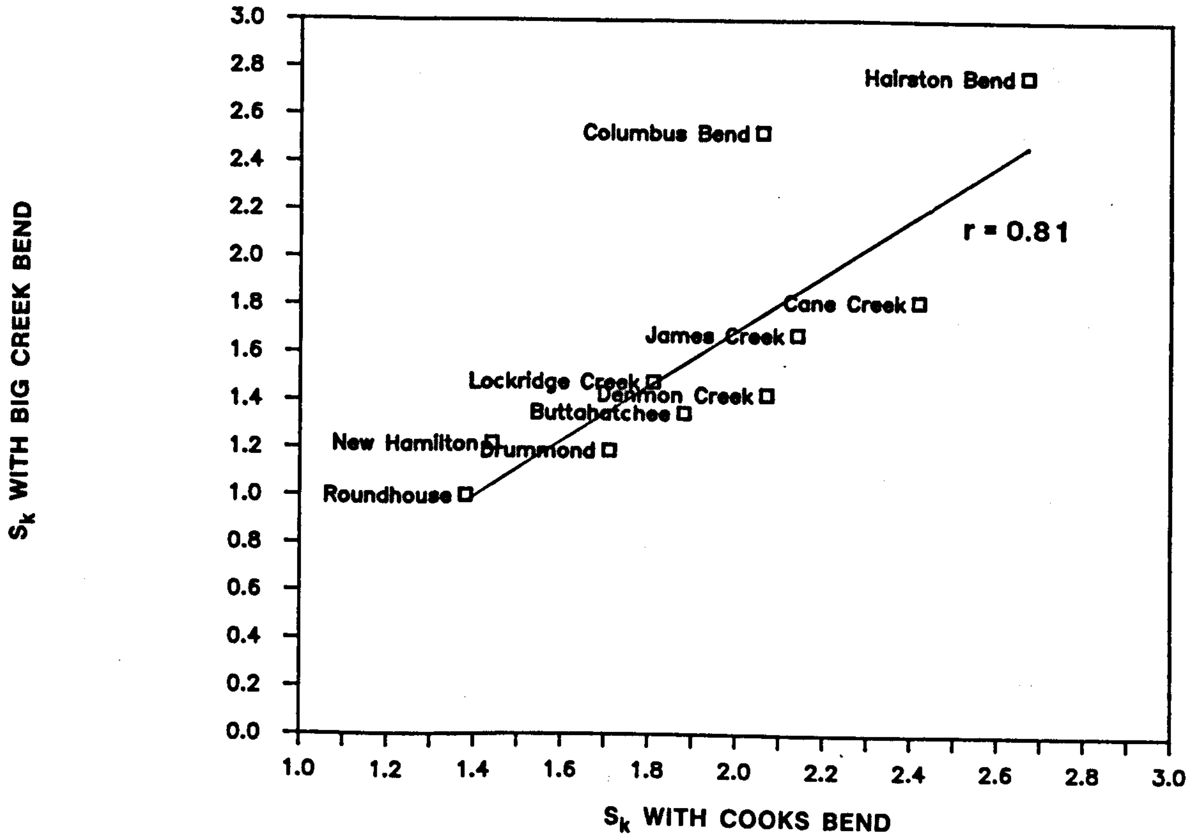


Figure 9. TTW bendway Kulczynski Type I similarity coefficients (S_k)

