# AN ABSTRACT OF THE THESIS OF

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in Biology presented on December 1, 1993

Title: Habitat restoration and seasonal habitat use by Neosho madtoms (*Noturus placidus*), and spatio-temporal variation of fish assemblages in the Cottonwood River, Kansas.

Abstract approved: David R. Edds

An artificial riffle was constructed in an area previously dredged of gravel on the Cottonwood River, Chase County, Kansas in February 1992, to restore habitat for the Neosho madtom (*Noturus placidus*), a federally threatened catfish. The artificial riffle and two natural riffles were sampled for one year to assess use of the artificial structure by Neosho madtoms and determine extent of fish colonization on the structure. Physical characteristics of the artificial riffle and species richness, diversity, and stability of its fish assemblage were assessed and compared to those of natural riffles. *Noturus placidus* seasonal densities were calculated, and population estimates were made by mark-recapture and depletion removal. Neosho madtoms (n = 255) on each riffle were given different subcutaneous marks in an attempt to document inter-riffle movement by the species. Length-frequency data were compiled, and seasonal habitat use by Neosho madtoms was determined. I used monthly samples to determine amounts of spatial and temporal variation in riffle and pool assemblages and identify which species varied in abundance seasonally.

Before construction, the artificial riffle site was inhabited by "pool" species, whereas post-construction the structure was rapidly colonized and provided suitable habitat for riffle dwellers, including _N_. _placidus_. The artificial riffle assemblage was stable and similar to that of natural riffles.

Neosho madtoms exhibited limited seasonal variability in habitat use and appeared to be year-round riffle dwellers. Young-of-year were observed in July, suggesting a June spawn. Only one inter-riffle movement was documented, demonstrating little dispersion among riffles throughout the year. Current speed at the substrate surface, low variance in current speed, shallow water, and loosely embedded substratum were variables most useful in predicting Neosho madtom presence.

Cannonical correspondance analysis of the overall fish assemblage (six sites) demonstrated differences between riffle and pool assemblages and indicated seasonal variation, but did not show longitudinal variation in the assemblage. Pool and riffle fish assemblages, independently, did not exhibit spatial variation, but were seasonally variable. Riffles were more temporally variable than pools, with 60% of the total fish captured on riffles showing seasonal variation, compared to 12% for pools.

# HABITAT RESTORATION AND SEASONAL HABITAT USE BY NEOSHO MADTOMS (<u>NOTURUS PLACIDUS</u>), AND SPATIO-TEMPORAL VARIATION OF FISH ASSEMBLAGES IN THE COTTONWOOD RIVER, KANSAS

A Thesis Submitted to the
Division of Biological Sciences
Emporia State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science

by
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December, 1993

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# Acknowledgements

This study was funded by the Kansas Department of Wildlife and Parks through the Chickadee Checkoff fund, Emporia State University via a Faculty Research and Creativity grant, and the U. S. Fish and Wildlife Service. Additional funding for materials was provided by a Wildlife Extension Agreement through Flint Hills National Wildlife Refuge. Northwest Marine Technologies, Inc. contributed marking equipment, Martin-Marietta quarries donated rock and gravel, the Kansas Department of Wildlife and Parks constructed the riffle, and Bethany College granted permission to use their land. Lyon County contributed surveying and hauling. Some necessary field equipment was designed and maintained by R. Ferguson.

I extend special gratitude for support and guidance given by D. Edds, my major advisor. My committee members T. Mosher, C. Prophet, and R. Sobieski offered helpful technical advice. D. Gabelhouse reviewed manuscripts and provided assistance with figures. For their assistance in implementing this project I thank E. Schenck, D. Wiseman, R. Benteman, and T. Jones. Assistance with statistical analyses and preparation of figures was provided by L. Scott and D. Moore. Many students assisted in field work including (but not limited to) F. Durbian, D. McLeod, J.

Sumner, J. Dorlac, V. Hesting, D. Pfingsten, M. Lane, and T. Thompson. I especially thank T. Hirata-Edds who provided child care on field days and J. Penrose and B. Stewart for their understanding.

# Preface

In October 1990, an instream gravel dredging operation on the Neosho River, Kansas, was halted by a cease and desist order for destroying habitat of a federally threatened catfish, the Neosho madtom. This action caused concern among local dredgers and land owners and prompted government agencies to investigate possible mitigatory measures for Neosho madtom habitat loss. This thesis stems from that incident and represents the combined efforts of many persons concerned with the preservation of threatened species and the maintenance of diverse aquatic ecosystems.

My thesis is an in-depth investigation of the structure and function of stream fish assemblages in the Cottonwood River, Kansas. It is divided into three autonomous manuscripts prepared for submission to appropriate scientific journals. Each chapter is written in the style dictated by the journal to which it will later be submitted, thus some background information is repeated and format varies among chapters. The three manuscripts encompass different aspects of fish ecology, including habitat restoration, life history information, and fish assemblage structure and will contribute to current literature in fisheries and fish ecology. Understanding the structure and function of natural systems is fundamental to investigating driving forces behind system evolution and is necessary for preserving ecosytems.

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# Chapter 1

# An Artificial Riffle as Fish Habitat Restoration Following Instream Gravel Dredging

## Abstract

An artificial riffle was constructed in an area previously dredged of gravel in the Cottonwood River, Kansas to restore habitat for the Neosho madtom (Noturus placidus), a federally threatened catfish. Colonization of fishes was monitored for one year after riffle construction, and the fish assemblage and physical features of the artificial riffle were compared to those of two natural riffles, one upstream and one downstream from the structure. Colonization of fishes onto the artificial riffle was rapid, and its species diversity and richness were eventually similar to those of natural riffles. Whereas the pre-construction fish assemblage was dominated by "pool species" such as orangespotted sunfish (Lepomis humilis), the post-construction artificial riffle fish assemblage consisted of "riffle species" including orangethroat darter (Etheostoma spectabile) and Neosho madtom. Relative abundance of fishes on the artificial riffle was similar to that of natural riffles and was similar between consecutive samples, indicating stability of the colonizing assemblage. Water on the artificial riffle was deeper and had a lower current velocity than on natural riffles, but provided suitable habitat for N. placidus and other riffle-dwelling fishes.

Effects of gravel dredging upon stream hydrodynamics and communities is well documented. "The resultant effects of gravel mining in the stream channel are often quite similar to severe channelization" (Brown and Baker, 1975). Gravel dredging results in the destruction of fish spawning beds and nursery habitat, subsequently reducing fish densities, altering fish species composition, and eliminating benthic macroinvertebrate assemblages (Crunkilton, 1982; Harvey, 1986). Dredging also has marked effects on morphodynamics of stream systems as manifested in upstream head-cutting, lateral bank erosion, and increased sediment discharge (Rivier and Seguier, 1985). Stream channel morphology, including the spacing and formation of riffles and pools, and other hydrodynamic processes "dictate habitat quantity and quality for different life stages of fishes" (Heede and Rinne, 1990). Jutila (1985) found that returning dredged gravel to riverbeds resulted in increased densities and recruitment of salmon and trout species. Artificial riffles have been constructed in freshwater streams to mitigate habitat loss due to channelization (Stuart, 1953; Edwards et al., 1984; Carline and Klosiewski, 1985), develop sport fish habitat (Miller and Herrig, 1990), and control the gradient of channelized streams (Brown, 1990), but colonization of artificial riffles by stream fish assemblages and suitability of these structures for non-game fish habitat restoration have not been investigated.

Effects of gravel dredging upon stream hydrodynamics and communities is well documented. "The resultant effects of gravel mining in the stream channel are often quite similar to severe channelization" (Brown and Baker, 1975). Gravel dredging results in the destruction of fish spawning beds and nursery habitat, subsequently reducing fish densities, altering fish species composition, and eliminating benthic macroinvertebrate assemblages (Crunkilton, 1982; Harvey, 1986). Dredging also has marked effects on morphodynamics of stream systems as manifested in upstream head-cutting, lateral bank erosion, and increased sediment discharge (Rivier and Seguier, 1985). Stream channel morphology, including the spacing and formation of riffles and pools, and other hydrodynamic processes "dictate habitat quantity and quality for different life stages of fishes" (Heede and Rinne, 1990). Jutila (1985) found that returning dredged gravel to riverbeds resulted in increased densities and recruitment of salmon and trout species. Artificial riffles have been constructed in freshwater streams to mitigate habitat loss due to channelization (Stuart, 1953; Edwards et al., 1984; Carline and Klosiewski, 1985), develop sport fish habitat (Miller and Herrig, 1990), and control the gradient of channelized streams (Brown, 1990), but colonization of artificial riffles by stream fish assemblages and suitability of these structures for non-game fish habitat restoration have not been investigated.

The U.S. Fish and Wildlife Service (USFWS, 1991) suggested that artificial riffles could be used to mitigate instream gravel dredging and restore critical habitat of the federally threatened Neosho madtom, Noturus placidus. This madtom inhabits gravel riffles primarily in the Neosho and Cottonwood rivers in Kansas, where it lives in the interstices of loose gravel (Moss, 1981). Its range has been reduced by the construction of mainstem impoundments, and instream gravel mining poses an additional threat to the species (USFWS, 1991). A moratorium on instream gravel dredging on the mainstems of the Cottonwood and Neosho rivers in Kansas was instated in the spring of 1991 to protect optimal habitat of N. placidus, yet gravel dredging in rivers remains a concern for stability of these aquatic systems and maintenance of a diverse ichthyofauna.

To restore habitat for N. placidus, an artificial riffle was constructed on a river reach where a gravel riffle had previously been dredged from the streambed. I compared fish assemblage structure of the artificial riffle to that of two natural riffles. I hypothesized that the artificial riffle would be colonized by fishes, with no difference in ichthyofaunal assemblages between it and adjacent natural riffles, and that Neosho madtom abundance on the artificial riffle would be equal to that of natural riffles.

## Study Site

The study site was located on the Cottonwood River, a low gradient, fourth order stream in Chase County, Kansas (NW 1/4 Sec 28 T19S R8E) near Cottonwood Falls (Fig. 1). The predominant substratum is chert gravel, and the stream is bordered by a riparian corridor of deciduous trees and agricultural fields. According to county records, the site was last dredged in January 1988, when 4664 $m^3$ of gravel was mined from the streambed to a depth of 3 m. Natural gravel replacement in the area was incomplete in 1992. Riffles 1, 3, and 4 were natural riffles, with Neosho madtoms present, upstream and downstream from riffle 2, the artificial riffle (Figure 1). Riffle 4 was not used in analyses, but Neosho madtoms were marked at this site.

Riffle construction.-The artificial riffle was constructed by the Kansas Department of Wildlife and Parks on 28 February 1992, and was designed to provide suitable N. placidus habitat, create a natural gravel "trap" that would subsequently fill with chert gravel by natural deposition, have minimum impact on stream morphology, and permit flow during periods of low discharge. The riffle was constructed of quarried limestone rock, and stretched 23 m, the width of the river channel. The structure was 0.6 m tall, "V"-shaped, pointing upstream, with a depression at the thalweg, the deepest part of the channel (Figure 2). The riffle base

Figure 1.

Study site on Cottonwood River, Chase County, Kansas. Sites 1, 3, and 4 are natural riffles; site 2 is the artificial riffle; A, B, and C are pools. Riffle and pool sizes are not to scale; distance is from the midline of one site to the midline of next.