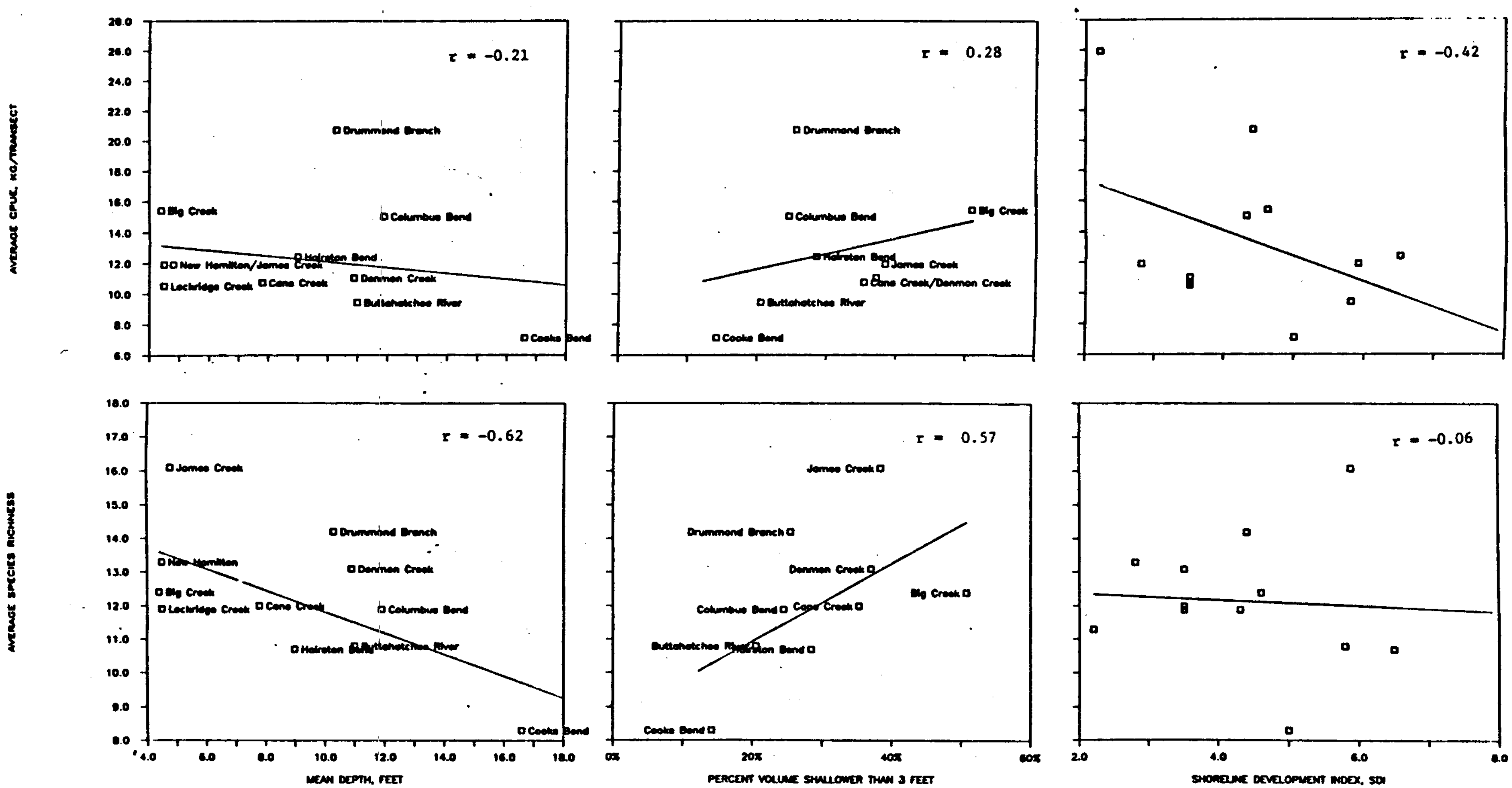


Figure 10. Average catch per unit effort and species richness versus key physical variables, TTW bendways (electrofishing data only)