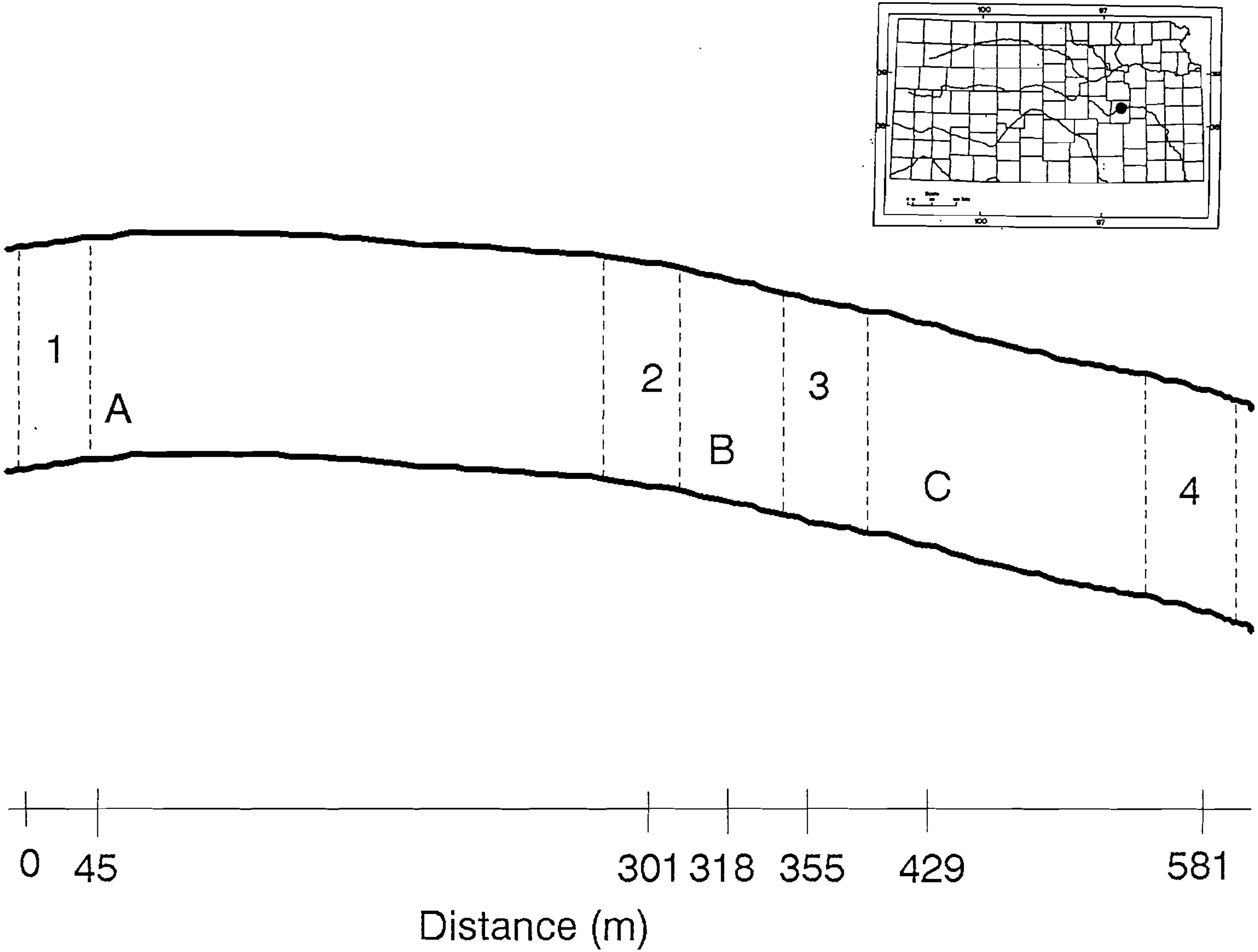
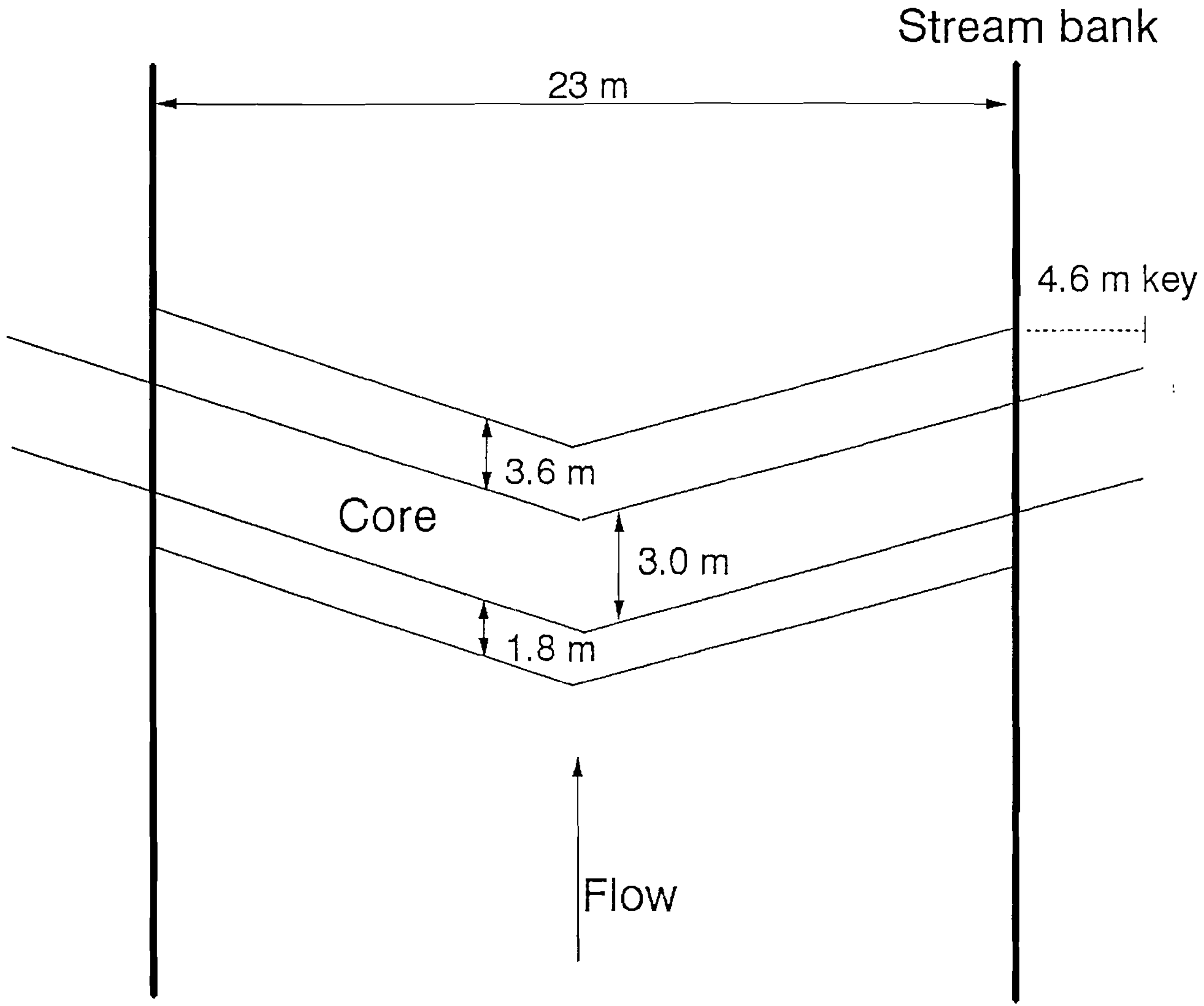

100
97
1
A
2
B
3
C
4
0
45
301
318
355
429
581
Distance (m)

Figure 2.

Plan view of artificial riffle constructed in the Cottonwood River, Chase Co., Kansas. Core is composed of rip-rap limestone, overlaid with crushed limestone gravel.


Stream bank
23 m
4.6 m key
3.6 m
Core
3.0 m
1.8 m
Flow

was composed of 305 metric tons of rip-rap, 15 - 46 cm diameter, and "keyed" 4.6 m into each bank to provide stability during high flows. Based on habitat preference data (Moss, 1981), 203 metric tons of gravel, 2 - 64 mm diameter, was spread over the base structure extending upstream and downstream to provide immediate habitat for Neosho madtoms.

Sampling.-Riffles 1 - 3 were sampled 23 times from February 1992 to March 1993, with one pre-construction sample taken in February 1992 (Appendix A). To monitor fish colonization, I sampled weekly for three months, February - April 1992; every two weeks for two months, May and June; and monthly from July 1992 to March 1993. The study site was inaccessible during December because of high water, when no sample was taken. I used stream discharge data from the U.S. Geological Survey gaging station on the Cottonwood River at Plymouth, Kansas, approximately 17 km downstream from my study site, to examine river discharge.

Fishes were collected during daylight hours with a double-weighted, 4.6-m x 1.8-m seine with 4.7-mm mesh. With the assistance of two other people, I kick-seined at five, 8-$m^2$ areas along a transect across each riffle; seine width was modified to 4 m, and gravel disturbance by two "kickers" began 2 m from the seine poles. Seining was not possible in depths greater than 140 cm and currents faster than 72 cm/sec. Thus, during high water events, accessible areas were limited to within 8 m of shoreline, and we seined five points from downstream toward the upstream area of a riffle.

I identified and returned fishes live to the water following completion of each transect. Neosho madtoms on each riffle were marked in a distinctive body location with a different color Visible Implant Fluorescent (VIF) tag (Northwest Marine Technologies, Inc.). Marks were verified by viewing fish under a portable black light. These tags have been tested on darters, and remained "highly visible" after 13 months (Haw et al., 1990). I collected and marked Neosho madtoms on riffles 1 and 3 prior to sample 1 on 15 February 1992, and on 7 September and 20 September 1992 in an attempt to determine direction of movement of colonizers. Two-hundred fifty-five Neosho madtoms were marked in systematic and supplemental "marking" samples on riffles 1 - 4.

To compare physicochemical characteristics of riffles 1 - 3, I measured pH, total hardness, total alkalinity, dissolved oxygen, and water temperature with a standard Hach water analysis kit, model AL-36B, at each site. At each of the five transect points on a riffle, I measured current speed, depth, percentage composition of rock, cobble, gravel, sand, and silt substratum, and substratum embeddedness. I measured depth with a calibrated wading rod, and current with a Teledyne Gurley pygmy current meter (no. 625) at the surface of the substrate and at 60% depth. I sampled substratum with a shovel (Grost et al., 1991) and made visual estimations of percent composition using the following size approximations based on a modification of the Wentworth scale (Cummins, 1962; Hynes, 1970): rock > 200 mm; cobble = 65 - 200 mm; gravel = 2 - 64 mm; sand = 1 - 2 mm; silt < 1 mm. On the artificial riffle, I estimated percentage of natural gravel in the substratum. Embeddedness was coded on a scale from 1, very loose, non-compacted substrate, to 3, very heavily embedded (100% silt).

Analyses.-The Statistical Analysis System (SAS Institute, 1985) was used for statistical analyses. Kruskal-Wallis ranked analysis of variance (ANOVA) was used to test for differences in physical characteristics and relative abundance of fishes among riffles, and Ryan-Einot-Gabriel-Welsch multiple F-tests were used to examine differences among riffles. To examine heterogeneity in current speed, depth, and embeddedness of substratum on riffles, I included the variance of these physical parameters in ranked ANOVA.

I calculated Morisita's (1959) index of similarity between consecutive samples on each riffle to examine stability of fish assemblages throughout the year. Index values range from 0, no similarity, to slightly more than 1, indicating identical assemblages. Shannon-Weaver diversity index values (Shannon and Weaver, 1963) were used as a measure of species diversity, and number of species present was used to characterize species richness. Parametric ANOVA of similarity, diversity, and richness was used to determine differences in these characteristics among riffles (Meador and Matthews, 1992). These data were normally distributed and exhibited homoscedasticity.