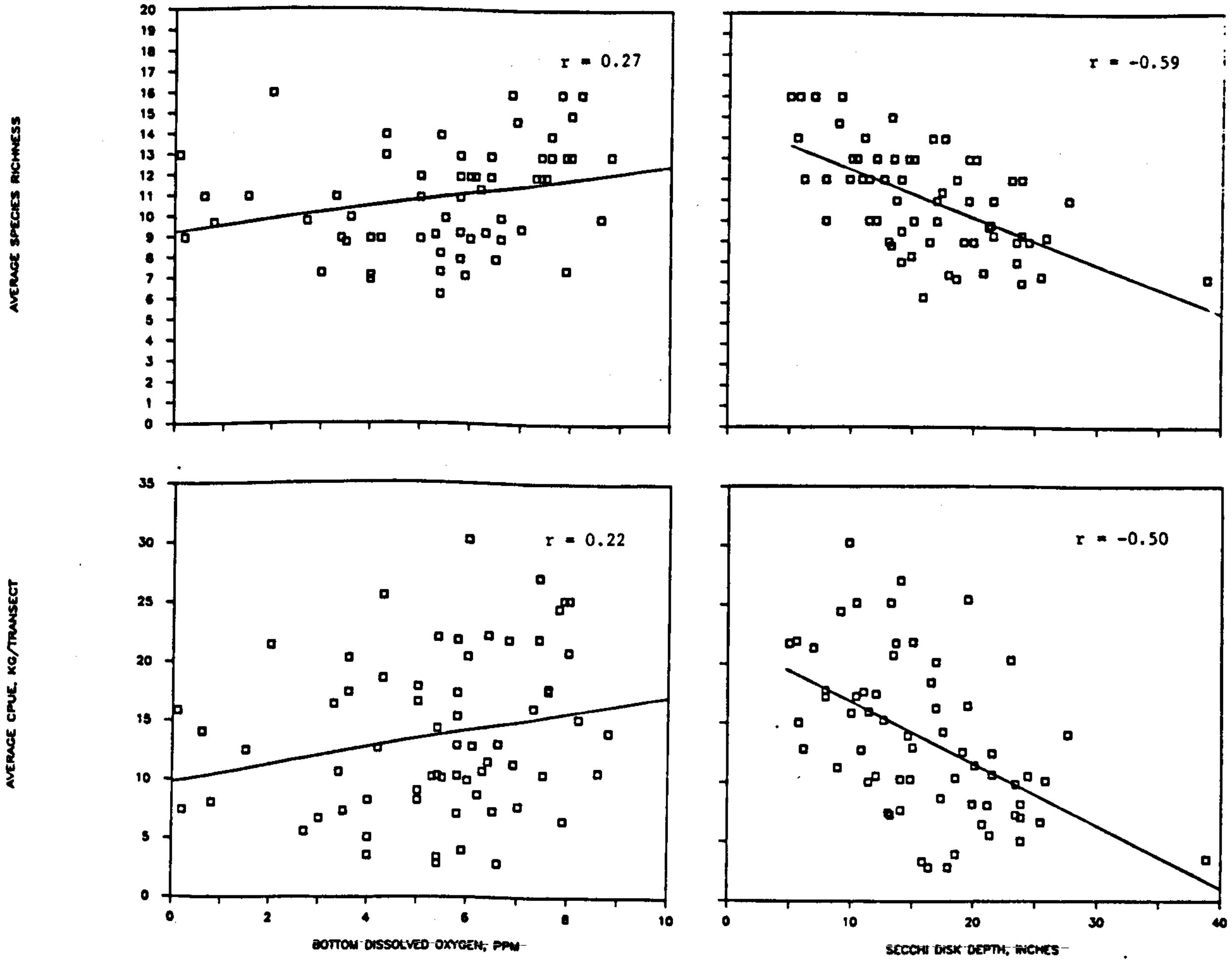


Figure 11. Average electrofishing results and key water quality variables

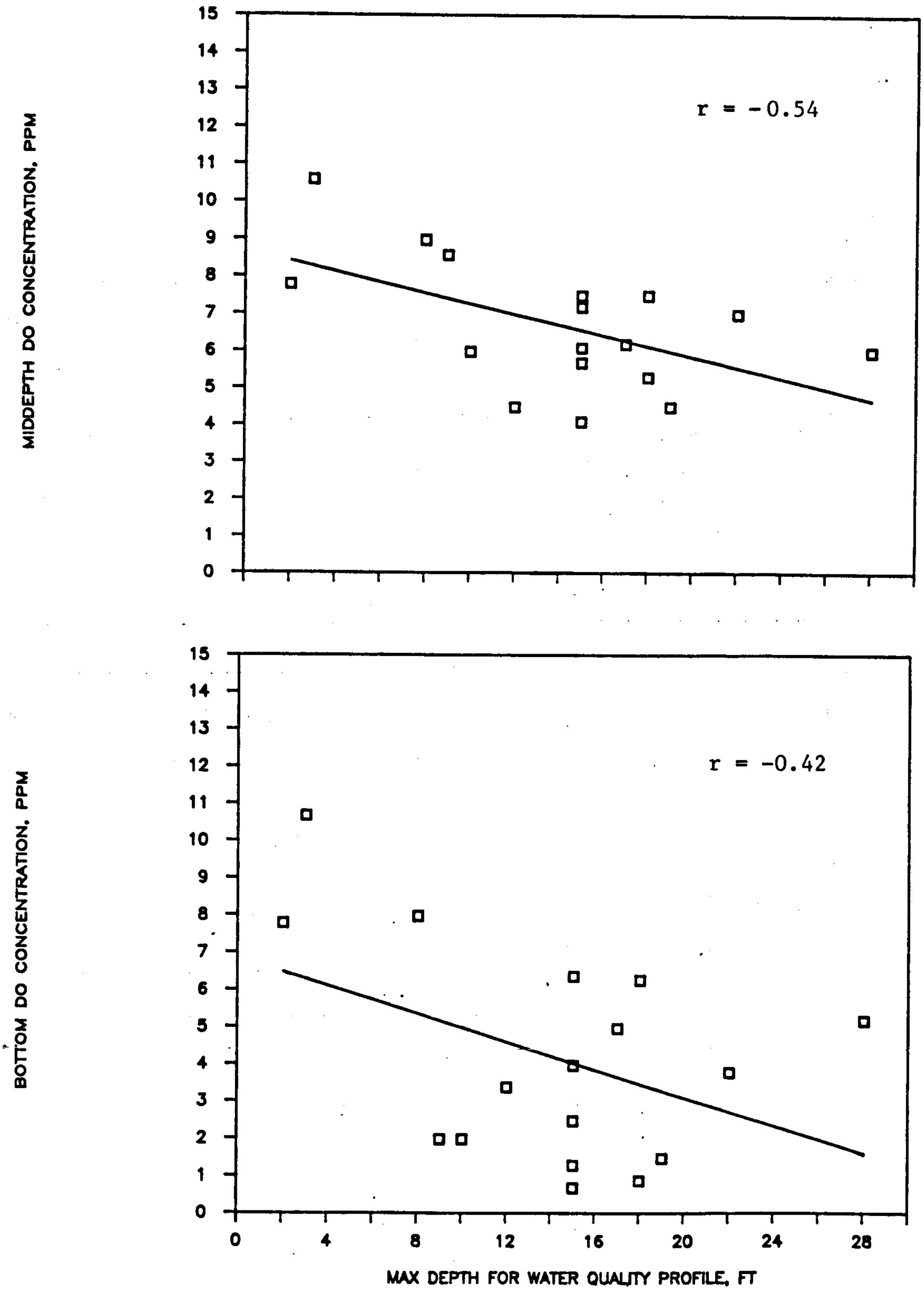


Figure 12. Middepth and bottom dissolved oxygen concentration versus maximum depth, August 1985, TTW bendways

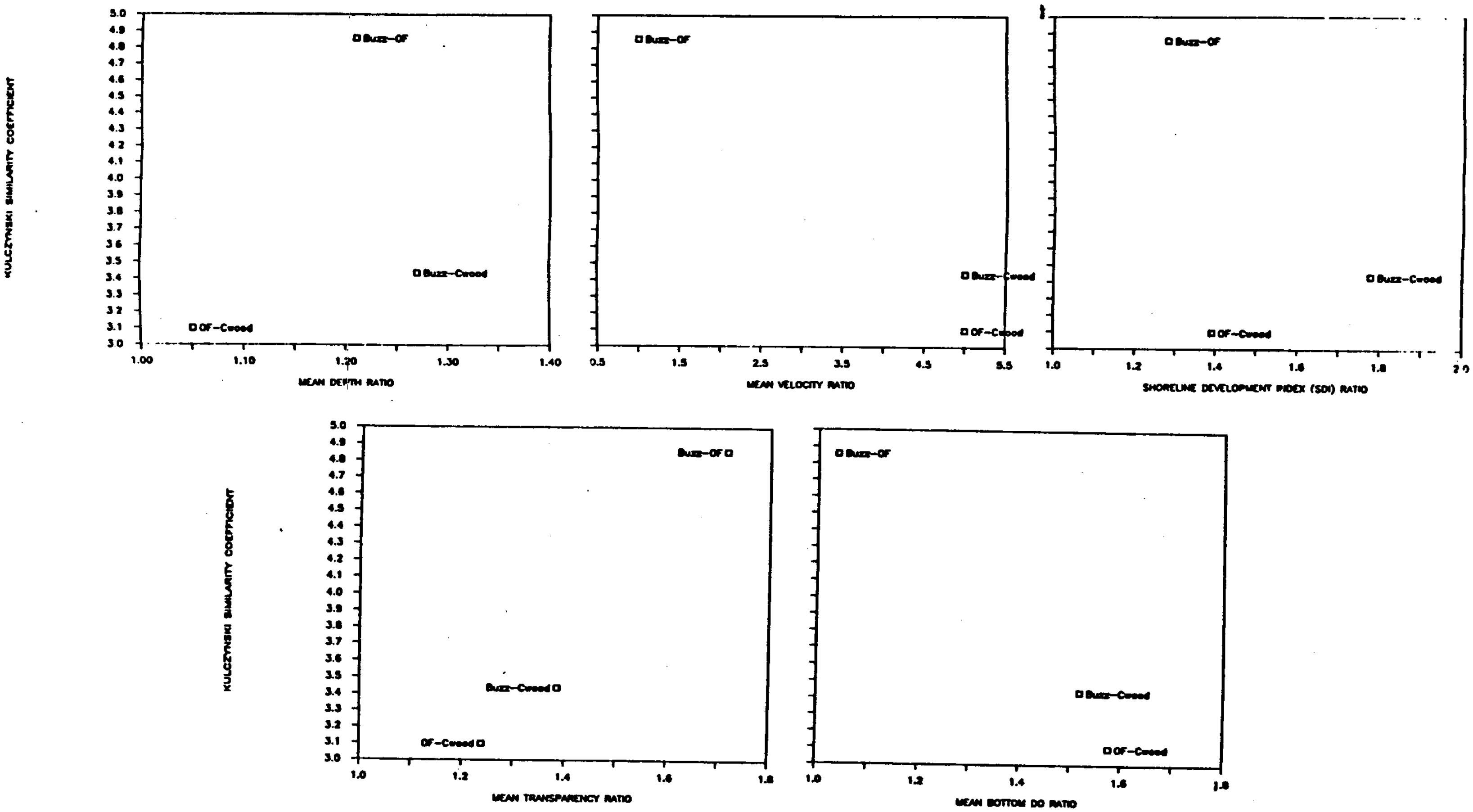


Figure 13. Similarity coefficients, upper Mississippi River side channels (Buzzard, Orton-Fabius, and Cottonwood Islands) versus ratios of key physical variables

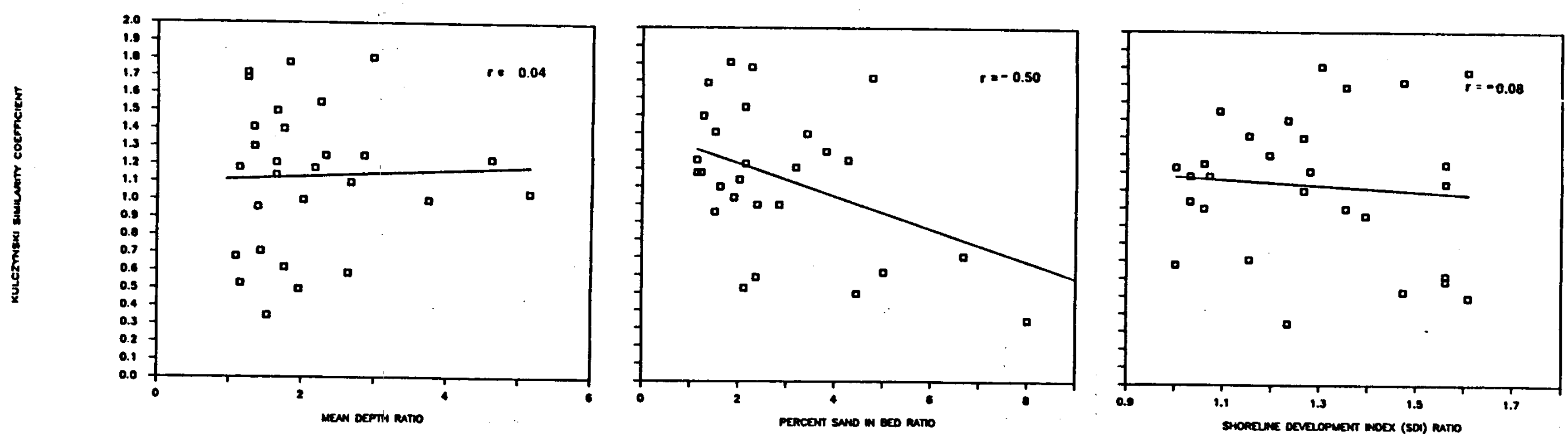


Figure 14. Similarity coefficients, Lower Mississippi River floodplain lakes versus ratios of key physical variables