Fishes were designated as riffle or pool dwellers, based on life history information from Cross and Collins (1975), Pflieger (1975), Lee et al. (1980), and Robison and Buchanan (1984). Relative percentage of riffle and pool dwellers (Appendix A) collected in post-construction samples was compared between natural (two natural riffles pooled) and artificial riffles using parametric t-tests with data arcsine $x^{1/2}$ transformed. Variances were equal for riffle and pool species, and data were normally distributed for riffle dwellers. Although data were not normally distributed for pool dwellers, sample sizes and population variances were equal. A Mann-Whitney ranked t-test was used to compare differences in total number of fishes caught on natural and artificial riffles. To further examine stability of the artificial riffle fish assemblage throughout the year, I arbitrarily defined a "resident species" as having occurred in at least 15% of the 23 samples. In community analyses, species occurring in less than 5% of samples are considered rare (Gauch, 1982), thus my designation is conservative. A colonizer was defined as a species appearing on the artificial riffle in the first post-construction sample.

## Results

A total of 28 fish species was collected on riffles in 11 months (Appendix B). Twenty-four species were collected on the site of the artificial riffle, three of which, *Gambusia affinis*, *Carpiodes carpio*, and *Lepomis macrochirus*, appeared only in the pre-construction sample. Sixteen species were resident species (Table 1), and 11 of those were present in the first post-construction sample. The pre-construction artificial riffle sample (n = 423) consisted of 95% pool dwellers, and included the following: *Cyprinus carpio*, *Cyprinella lutrensis*, *Notropis buchanani*, *Pimephales notatus*, *P. tenellus*, *Gambusia affinis*, *Lepomis cyanellus*, *L. humilis*, *L. macrochirus*, and *Percina phoxocephala*. Six days post-construction (sample day 2), the assemblage (n = 95) contained 54% riffle dwellers: *Noturus placidus*, *Campostoma anomalum*, *Cyprinella lutrensis*,

Table 1. Resident and initial colonizing species on the artificial riffle in the Cottonwood River, Kansas; sampled February 1992 through March 1993. C = colonizer, R = resident

| | | |
|---|---|---|
| *Noturus placidus* | C | R |
| *Campostoma anomalum* | C | R |
| *Cyprinella camura* | | R |
| *C. lutrensis* | C | R |
| *Lythrurus umbratilis* | | R |
| *Notropis buchanani* | C | R |
| *N. stramineus* | | R |
| *N. volucellus* | | R |
| *Phenacobius mirabilis* | C | R |
| *Pimephales notatus* | C | R |
| *P. tenellus* | C | R |
| *Lepomis cyanellus* | | R |
| *L. humilis* | | R |
| *Etheostoma spectabile* | C | R |
| *Percina caprodes* | C | R |
| *P. copelandi* | C | R |
| *P. phoxocephala* | C | R |

Lythrurus umbratilis, Notropis buchanani, Phenacobius mirabilis, Pimephales notatus, P. tenellus, Etheostoma spectabile, Percina caprodes, P. copelandi, and P. phoxocephala.

Riffle inhabitants on the artificial riffle increased from 5% pre-construction to a mean of 36%, post-construction (Figure 3). Sample sizes on days 21 - 23 were small, due to high water (11, 40, and 15 on the artificial; 8, 2, and 11 on natural riffles), compared to the mean sample sizes of 159 on the artificial and 90 on natural riffles for days 1 - 20. Mean percentage of riffle dwellers on natural riffles was 54.4%, and higher than that of the artificial riffle ($t = -2.24$, $P < 0.03$). There were no differences between artificial and natural riffles in percentage of pool dwellers or in total number of fishes collected.

Relative abundances of 5 of 28 fishes were different among riffles (Table 2), with Percina phoxocephala less abundant on the artificial riffle than on either natural riffle. Noturus placidus abundance was lowest on the artificial riffle, but not significantly lower than on riffle 1, and although Ictalurus punctatus abundance was lowest on the artificial riffle, it was not different from riffle 3. Notropis volucellus and Pimephales notatus had highest abundance on the artificial riffle, though not significantly higher than on riffle 3.

Figure 3.

Proportion of riffle dwellers on artificial and natural riffles in the Cottonwood River, Chase Co., Kansas. Natural riffles 1 and 3 are pooled.

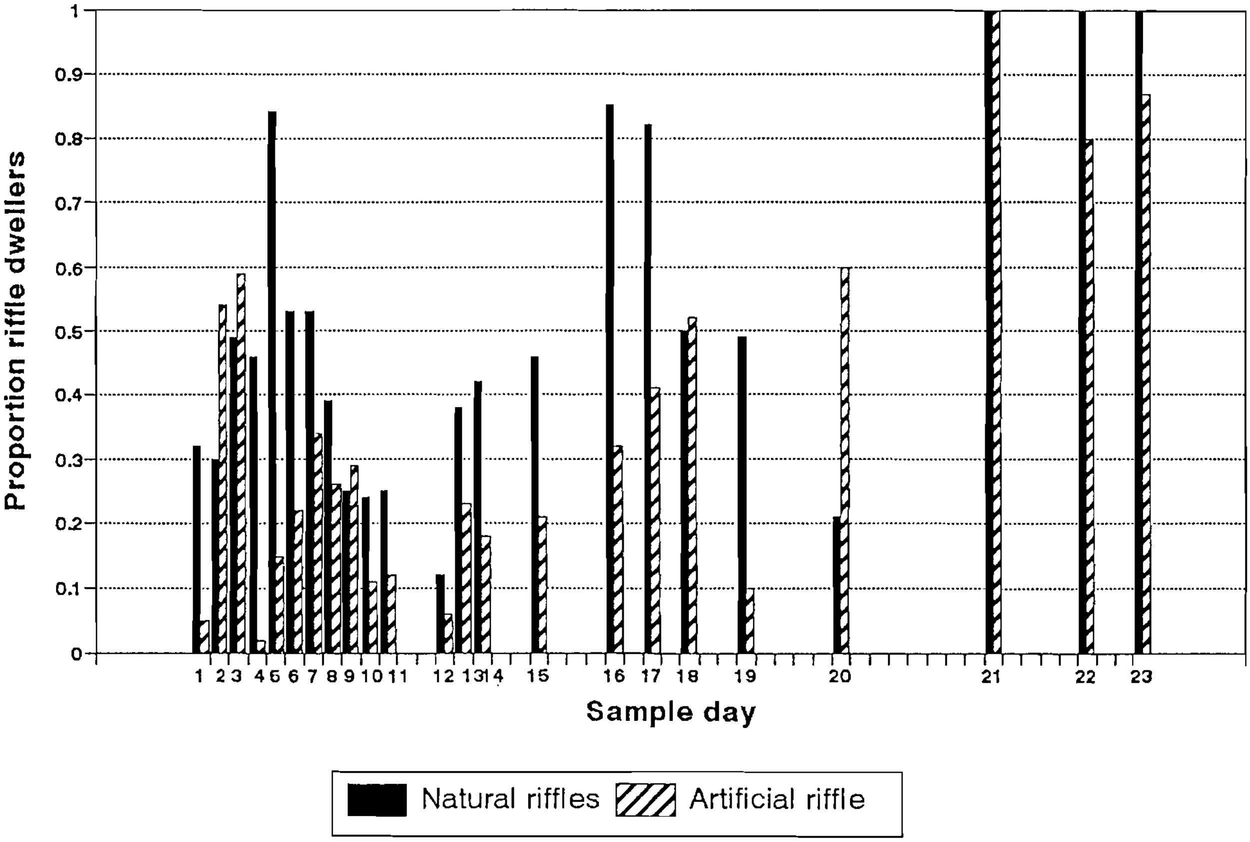

Proportion riffle dwellers
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Sample day
Natural riffles
Artificial riffle

Table 2. Results of ranked ANOVA of relative species abundances among natural and artificial riffles in the Cottonwood River, Kansas, February 1992 through March 1993. Riffle 2 = artificial riffle; riffles 1 & 3 are natural riffles. REGWF = Ryan-Einot-Gabriel-Welsch multiple F test. Riffles are listed from left to right in order of decreasing abundance; lines indicate means not significantly different.

| Species | P > F | REGWF |
|---|---|---|
| *Percina phoxocephala* | 0.0001 | $\underline{1\ 3}\ \underline{2}$ |
| *Noturus placidus* | 0.0003 | $\underline{3}\ \underline{1\ 2}$ |
| *Notropis volucellus* | 0.01 | $\underline{2\ 3}\ 1$<br>$2\ \underline{3\ 1}$ |
| *Ictalurus punctatus* * | 0.02 | $\underline{1\ 3}\ 2$<br>$1\ \underline{3\ 2}$ |
| *Pimephales notatus* | 0.04 | $\underline{2\ 3}\ 1$<br>$2\ \underline{3\ 1}$ |

* Young-of-year

Young-of-year (YOY) fishes collected on the artificial riffle included Cyprinella lutrensis, Campostoma anomalum, Ictalurus punctatus, and Noturus placidus. Twelve N. placidus were recaptured on riffles 1, 3, and 4 but none was recaptured on the artificial riffle; hence the origin of colonizers was unknown.

There were no differences in similarity, diversity, or species richness between natural and artificial riffles (Table 3). Similarity of the pre-impact sample and the first post-construction sample (day 2) on the artificial riffle was very low (0.2), as expected, but day 2 was very similar to day 3 (0.75), and assemblage similarity between consecutive sample days remained high ($\bar{x}$ = 0.80) throughout the year (Figure 4).

The artificial riffle retained integrity, and deposition of natural gravel on the core structure occurred throughout the year (Figure 5). Percentage natural gravel was higher during high water events, such as days 4 and 12 (Figure 5), because inundated shoreline containing natural gravel deposits was sampled. Day 1 was the pre-construction sample, so all gravel was natural (Figure 5). High discharge during the study period (Figure 6) caused more scouring of gravel than anticipated, resulting in greater depth in mid-channel areas of the artificial riffle. During high water events, artificial gravel was washed from the

Table 3. Mean values for Shannon-Weaver diversity (H'), Morisita's similarity index ($I_m$), and richness (±SE) for riffles 1, 2, and 3 in the Cottonwood River, Kansas; sampled February 1992 through March 1993.

| Site | H' | $I_m$ | Richness |
|---|---|---|---|
| 1 | 1.28 (0.1) | 0.741 (0.1) | 7.0 (0.7) |
| 2 | 1.47 (0.1) | 0.798 (0.04) | 9.0 (0.7) |
| 3 | 1.48 (0.1) | 0.816 (0.04) | 8.8 (0.7) |

Figure 4.

Morisita's index of similarity for consecutive sample days on an artificial riffle in the Cottonwood River, Kansas. Days compared refers to comparison of 1 with 2, 2 with 3, etc.

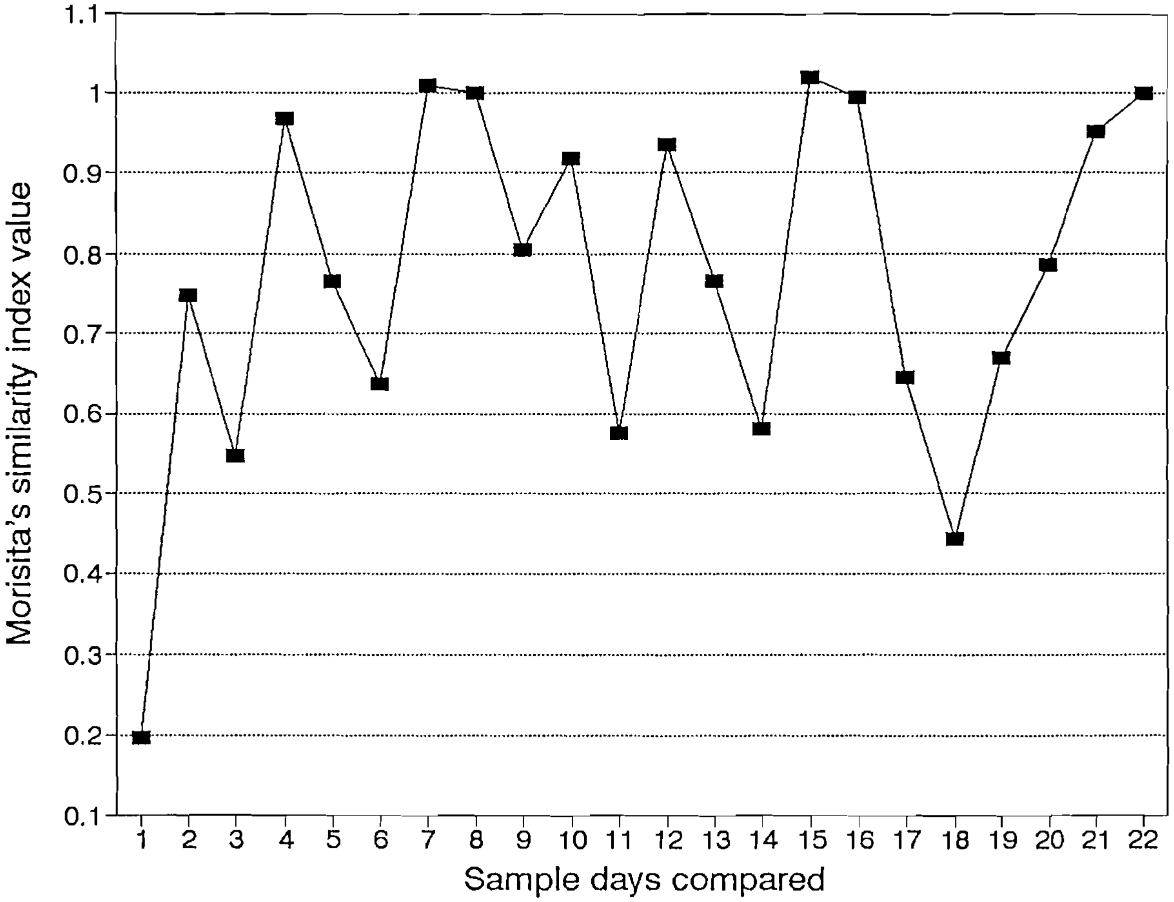

Morisita's similarity index value
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Sample days compared

Figure 5.

Percentage of natural gravel in substratum samples on an artificial riffle in the Cottonwood River, Kansas (site 2).

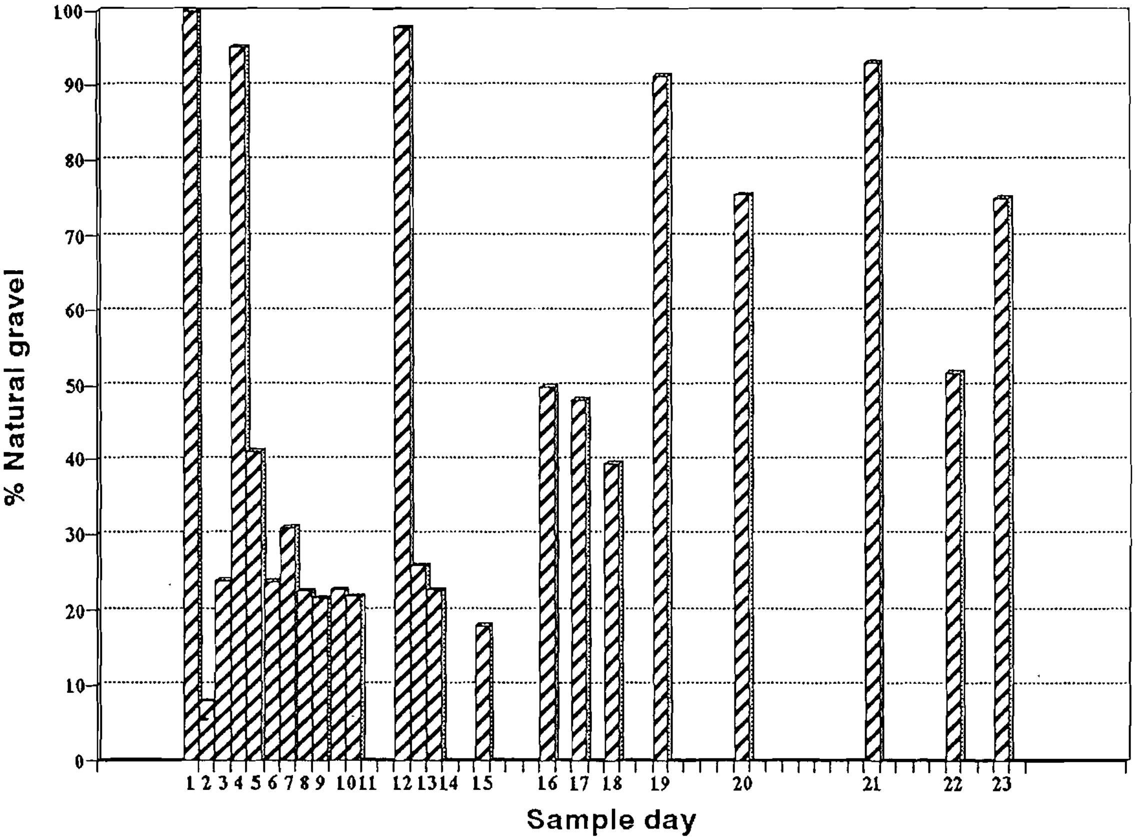
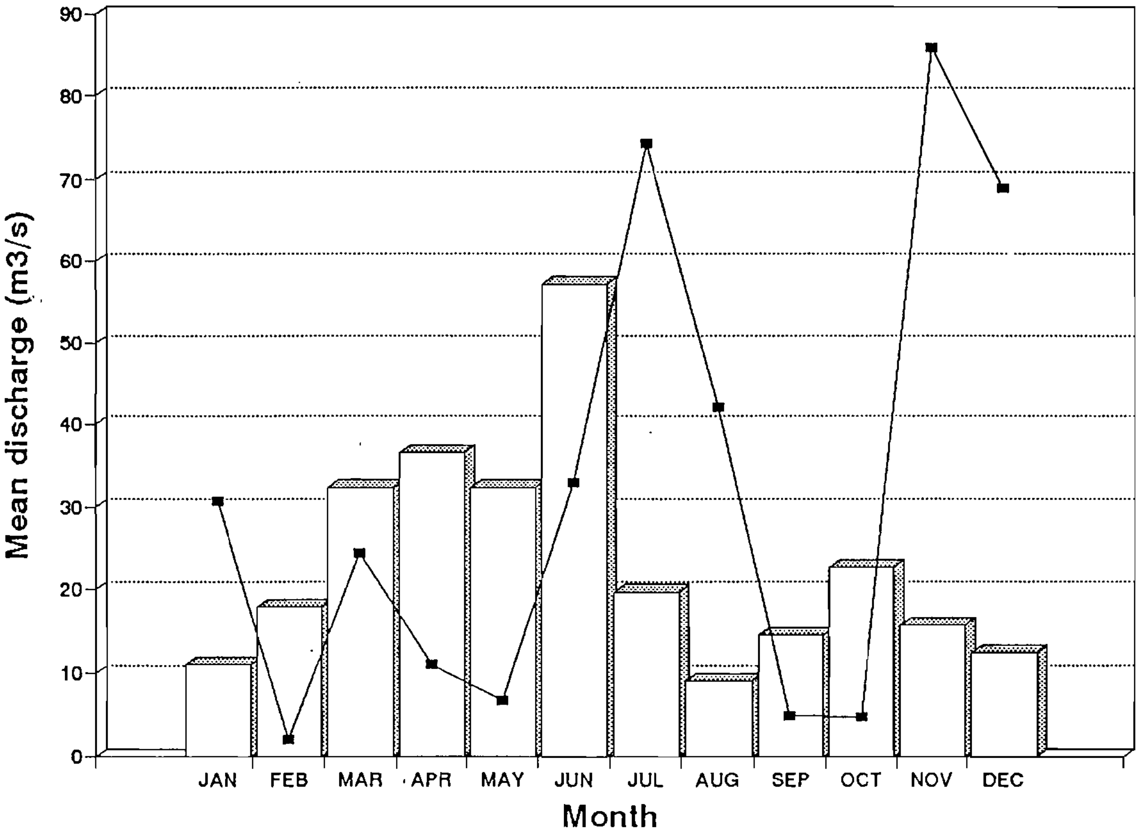

% Natural gravel
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Sample day

Figure 6.

Mean stream discharge 1963 - 1991 (bars), and during the sample year (line) on the Cottonwood River, Plymouth, Kansas.



90
80
70
60
50
40
30
20
10
0
Mean discharge (m3/s)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month

structure, causing temporary exposure of the rip-rap base in the substrate. Artificial riffle gravel appeared in the 29 August and subsequent substratum samples from the pool and riffle immediately downstream from the structure, constituting up to as much as 5% of the gravel present.

Substratum composition, embeddedness, current speed, and depth varied among riffles (Tables 4 & 5). The artificial riffle was lower in percentage cobble and sand, and had a higher percentage gravel substratum than did natural riffles. The artificial riffle was no different from riffle 3 in percentage rock substratum, but both had less rock than the upstream natural riffle. Riffle 3 was least variable in percentage rock substratum, but there was no difference in variation of rock between the artificial riffle and riffle 1. The artificial riffle had the lowest percentage silt substratum, but not different from riffle 3, and percentage cobble was less variable on the artificial riffle. Substratum embeddedness was not different on the artificial riffle and riffle 3, but riffle 1 was the most embedded of the three. Riffle 1 was the least variable in embeddedness, and the artificial riffle was most variable, though not significantly different from riffle 3. The artificial riffle had the lowest current speeds at 60% depth and at the bottom, but it was not significantly different from riffle 1. The artificial riffle was the

Table 4. Differences in means and variances of physical characteristics among riffles as determined by ranked ANOVA. Riffle 2 = artificial riffle and 1 & 3 are natural riffles in the Cottonwood River, Kansas, sampled February 1992 through March 1993. REGWF = Ryan-Einot-Gabriel-Welsch multiple F test. Riffles listed from left to right in order of decreasing variable value; lines indicate means not significantly different. Current 60% = current speed at 60% depth; current sub = current at substrate surface.

| Variable | P > F | REGWF | Variable | P > F | REGWF |
|---|---|---|---|---|---|
| Mean: | | | Variance: | | |
| Embeddedness | 0.0001 | $\underline{1}\ \underline{2\ 3}$ | Depth | 0.0004 | $\underline{2}\ \underline{3\ 1}$ |
| % Cobble | 0.0001 | $\underline{1}\ \underline{3}\ \underline{2}$ | % Rock | 0.001 | $\underline{1\ 2}\ \underline{3}$ |
| % Gravel | 0.0001 | $\underline{2}\ \underline{3}\ \underline{1}$ | % Cobble | 0.001 | $\underline{1\ 3}\ \underline{2}$ |
| % Sand | 0.0001 | $\underline{1\ 3}\ \underline{2}$ | Embeddedness | 0.001 | $\underline{2\ 3}\ \underline{1}$ |
| % Rock | 0.0004 | $\underline{1}\ \underline{2\ 3}$ | | | |
| % Silt | 0.004 | $\underline{1\ 3}\ 2$<br>$\phantom{1}\ \underline{\phantom{3\ 2}}$ | | | |
| Current 60% | 0.02 | $\underline{3}\ \underline{1\ 2}$ | | | |
| Current sub | 0.02 | $\underline{3}\ \underline{1\ 2}$ | | | |
| Depth | 0.02 | $\underline{2\ 1}\ 3$<br>$\phantom{2}\ \underline{\phantom{1\ 3}}$ | | | |