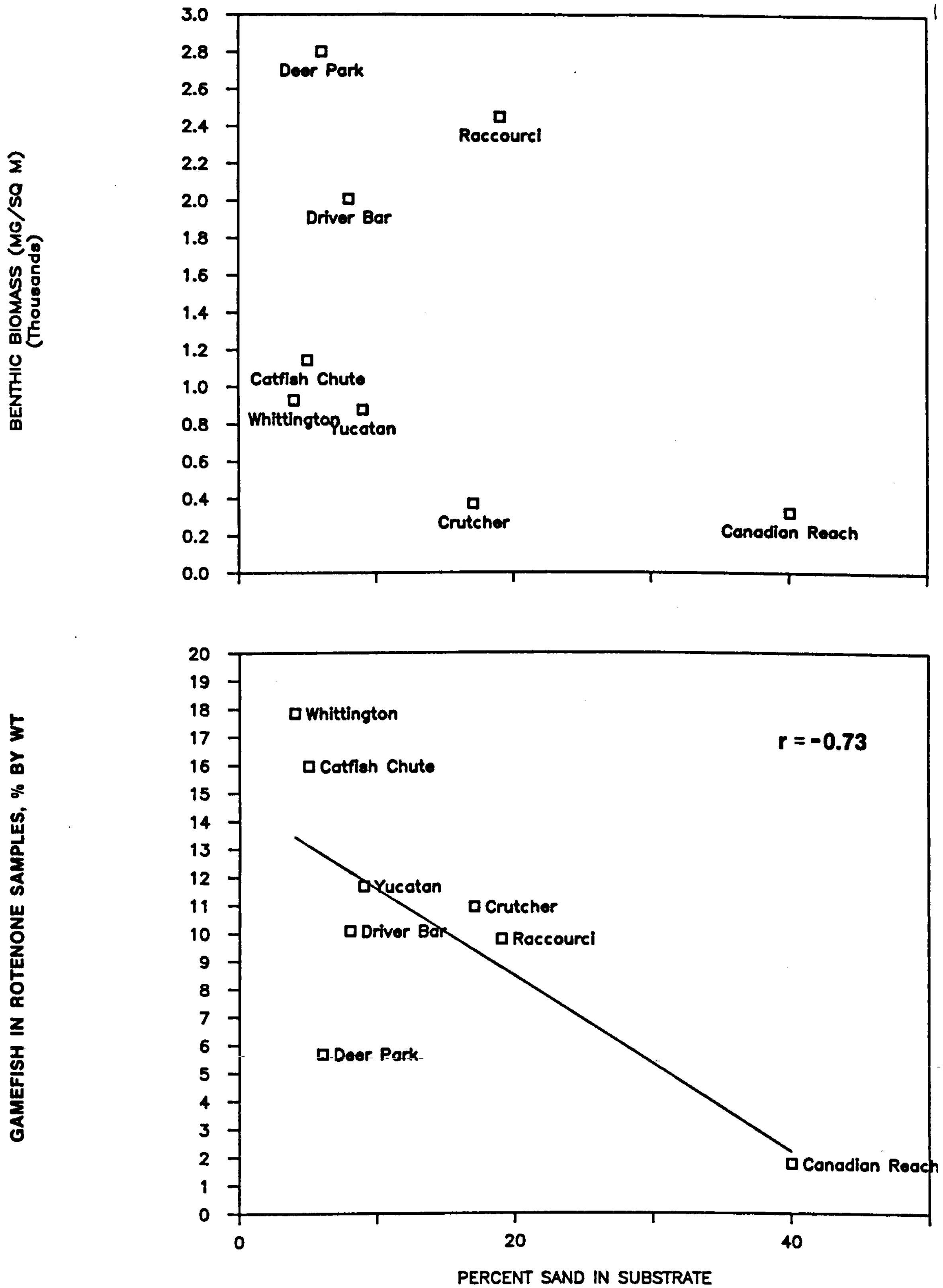


Figure 15. Benthic biomass percent gamefish versus percent sand in substrate, Lower Mississippi River floodplain lakes