Table 5a. Descriptive statistics for physical characteristics of site 1, the riffle upstream from the artificial riffle in the Cottonwood River, Kansas; sampled February 1992 through March 1993. Total hardness and total alkalinity were measured in grains/l $CaCO_3$, and dissolved oxygen was measured in mg/l, SE = standard error, $s^2$ = variance.

| Variable | Mean (±SE) | $s^2$ | Range |
|---|---|---|---|
| Embeddedness | 2.1 (0.1) | 0.1 | 1.8 - 3.0 |
| Depth (cm) | 53.3 (0.1) | 0.4 | 21.3 - 94.5 |
| Current 60% (cm/s) | 42.2 (2.8) | 164.0 | 26.8 - 68.0 |
| Current sub (cm/s) | 21.7 (1.5) | 50.2 | 13.0 - 41.0 |
| %Rock | 9.1 (1.7) | 67.7 | 0.0 - 28.0 |
| %Cobble | 19.6 (1.9) | 85.2 | 0.0 - 38.0 |
| %Gravel | 44.3 (2.7) | 168.0 | 0.0 - 62.0 |
| %Sand | 13.5 (1.1) | 32.1 | 0.0 - 27.0 |
| %Silt | 13.5 (4.2) | 396.3 | 3.0 - 100.0 |
| Water temp (°C) | 14.5 (1.8) | 70.2 | 0.5 - 27.0 |
| Dissolved oxygen | 9.6 (0.6) | 8.7 | 4.0 - 15.0 |
| Total alkalinity | 3.9 (0.3) | 7.0 | 2.6 - 8.7 |
| Hardness | 6.7 (0.6) | 31.3 | 3.4 - 17.6 |
| pH | 7.9 (0.1) | 0.2 | 7.2 - 8.9 |

Table 5b. Descriptive characteristics for the artificial riffle, site 2, in the Cottonwood River, Kansas; sampled February 1992 through March 1993.

| Variable | Mean (±SE) | $s^2$ | Range |
|---|---|---|---|
| Embeddedness | 1.8 (0.1) | 0.2 | 1.0 - 2.6 |
| Depth (cm) | 61.0 (0.1) | 0.1 | 36.6 - 82.3 |
| Current 60% (cm/s) | 41.0 (3.0) | 161.0 | 20.6 - 63.6 |
| Current sub (cm/s) | 19.5 (2.1) | 93.7 | 1.2 - 37.6 |
| %Rock | 4.6 (1.5) | 50.1 | 0.0 - 28.0 |
| %Cobble | 4.5 (1.1) | 26.7 | 0.0 - 20.0 |
| %Gravel | 77.8 (2.7) | 169.1 | 50.0 - 95.0 |
| %Sand | 7.6 (0.1) | 15.6 | 1.0 - 14.0 |
| %Silt | 5.5 (1.8) | 12.0 | 1.0 - 18.0 |
| Water temp. (°C) | 15.3 (0.5) | 69.4 | 1.0 - 28.0 |
| Dissolved oxygen | 10.0 (1.7) | 6.2 | 6.0 - 16.0 |
| Total alkalinity | 15.3 (0.8) | 13.2 | 11.0 - 28.0 |
| Hardness | 24.4 (1.5) | 53.9 | 14.0 - 43.0 |
| pH | 7.9 (0.1) | 0.2 | 7.0 - 8.4 |

Table 5c. Descriptive statistics for site 3, the riffle immediately downstream from the artificial riffle in the Cottonwood River, Kansas; sampled February 1992 through March 1993.

| Variable | Mean (±SE) | $s^2$ | Range |
|---|---|---|---|
| Embeddedness | 1.8 (0.1) | 0.1 | 1.0 - 3.0 |
| Depth (cm) | 48.8 (0.1) | 0.3 | 25.6 - 82.9 |
| Current 60% (cm/s) | 54.6 (3.7) | 235.4 | 34.0 - 84.6 |
| Current sub (cm/s) | 27.0 (2.1) | 89.7 | 1.2 - 37.6 |
| %Rock | 1.5 (0.9) | 18.7 | 0.0 - 18.0 |
| %Cobble | 8.9 (1.3) | 36.5 | 0.0 - 27.0 |
| %Gravel | 69.1 (2.1) | 93.3 | 40.0 - 81.0 |
| %Sand | 11.5 (0.9) | 15.2 | 3.0 - 17.0 |
| %Silt | 7.7 (1.3) | 36.5 | 3.0 - 30.0 |
| Water temp (°C) | 16.8 (1.7) | 55.4 | 4.0 - 29.0 |
| Dissolved oxygen | 9.2 (0.5) | 5.1 | 6.0 - 14.0 |
| Total alkalinity | 15.8 (1.4) | 42.6 | 6.0 - 37.0 |
| Hardness | 27.5 (2.5) | 134.9 | 14.0 - 67.0 |
| pH | 7.7 (0.2) | 0.4 | 6.1 - 8.4 |

deepest and the most variable in depth of the three sites, though it was not significantly deeper than riffle 1. There were no significant differences in water chemistry variables among the three riffles.

## Discussion

Instream gravel excavations can influence fish populations by "eliminating spawning and nursery habitat, altering habitats, and by influencing the trophic dynamics of fish communities, thereby affecting the nutrition and health of fish" (Kanehl and Lyons, 1992). Instream gravel dredging operations in the River Loire, France, resulted in decreases in fish numbers and biomass, reductions in riffle fishes, an increase in pool species, and an assemblage composed of silt-tolerant, deep-water fishes (Rivier and Seguier, 1985). Downstream from gravel removal operations in the Brazos River, Texas, Forsage and Carter (1973) recorded reductions in minnow and sunfish species, the elimination of a darter species, and an increase in sucker species; they assumed changes were due to alterations in habitat and cover, and reduction in food sources.

The natural spacing of riffles in a stream is strongly influenced by stream width and channel gradient, hence any manipulation, such as dredging, that alters these factors affects riffle-pool sequences (Keller, 1978). Brown and

Lyttle (1992) found riffles in Ozark streams disturbed by gravel dredging were spaced further apart than the expected five to seven stream widths observed in undisturbed areas. The construction of riffle and pool sequences in low gradient, channelized areas can provide increased productivity and reduce effects of channelization (Keller, 1978). Edwards et al. (1984) showed that areas with artificial riffles had fish species abundances intermediate between natural areas and channelized, unmitigated areas; they attributed the lower species abundances on artificial riffles to a lack of habitat heterogeneity. Carline and Klosiewski (1985) found that fishes responded positively to rock sills constructed in channelized areas and maintained that although short-term assessment of mitigative efforts revealed only limited success, the construction of restoration structures should be considered in habitat management.

I studied an artificial riffle constructed in a stream reach from which a riffle had been dredged. The pre-construction fish assemblage consisted of many slow-water inhabitants, including centrarchids, mosquitofish, and carpsuckers, but the post-construction assemblage was comparable to that of natural riffles, and included darters, madtoms, and central stonerollers.

Noturus placidus was as abundant on the artificial riffle as on natural riffle 1 and, although riffle 3 had more Neosho madtoms, both adult and YOY Neosho madtoms were present on the artificial riffle. Water depth on the artificial riffle was greater than the 4 - 54 cm preference reported for N. placidus, but both current at 60% depth and at the substrate surface were within the species' 10 - 50 cm/s range of habitat suitability (Moss, 1983; Luttrell et al., 1992; Wenke et al., 1992). Adult Neosho madtoms were present six days post-construction, and became a resident species. Noturus placidus YOY were collected on the artificial riffle July through October.

Presence of loosely embedded substratum influences Neosho madtom abundance (Moss, 1981; USFWS, 1991; Luttrell et al., 1992; Chapter 2). The artificial riffle had the least embedded substratum of the three riffles and was relatively homogeneous with an abundance of gravel, but very little cobble, sand, or silt. Noturus flavus, a species suspected of competing with N. placidus (Moss, 1983), was not collected on the riffle, possibly because that species utilizes cobble substratum (Moss, 1981, 1983). It is apparent from differences in physical structure and species abundance that variation among natural riffles exists. Riffle 3, downstream from the artificial riffle, may be thought of as "good" Neosho madtom habitat, whereas riffles such as site 1 and the artificial riffle are "average" quality, providing suitable habitat for fewer N. placidus.

Fishes are known to recover rapidly in defaunated areas (Larimore et al., 1959; Olmsted and Cloutman, 1974; Meffe and Sheldon, 1990), and a disturbed area can be recolonized by a fish assemblage within 95% of its pre-disturbance composition in less than 10 days (Peterson and Bayley, 1991). Movement of fishes onto the artificial riffle was rapid, and initial colonizers were resident species typical of natural riffles in the Cottonwood River. Stability of the artificial riffle fish assemblage was not different from that of natural riffles, suggesting possible utility in construction of artificial riffles to restore habitat disrupted by activities such as instream gravel dredging.

Though separate age classes of fishes were not analyzed, the presence of YOY and adults shows the artificial riffle was used by different life stages of stream fishes. Young of both Ictalurus punctatus and Pylodictis olivaris inhabit riffles in spring and summer (Cross and Collins, 1975; Pflieger, 1975), and were collected on the artificial riffle. Construction of artificial riffles may benefit game fish populations by providing suitable habitat in which young fish feed and mature. Fishing riffles in Iowa, constructed primarily to create pool habitat for large game fishes, particularly channel catfish, were successful at aggregating fishes in areas of high angler pressure, though benefits for non-game species were minimal (Miller and Herrig, 1990). The artificial riffle constructed on the Cottonwood River provided habitat for game fish and non-game species targeted for habitat restoration.

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Appendix A. Sample days as they correspond to dates and days post-construction for study site on Cottonwood River, Kansas sampled February 1992 through March 1993.

| Sample day | Date | Days post-construction |
|---|---|---|
| 1 | 23 Feb 1992 | pre-construction |
| 2 | 5 Mar 1992 | 6 |
| 3 | 15 Mar 1992 | 16 |
| 4 | 21 Mar 1992 | 22 |
| 5 | 29 Mar 1992 | 30 |
| 6 | 5 Apr 1992 | 37 |
| 7 | 12 Apr 1992 | 44 |
| 8 | 17 Apr 1992 | 49 |
| 9 | 26 Apr 1992 | 58 |
| 10 | 7 May 1992 | 69 |
| 11 | 19 May 1992 | 81 |
| 12 | 3 Jun 1992 | 96 |
| 13 | 23 Jun 1992 | 116 |
| 14 | 30 Jun 1992 | 123 |
| 15 | 14 Jul 1992 | 137 |
| 16 | 17 Aug 1992 | 171 |
| 17 | 29 Aug 1992 | 183 |
| 18 | 12 Sep 1992 | 197 |
| 19 | 10 Oct 1992 | 225 |
| 20 | 14 Nov 1992 | 260 |

Appendix A. continued

| | | |
|---|---|---|
| 21 | 17 Jan 1993 | 324 |
| 22 | 21 Feb 1993 | 359 |
| 23 | 14 Mar 1993 | 380 |

Appendix B. Number of fishes collected on artificial and natural riffles in Cottonwood River, Chase Co., Kansas, sampled February 1992 through March 1993. * = "riffle" fishes, all others are "pool" species.