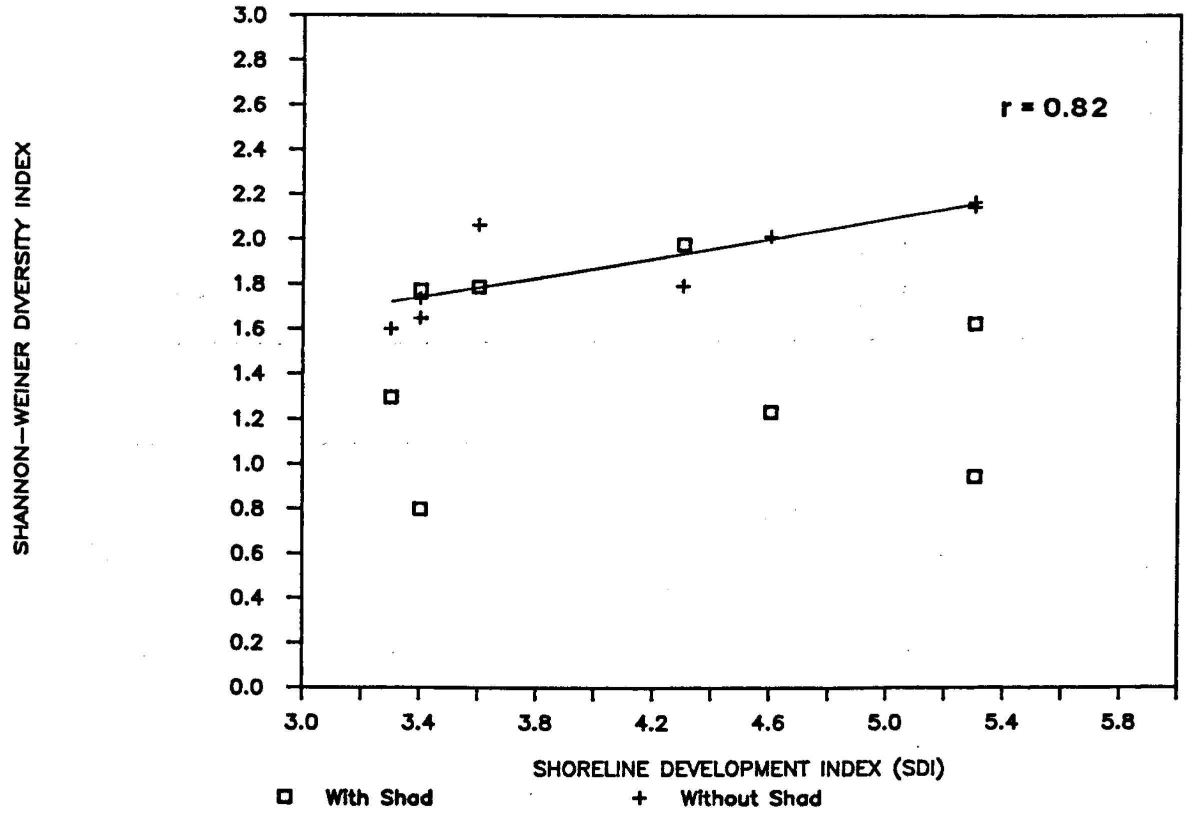


Figure 16. Shannon-Weiner Diversity Index versus Shoreline Development Index, Lower Mississippi River floodplain lakes

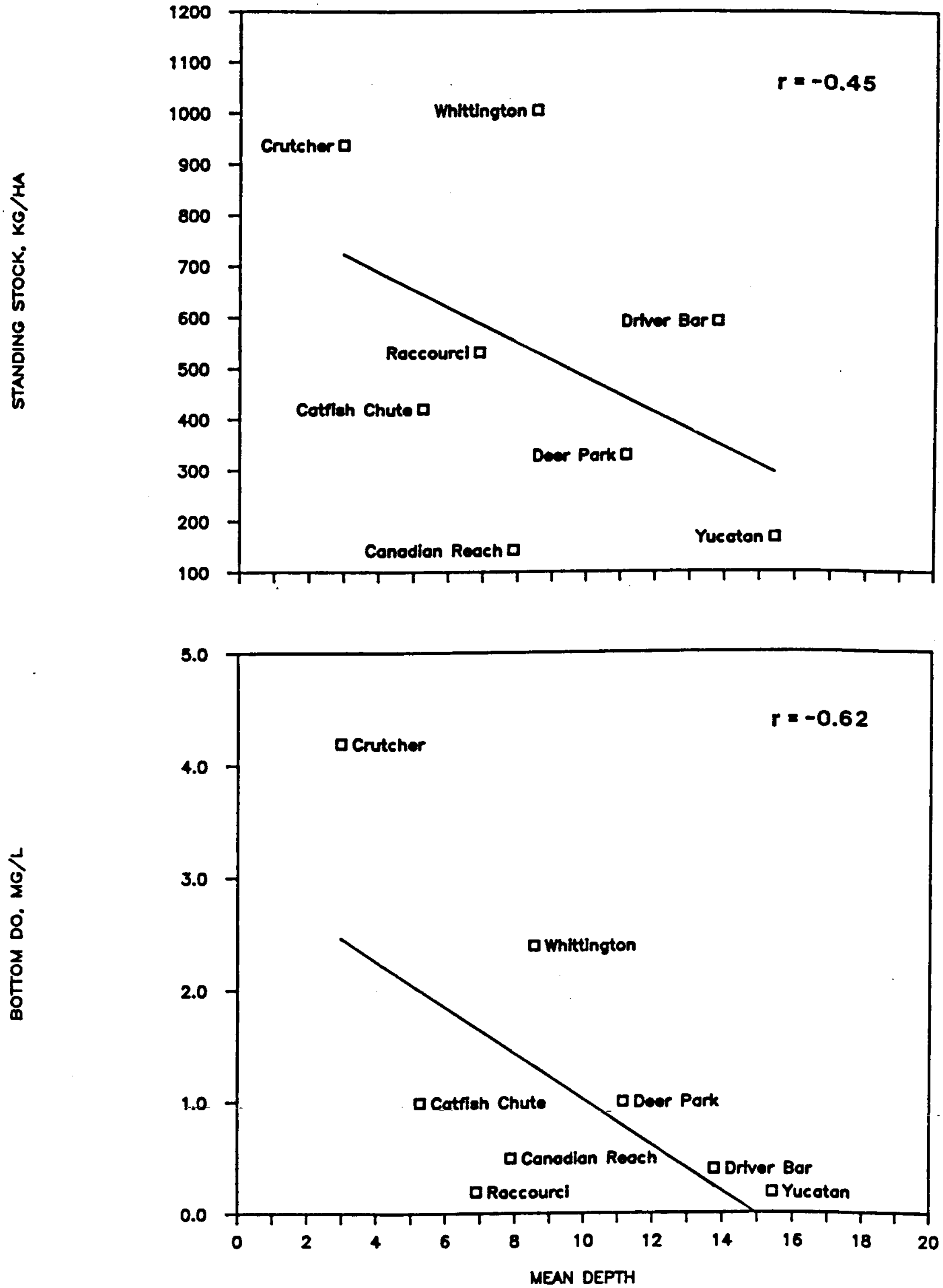


Figure 17. Standing stock and minimum DO concentrations, Lower Mississippi River floodplain lakes

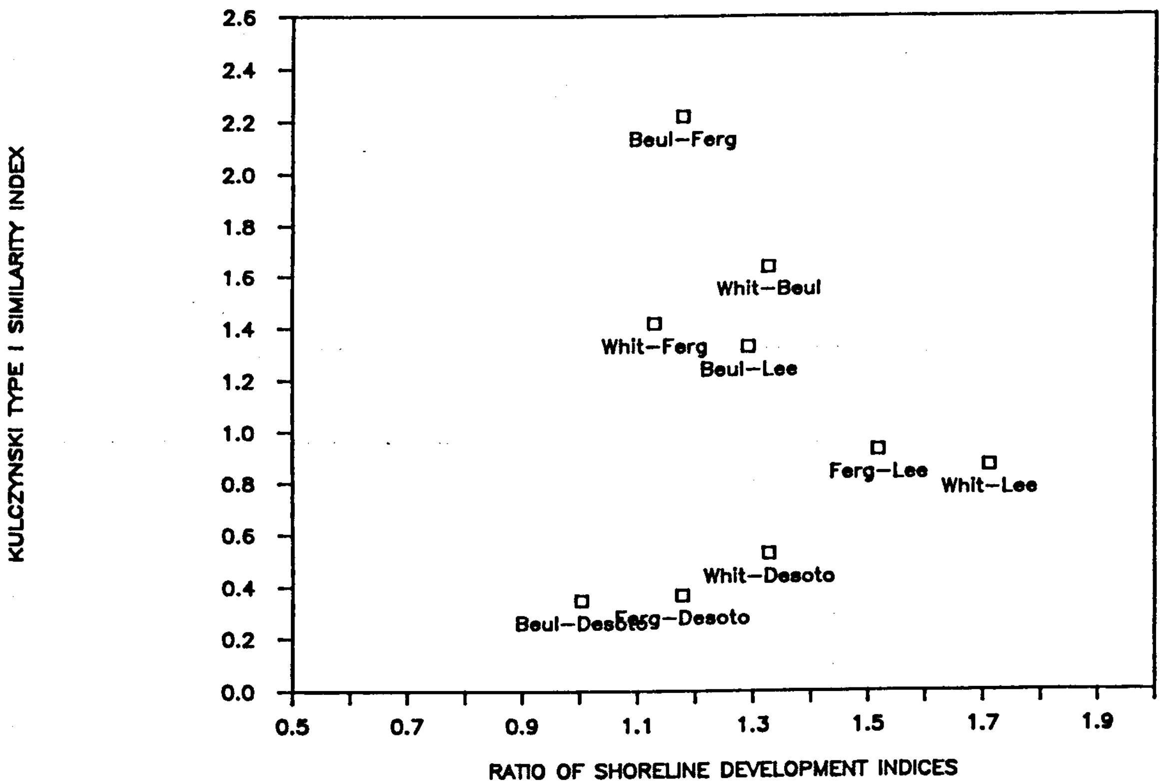


Figure 18. Similarity coefficients versus Shoreline Development Index ratio, Lower Mississippi River floodplain lakes

APPENDIX A: ADDITIONAL INFORMATION REGARDING CORRELATION ANALYSES

1. Three techniques were used in this study to examine associations between pairs of variables: comparison of group means (such as upper, middle, and lower pool bendways), scatter plots, and correlation analyses. Since the goal of the correlation analyses was to gage association and not to develop predictive models, regression equations are not presented. However, several other statistics arising from the correlation analysis are tabulated in Table A1. The coefficient of determination, r^2 , is the fraction of the variance in the dependent variable that is explained by the regression equation. The correlation coefficient, r , is the square root of r^2 . The standard deviation of residuals is the standard deviation of the differences between the observed and predicted values of the dependent variable. The probability values associated with the regression equation slope and intercept are the probability that these values are not significantly different from zero.