| Species | Riffle 1 | Riffle 2 | Riffle 3 |
|---|---|---|---|
| *Campostoma anomalum* * | 11 | 45 | 23 |
| *Carpiodes carpio* [1] | | 1 | 1 |
| *Cyprinella camura* | 3 | 16 | 6 |
| *C. lutrensis* | 433 | 1125 | 619 |
| *Etheostoma spectabile* * | 29 | 110 | 26 |
| *Gambusia affinis* [1] | | 1 | 1 |
| *Ictalurus punctatus* * [2] | 28 | 5 | 13 |
| *Labidesthes sicculus* [3] | | 2 | |
| *Lepomis cyanellus* | 1 | 6 | |
| *Lepomis humilis* | 28 | 163 | 32 |
| *Lepomis macrochirus* [1] | | 1 | |
| *Lythrurus umbratilis* | 1 | 4 | 1 |
| *Micropterus punctulatus* | | 1 | |
| *Micropterus salmoides* | | | 1 |
| *Moxostoma erythrurum* | | | 1 |
| *Notropis buchanani* | 12 | 64 | 35 |
| *N. stramineus* | 1 | 23 | 17 |
| *N. volucellus* | 11 | 70 | 44 |
| *Noturus flavus* * | 6 | | 3 |

Appendix B. continued

| | | | |
|---|---|---|---|
| *N. placidus* * | 15 | 5 | 56 |
| *Percina caprodes* * | 28 | 23 | 12 |
| *P. copelandi* * | 12 | 62 | 31 |
| *P. phoxocephala* * | 532 | 246 | 384 |
| *Phenacobius mirabilis* * | 35 | 111 | 92 |
| *Pimephales notatus* | 117 | 562 | 174 |
| *P. tenellus* | 424 | 546 | 384 |
| *Pomoxis annularis* | 1 | | |
| *Pylodictis olivaris* *[2] | 2 | 1 | |

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1 = on riffle 2 present only in pre-construction sample

2 = young-of-year

3 = flood day sample

# Chapter 2

# *Noturus placidus* (Siluriformes, Ictaluridae)
# Seasonal Habitat Use

ABSTRACT--I sampled a series of riffles and pools on the Cottonwood River, Kansas, for one year to determine seasonal densities, habitat use, and the extent of inter-riffle movements of the Neosho madtom (Noturus placidus), a federally threatened catfish. The species exhibited limited seasonal variability in habitat use and appeared to be a year-round riffle inhabitant. Neosho madtoms inhabited shallower riffle areas in spring and summer, sites with greater water velocities in spring, and slower velocities in winter. Madtoms used sites with greater percentage rock substratum in winter, and substratum embeddedness was consistently low at sites of madtom presence. Current speed at the substrate surface, low variance of current speed, shallow water, and loosely embedded substratum were variables most useful in predicting madtom presence. Only one inter-riffle movement was documented, demonstrating little dispersion among riffles throughout the year. Two age classes were obvious in length-frequency histograms; YOY appeared in July, suggesting a June spawn. Neosho madtom populations were assessed by mark-recapture (47 madtoms/100 $m^2$), depletion removal (22 ± 4 /100 $m^2$), species specific (15.5 /100 $m^2$), and overall (3.3 /100 $m^2$) density calculations.

There are 25 species of madtoms, genus Noturus, worldwide (Robins et al., 1991) and 18 of these are threatened or endangered (Johnson, 1987). The Neosho madtom, N. placidus, was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in June 1990 (55 FR 21148). Very little is known of N. placidus life history, and this paucity of information may impede recovery of the species (USFWS, 1991). Neosho madtoms occur almost exclusively in the Cottonwood and Neosho rivers in southeast Kansas, and the Neosho River in Oklahoma (Moss, 1981; USFWS, 1991; Luttrell et al., 1992). Although reaches of the Cottonwood and Neosho rivers in Kansas are state-designated critical habitat for the species, mainstem impoundments have eliminated approximately one-third of the historical range of the Neosho madtom (USFWS, 1991).

Neosho madtoms are found on riffles with loose, clean gravel, and swift current speeds, where adults hide in the gravel interstices during the day and feed nocturnally on aquatic insects (Cross and Collins, 1975; Pflieger, 1975; Miller and Robison, 1980; Moss, 1981; 1983; Page and Burr, 1991). The USFWS Neosho madtom recovery plan (1991) designated investigation of inter-riffle movement and study of the species' reproductive biology as priorities. Nests of Neosho madtoms have never been observed in the field, but young-of-year (YOY) Neosho madtoms are said to inhabit slower flowing waters downstream from riffles, and use of pools and backwaters as nursery areas is presumed (Moss, 1981). Microhabitat preference has been investigated by Moss (1983), and Wenke et al. (1992) calculated winter Neosho madtom densities, but seasonal habitat use and inter-riffle movements of juvenile and adult Neosho madtoms have not been investigated. Knowledge of variation in seasonal habitat use is critical for designing monitoring programs and assessing this species' recovery.

Objectives of this investigation were to determine Neosho madtom seasonal habitat use and densities, and to evaluate the extent and direction of inter-riffle movement by the species. I collected, marked, and measured Neosho madtoms, and documented habitat use throughout one year in a series of riffles and pools in southcentral Kansas.

MATERIALS AND METHODS-My study area was located on the Cottonwood River, a low gradient, fourth order stream in Chase County, Kansas (NW 1/4 Sec. 28 T19S R8E) near Cottonwood Falls (Fig. 1). Stream discharge data collected from the U. S. Geological Survey gaging station at Plymouth, Kansas, approximately 17 km downstream from my study area, showed a mean discharge for February through October 1992 of 24.8 $m^3/s$. Highest mean discharge is typically in June (USFWS, 1991); however, during 1992 discharge peaked in November at 85.8 $m^3/s$ (Fig. 2). High turbidity year-round precluded visual observation of fish or nests in the

Cottonwood River. The predominant substratum is chert gravel, and the stream is bordered by a riparian corridor and agricultural fields. I sampled seven sites, including four riffles (sites 1 - 4) and the pool immediately downstream from the first three riffles (sites A - C) (Fig. 1). Site 2 was an artificial riffle constructed of crushed limestone gravel as part of a habitat enhancement study in an area dredged of gravel in 1988 (Chapter 1). Site 4 was not sampled seasonally, but was a location for additional "marking" samples.

Sites were sampled 23 times from February 1992 to March 1993. I sampled weekly for three months, February - April 1992; every two weeks for two months, May and June; and monthly from July 1992 to March 1993. The study site was inaccessible during December because of high water, so no sample was taken. Fishes were collected during daylight hours with a double-weighted 4.6 m x 1.8 m seine with 4.7 mm mesh. To standardize samples, an assistant an I seined each pool for 20 minutes, covering as much area as possible (20 - 50 m shoreline length, depending on pool size). On riffles, fishes were collected by kick seining at five, evenly spaced, 8-m$^2$ areas along a transect across the riffle. Seine width was modified to 4 m, and gravel disturbance by two "kickers" began 2 m from the seine poles. Kick seining was not possible in depths greater than 140 cm, and currents faster than 72 cm/sec. Thus, during high water events,

Figure 1.

Study site on the Cottonwood River, Chase County, Kansas. Sites 1 - 4 are riffles, and sites A - C are pools. The area of riffles is not to scale.

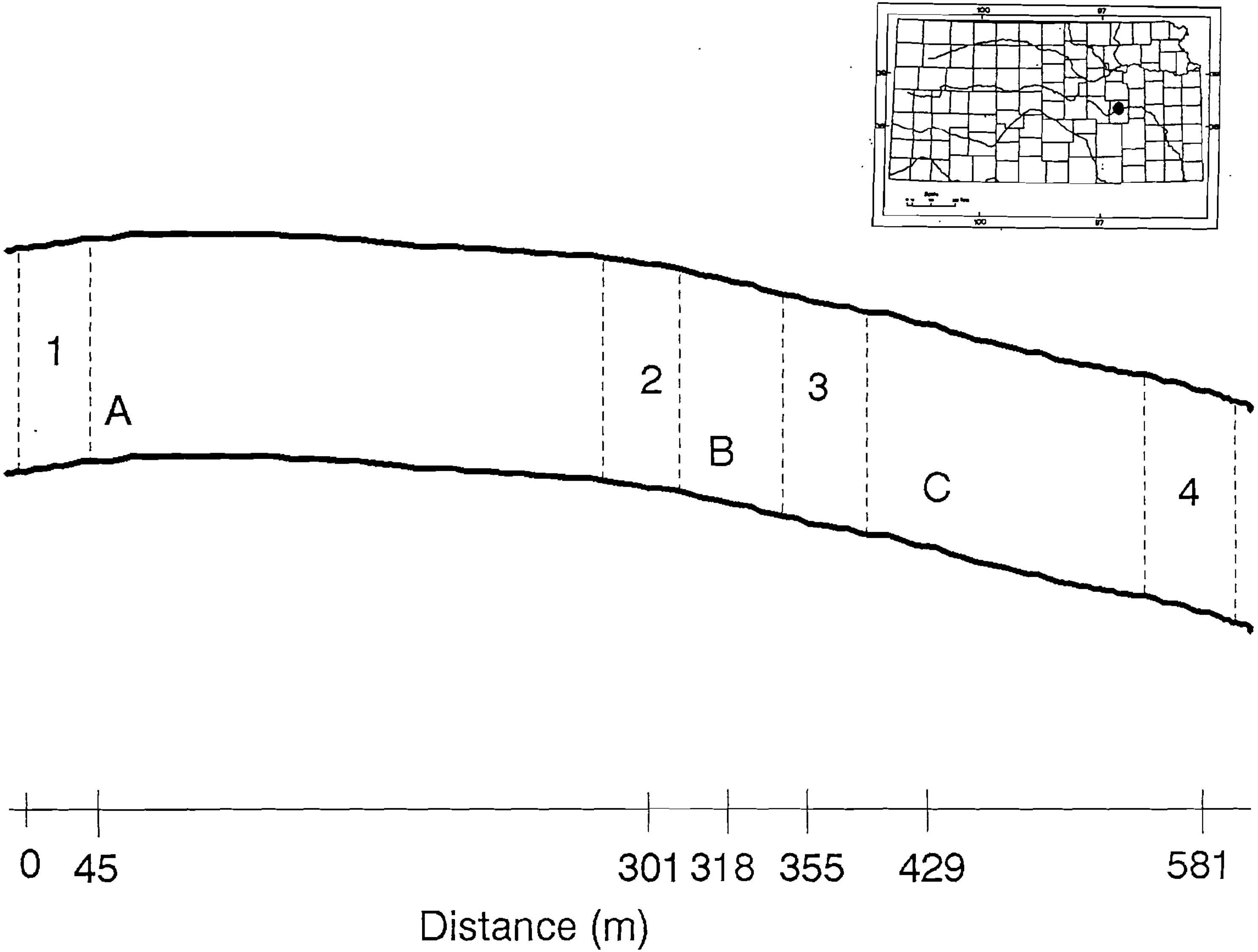
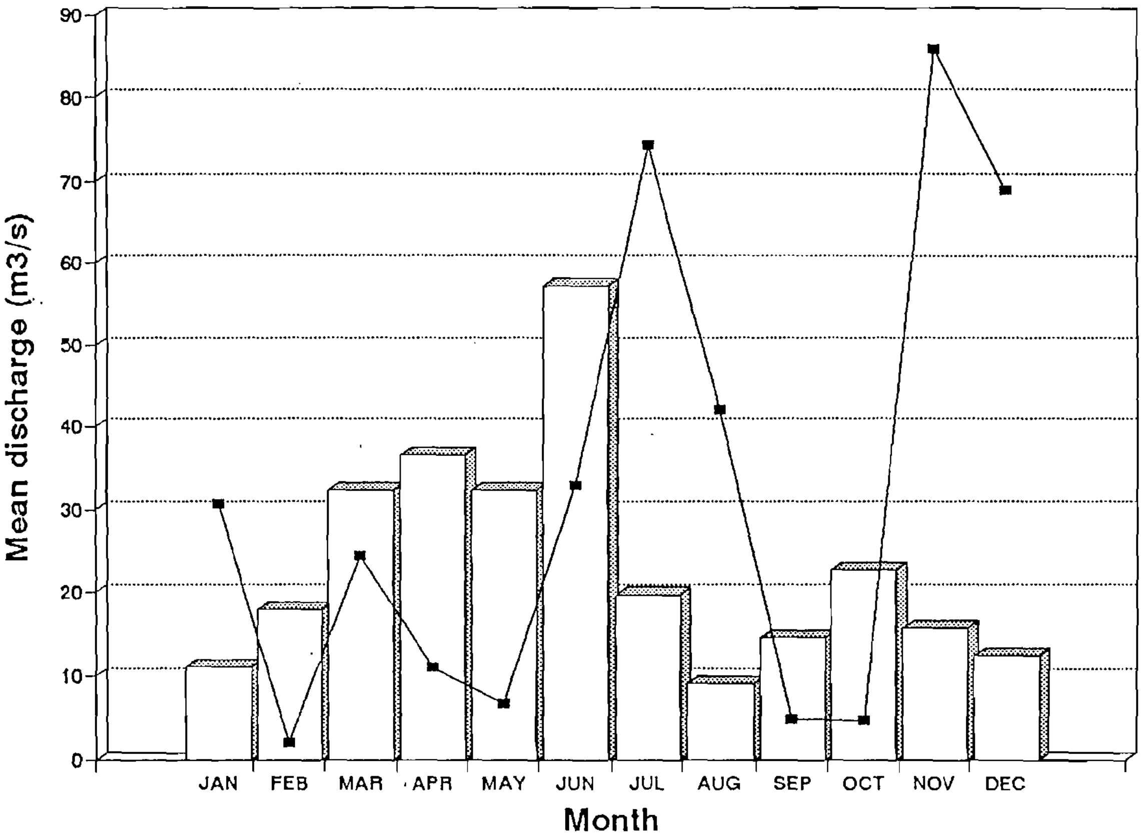

1
A
2
B
3
C
4
0
45
301
318
355
429
581
Distance (m)

Figure 2.

Mean stream discharge for 1963 - 1991 (bars), and from February 1992 - January 1993 (line) on the Cottonwood River, Plymouth, Kansas.



Mean discharge (m3/s)
0
10
20
30
40
50
60
70
80
90
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month

accessible areas were limited to within 8 m of shoreline, and I sampled five points from downstream toward the upstream area of the riffle.

All fishes collected on riffles were identified and returned alive to the water. Fishes from pools, with the exception of N. placidus, were preserved in 10% formalin for subsequent identification. I collected and marked Neosho madtoms on each riffle, according to the riffle on which they were captured, on 15 February, 7 September, and 20 September 1992. These additional samples, referred to as "marking samples", were not included in analyses of standard collections. I recorded total length (TL) of Neosho madtoms and marked them with Visible Implant Fluorescent (VIF) tags manufactured by Northwest Marine Technologies, Inc. Neosho madtoms on each riffle were marked with a different color tag in a distinctive body location; tags were injected on the left or right side of the body at the base of the dorsal or adipose fin. I verified marks by viewing fish under a portable black light. I tested this marking method on stonecats (Noturus flavus), freckled madtoms (N. nocturnus), and young-of-year (YOY) channel catfish (Ictalurus punctatus) for approximately one month in lab aquaria and observed no tag loss. These tags have been tested on darters and remained "highly visible" after 13 months (Haw et al., 1990).

I measured pH, total hardness, total alkalinity, dissolved oxygen, and water temperature with a Hach water analysis kit, model AL-36B, at each site. At each transect point on riffles and at five transect points in pools, I measured environmental variables, including current speed, depth, percentage composition of rock, cobble, gravel, sand, and silt substratum, and substratum embeddedness. I measured depth with a calibrated wading rod, and current with a Teledyne Gurley pygmy current meter (no. 625) at the substrate surface and at 60% depth. I sampled substratum with a shovel (Grost et al., 1991), and visual estimation of percent composition of substratum was based on the modified Wentworth scale (Cummins, 1962; Hynes, 1970). Embeddedness was coded on a scale from one, very loose substrate, to three, very heavily embedded (100% silt).

The Statistical Analysis System (SAS Institute, 1985) was used for statistical analyses. Kruskal-Wallis ranked analysis of variance (ANOVA) was used to test for differences in habitat between sites of madtom presence and absence within seasons. I used those variables significantly different within seasons in a ranked ANOVA and Ryan-Einot-Gabriel-Welsch multiple F tests (REGWF) to identify which variables also differed among seasons. Stepwise regression (STEPWISE) with minimum $r^2$ selection (MINR) was used to create a model that best described sites of madtom occurrence throughout the year. Percentage data were arcsine $x^{½}$ transformed. Multiple regression analysis

(REG) was used to examine quality of fit and prediction for the model. Seasons were defined by solstice and equinox dates.

Neosho madtom age class ratios were determined from length-frequency histograms for all months madtoms were collected. I calculated species specific and overall densities of Neosho madtoms at each site seasonally. Species-specific density is the number of Neosho madtoms collected, divided by the area in which they occurred; overall density is the number of Neosho madtoms collected, divided by the entire area of riffle sampled (Moss, 1983; Luttrell et al., 1991; Wenke et al., 1992). Mark-recapture population estimates were calculated by the Schnabel method (Ricker, 1973; Davis and Winstead, 1980) at sites of recapture. As an independent measure of density, I estimated Neosho madtom numbers at site 3 by depletion removal (Zippin, 1958) and calculated goodness of fit for the estimate (Platts et al., 1983). For this estimation, I collected fishes by kick seining while simultaneously electroshocking with a backpack electroshocker in a 155 $m^2$ area of riffle, passing five times over the area sampled.

RESULTS--I collected and marked 255 Neosho madtoms; 77 Neosho madtoms were captured in standard samples, and 178 occurred in additional marking samples. Twelve Neosho madtoms were recaptured, and 266 lengths were measured.

Neosho madtoms did not occur in January, June, or November samples.

Neosho madtoms were collected on riffles with predominantly gravel substrate, low embeddedness, shallow depths, swift currents, and high dissolved oxygen (Table 1). Two Neosho madtoms were collected in pool samples, both at site B, one on 5 March and one 10 October 1992. These madtoms were found downstream from, and in close proximity to, riffle site 2 in a shallow ($\bar{x}$ = 45.7 cm) backwater area less than 4 m from shore. In this area, current at 60% depth was 8.5 cm/s, the substratum was loosely embedded ($\bar{x}$ = 1.5) and had a mean composition of 10% cobble, 75% gravel, 10% sand, and 5% silt.

ANOVA between sites of madtom presence and absence within each season removed the effect of seasonal weather variability, and revealed Neosho madtom seasonal habitat use. Neosho madtoms utilized areas with low embeddedness in the fall, summer, and winter (Table 2). Mean water depth at Neosho madtom sites was lowest in spring (28.8 cm), and deepest in fall (48.8 cm). Although Neosho madtom areas were not significantly deeper in winter, mean depth (45.0 cm) in winter at Neosho madtom sites was greater than spring (28.8 cm) and summer (42.6 cm) depths. Neosho madtoms were found in areas with greater water velocity at 60% depth in spring and winter, and utilized higher current speed at the substrate in spring. In winter Neosho madtoms were

Table 1. Habitat variable means for Neosho madtom sites in the Cottonwood River, Kansas. Current 60% = current speed at 60% depth, current sub = current speed at substrate surface, DO = dissolved oxygen. Total alkalinity and total hardness measured in grains/l $CaCO_3$.

| Variable | n | Mean (±SE) | Range |
|---|---|---|---|
| Embeddedness | 50 | 1.6 (0.1) | 1.0 - 2.0 |
| Depth (cm) | 50 | 46.3 (0.1) | 15.2 - 109.7 |
| Current 60% (cm/s) | 39 | 46.2 (2.5) | 2.0 - 72.0 |
| Current sub (cm/s) | 49 | 24.8 (1.4) | 2.0 - 55.0 |
| % Rock | 50 | 3.8 (1.3) | 0.0 - 50.0 |
| % Cobble | 50 | 8.7 (1.6) | 0.0 - 50.0 |
| % Gravel | 50 | 68.8 (2.9) | 10.0 - 95.0 |
| % Sand | 50 | 10.4 (1.1) | 0.0 - 30.0 |
| % Silt | 50 | 6.4 (0.6) | 0.0 - 20.0 |
| Water temp. (°C) | 27 | 16.6 (1.2) | 7.2 - 29.0 |
| DO (mg/l) | 27 | 9.2 (0.3) | 6.0 - 12.0 |
| Total alkalinity | 28 | 4.2 (0.4) | 1.6 - 9.8 |
| Hardness | 28 | 7.5 (0.6) | 4.2 - 17.7 |
| pH | 18 | 7.9 (0.1) | 7.1 - 8.6 |

collected in areas with greater percentage rock substrate, and in fall they were found in areas with a higher percentage of sand. Neosho madtom sites had higher dissolved oxygen in the summer and lower total alkalinity in winter.

ANOVA of variables different within seasons showed no difference in embeddedness, dissolved oxygen or total alkalinity at Neosho madtom sites among seasons. Percentage rock substratum was greater in winter ($P < 0.0002$), percentage sand substratum was higher in fall ($P < 0.0001$), and depth was greater in fall ($P < 0.001$) than in other seasons. Current speed at 60% depth was highest in fall ($P < 0.02$), significantly higher than winter, but not different from other seasons, and current at the substrate surface was greatest in spring ($P < 0.0004$), though not different from fall and summer.

Stepwise regression analysis resulted in a four variable model including current speed at the substrate surface (cs), variance in current at the substrate (csv), depth (dep), and embeddedness (emb), useful in predicting sites of Neosho madtom presence (Np). Bounds on the condition number were 1.4 and 19.0, and Mallows' $C_p$ value was 2.9, indicating good quality of prediction. Multiple regression showed all variables in the model were significant ($P < 0.01$), and $r^2 = 0.30$ ($n = 67$), indicating good quality of fit for this model. The Durbin-Watson D

Table 2. Habitat variables significantly different in ranked ANOVA between sites of madtom presence and absence within each season. Crnt sub = current at substrate surface, crnt 60% = current at 60% depth, DO = dissolved oxygen; total alkalinity in grains/l $CaCO_3$.

| Season (n) | Variable | P > F | Range | Mean (±SE) |
|---|---|---|---|---|
| Spring | Crnt sub (cm/s) | 0.0005 | 2.0 - 55.0 | 28.8 (2.5) |
| (26) | Water depth (cm) | 0.002 | 15.2 - 91.4 | 39.6 (2.1) |
| | Crnt 60% (cm/s) | 0.01 | 2.0 - 72.0 | 49.5 (4.2) |
| Summer | Embeddedness | 0.02 | 1.0 - 2.0 | 1.6 (0.1) |
| (14) | Water depth (cm) | 0.02 | 21.3 - 67.0 | 42.6 (3.5) |
| | DO (mg/l) | 0.02 | 8.0 - 10.0 | 9.3 (0.6) |
| Fall | % Sand | 0.008 | 1.0 - 30.0 | 15.6 (2.4) |
| (8) | Embeddedness | 0.01 | 1.0 - 2.0 | 1.6 (0.2) |
| | Water depth (cm) | 0.02 | 30.5 - 60.9 | 48.8 (9.1) |
| Winter | Crnt 60% (cm/s) | 0.002 | 35.0 - 52.0 | 43.5 (8.5) |
| (4) | Embeddedness | 0.007 | 1.0 - 2.0 | 1.8 (0.3) |
| | % Rock | 0.02 | 0.0 - 10.0 | 3.8 (2.4) |
| | Total alkalinity | 0.02 | 2.4 - 5.9 | 2.5 (1.0) |

statistic was 2.2 and indicated these time-series data were not influenced by autocorrelation. The resulting multiple regression equation ($P < 0.0001$, $F = 7.31$, $df = 4$) predicting sites of Neosho madtom occurrence at this study site was:

$$Np = 5.87 - 0.008\ csv + 0.073\ cs - 1.69\ dep - 1.52\ emb$$

One marked Neosho madtom, 62 mm TL, collected 17 April 1992, had moved upstream from site 4 to site 3, a distance of approximately 225 m. All other recaptured madtoms were collected on riffles where they had been initially marked.