Table A1

Statistical Analysis of Correlations

Figure No.	Data Set	Independent Variable (x)	Dependent Variable (y)	No. of Observations	r	r^2	Std. Dev. of Residuals	Probability (α)* Intercept	Probability (α)* Slope	Signif. Corr.**
6	TTW	% vol < 3 ft deep	Mean width	14	-0.45	0.20	134	6.7E-4	0.11	
6	TTW	% vol < 3 ft deep	Mean depth	14	-0.85	0.72	2.77	<1E-4	1.1E-4	✓
8	TTW	Ratio of mean	S_k	55	-0.10	0.01	0.78	<1E-4	0.57	
8	TTW	Ratio of mean depths	S_k	55	-0.12	0.02	0.69	<1E-4	0.37	
9	TTW	S_k with Cooks	S_k with Big Ck	10	0.81	0.65	0.36	0.32	4.7E-3	
10	TTW	Mean depth	Ave CPUE	11	-0.21	0.04	3.73	8.0E-4	0.54	
	TTWLA	Mean depth	Ave CPUE	10	-0.49	0.24	2.27	<1E-4	0.15	
10	TTW	% vol < 3 ft deep	Ave CPUE	9	0.28	0.08	4.08	0.06	0.46	
	TTWLA	% vol < 3 ft deep	Ave CPUE	8	0.65	0.42	2.27	0.03	0.08	
10	TTW	Shoreline development	Ave CPUE	12	-0.42	0.17	4.96	2.5E-3	0.18	
	TTWLA	Shoreline development	Ave CPUE	10	-0.00	0.00	2.60	6.6E-3	0.90	
10	TTW	Mean depth	Ave species richness	11	-0.62	0.38	1.67	<1E-4	0.04	✓
10	TTW	% vol < 3 ft deep	Ave species richness	9	0.57	0.33	1.95	3.6E-3	0.11	
10	TTW	Shoreline development	Ave species richness	12	-0.06	3.7E-3	2.04	1.5E-4	0.85	
11	TTW	Bottom DO	Ave species richness	65	0.27	0.07	2.41	<1E-4	0.03	✓
11	TTW	Secchi disk	Ave species richness	63	-0.59	0.35	2.05	<1E-4	<1E-4	✓
11	TTW	Bottom DO	Ave CPUE	65	0.22	0.05	6.58	<1E-4	0.08	
11	TTW	Secchi disk	Ave CPUE	63	-0.50	0.25	5.83	<1E-4	<1E-4	✓
12	TTW	Max. depth	Middepth DO	17	-0.54	0.29	1.50	<1E-4	0.03	✓

(Continued)

Note: Data sets: TTW = Tennessee-Tombigbee bendways. TTWLA = Tenn-Tom bendways less Aberdeen Lake bendways. LMR1 = Lower Mississippi River floodplain lakes sampled by Lowery et al. (1987). LMR2 = Lower Mississippi River oxbow lakes sampled by Lucas (1985) and Lucas and King (1986).

* There are probabilities that the intercept and slope of the regression line are zero. The lower the probability, the less likely the slope or the intercept is equal to zero, and the more significant the regression.

** A check (✓) indicates correlations that are significant at the 95-percent confidence level. In other words, there is at most 5-percent probability that the correlation between the independent and dependent variable is due to chance alone.

Table A1 (Concluded)

Figure No.	Data Set	Independent Variable (x)	Dependent Variable (y)	No. of Observations	r	r^2	Std. Dev. of Residuals	Probability (α) Intercept	Probability (α) Slope	Signif. Corr.
12	TTW	Max. depth	Bottom DO	17	−0.42	0.18	2.69	6.6E−4	0.09	
14	LMR1	Mean depth ratio	S_k	28	0.04	0.00	0.41	<1E−4	0.82	
14	LMR1	Percent sand	S_k	28	−0.50	0.25	0.36	<1E−4	7.3E−3	✓
14	LMR1	SDI ratio	S_k	28	−0.08	0.01	0.41	0.01	0.68	
15	LMR1	Percent sand	Benthic biomass	8	−0.39	0.15	935	0.01	0.34	
15	LMR1	Percent sand	Benthic biomass	8	−0.36	0.13	947	Nonlinear regression		
15	LMR1	Percent sand	Percent gamefish	8	−0.73	0.53	3.80	4.1E−4	0.04	✓
15	LMR1	Percent sand	Percent gamefish	8	−0.72	0.51	90.4	Nonlinear regression		
16	LMR1	Shoreline development	Diversity index	8	0.82	0.66	0.14	0.01	0.01	✓
17	LMR1	Mean depth	Standing stock	8	−0.45	0.20	311	0.02	0.26	
17	LMR1	Mean depth	Bottom DO	8	−0.62	0.39	1.18	0.02	0.10	
18	LMR2	SDI ratio	S_k	10	0.01	0.00	1.11	1.05	−0.03	
	LMR2	Shoreline development	CPUE	5	0.05	0.00	1.01	3.08	−0.08	