Twelve recaptures of marked madtoms occurred in 1992: at site 3, one on 5 March, three on 17 April, one on 26 April, two on 7 May, one on 12 September, and two on 22 October; one at site 1 on 15 March; and one at site 4 on 20 September. Mark-recapture estimates for these samples likely violate the assumptions that no recruitment, immigration or emigration occurred in populations, thus the most accurate estimate is obtained using the earliest samples. I used capture numbers for the first four riffle 3 samples with recaptures. The resulting population estimate in 532 $m^2$ was 47 madtoms/100 $m^2$ with a 95% confidence interval of 41.6 - 53.4 madtoms/100 $m^2$.

A population estimate of 21.8 ± 3.5 Neosho madtoms/100 $m^2$ (SE = 2.8) was determined by depletion removal on 22 October 1992 at site 3, and had a high goodness of fit, $\chi^2 = 0.69$, $df = 2$, $0.975 > P > 0.95$ (Platts et al., 1983).

Overall and species-specific densities on riffles were not different among seasons and are reported here for comparisons to other studies (Table 3). Mean overall and species specific densities for the year were 3.3 madtoms/100 $m^2$ (range 0.3 - 11.1), and 15.5 madtoms/100 $m^2$ (range 12.5 - 25.8), respectively.

Young-of-year Neosho madtoms, 15 mm and 20 mm TL, were first captured in July. In August, September, and October, age 0 fish had modal lengths of 41 mm, 23 mm, and 32 mm, respectively. Moss (1981) suggested that YOY N. placidus increase in length 10 mm per month during periods of optimal growth, and described three age classes (n = 701), with age 2 fish occasionally surviving through July. Two size groups, age 0 and age 1, were evident in July and August at the study site (Fig. 3) with YOY/adult ratios of 0.5 and 8.0. Adult fish ranged in length from 33 mm (February sample) to 82 mm (March). Adults were less common after July, but occurred February through May, and July through August, with modal lengths of 51, 58, 58, 64, 70, and 72 mm, respectively (Fig. 3).

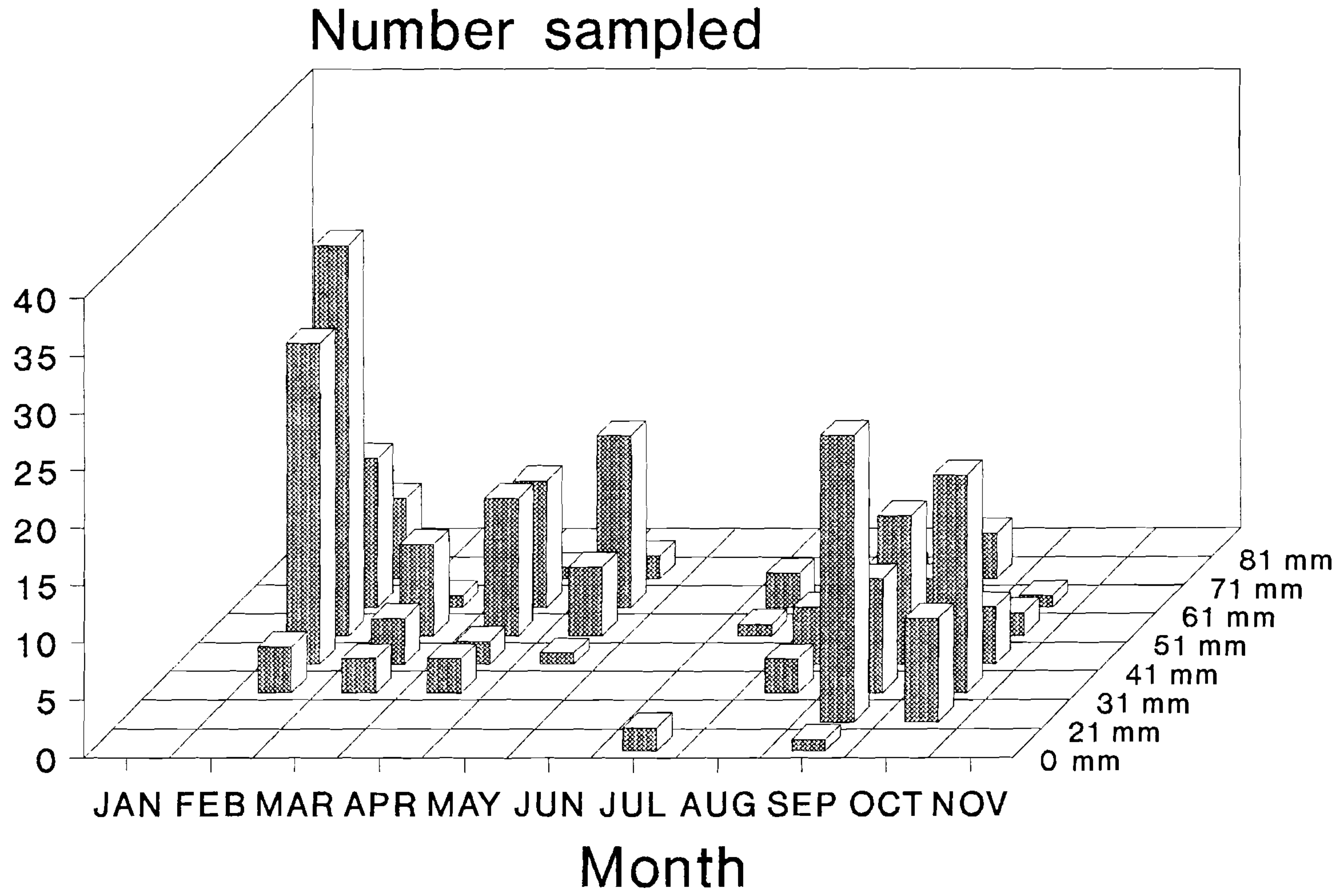
DISCUSSION--Neosho madtoms have been collected on riffles in water 3 cm to 79 cm deep, with temperatures ranging from 1°C to 27°C, and current speeds between 0 and 92 cm/s (Moss, 1981; Luttrell et al., 1991; Wenke et al., 1992). In my study, current velocity at the substrate surface was

Table 3. Noturus placidus densities /100 $m^2$ by season from February 1992 - March 1993 at three riffles in the Cottonwood River, Kansas.

| | Overall | | | | Species Specific | | | |
|---|---|---|---|---|---|---|---|---|
| Site | Win | Spr | Sum | Fall | Win | Spr | Sum | Fall |
| 1 | 2.1 | 2.6 | 0.8 | 2.5 | 15.6 | 15.6 | 12.5 | 12.5 |
| 2 | 0.4 | 0.3 | 0.4 | 2.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| 3 | 3.3 | 11.1 | 4.6 | 7.5 | 20.0 | 25.8 | 17.2 | 18.7 |

Figure 3.

Length-frequency histogram for *Noturus placidus* in eight months of 1992.


Number sampled
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
Month
81 mm
71 mm
61 mm
51 mm
41 mm
31 mm
21 mm
0 mm

consistently lower than at 60% depth, a point worth noting because some studies do not specify which measurement was used and therefore hinder comparisons. Moss (1981) showed Neosho madtoms were most abundant in areas with gravel 8 to 16 mm in diameter, where the fish maneuver into the loose substratum. Moss (1983) collected YOY Neosho madtoms in shallow (0.3 - 1.0 m) pools and on the periphery of riffles. Adult Neosho madtoms are most abundant on gravel riffles (Cross and Collins, 1975; Moss, 1981; USFWS, 1991), but have been collected in areas with little current over sand, fine gravel, and leaf litter substrata (Taylor, 1969; Moss, 1981).

I found Neosho madtoms in areas similar to those reported in previous studies. All Neosho madtoms were collected on riffles throughout the year, with the exception of two captured in a shallow, gravel bottom pool. At Neosho madtom sites, loosely embedded gravel was the predominant substratum, with little silt, swift current, and high dissolved oxygen. Neosho madtoms exhibited a preference for shallow water in spring and summer. Adult Neosho madtoms are known to prefer shallow riffles (Cross and Collins, 1975; Moss, 1983) and have been collected in March (Wenke et al., 1992) and August (V. Tabor, USFWS, pers. comm.) in water 4 cm deep.

Embeddedness was low at Neosho madtom sites among all seasons and Neosho madtoms inhabited more loosely embedded substrate in three seasons of the year. Loosely embedded substratum, a characteristic typically documented for this species (Cross and Collins, 1975; Moss, 1981, 1983; Luttrell et al., 1991), was important year-round for N. placidus. Neosho madtoms showed no preference for areas with less silt or more gravel on riffles in any season, indicating siltation of substratum was not a limiting factor for this species (Moss, 1981) at my study site.

Neosho madtoms used areas with swifter currents in the spring and winter, whereas in summer, when the smallest YOY madtoms were found, fish did not show a preference for higher current speeds. Differences in substratum preference and depth in fall may be an artifact of the type of habitat sampled during flood periods. Percentage sand substratum and depth were higher in this season because one of two fall samples was taken during extremely high flow, when I was limited to seining an inundated bank with predominately sand and silt substratum. Wintertime preference for areas with higher percentage rock substratum may be indicative of seasonal changes in invertebrate communities (Barnes and Mann, 1991) or other variables not measured here.

Habitat variables most important in predicting presence of Neosho madtoms on riffles included high current at the substratum surface, low variance of that current, shallow depth, and loosely embedded substratum. The best fit multiple regression model reiterates the importance of these variables that were also important seasonally, and shows Neosho madtom habitat is characterized by swift currents, shallow areas, and loosely embedded substratum.

Pool sampling resulted in a thorough representation of river fish species (Chapter 3), suggesting that methods were sufficient to detect pool use by Neosho madtoms. High water levels may limit effectiveness of seining, however Ross and Baker (1983) showed that fishes move into shallower water, closer to banks during floods. The pool in which I collected two adult Neosho madtoms was similar to the "riffle edge" where Moss (1981) collected YOY Neosho madtoms downstream of riffles on the Neosho River. These two specimens do not indicate substantial seasonal pool use by the species during my study. YOY Neosho madtoms did not seem to use backwater or pool areas as nursery habitat as hypothesized by Moss (1981).

Other Noturus species exhibit seasonal movements onto or off of riffles to spawn. Noturus nocturnus, N. eleutherus, and N. albater primarily inhabit riffles, but move into pools to spawn (Burr and Mayden, 1982; Starnes and Starnes, 1985), whereas N. exilis moves from pools to spawn on riffles (Mayden and Burr, 1981). Noturus gilberti inhabits riffles year round, though no nests have been observed for this species (Simonson and Neves, 1992).

Neosho madtoms were not found in pools during breeding season. Moss (1981) failed to locate Neosho madtom nests on riffles during breeding season (June and July), and noted an absence of adult Neosho madtoms in June samples. Though I did not observe nests, Neosho madtoms apparently spawned during June when they were absent from three successive collections. Their absence during June preceded collection of numerous YOY in July, and was not associated with periods of high discharge, relative to other months. Neosho madtoms collected from the Neosho River in Kansas deposited eggs under the flat surface of a cinder block in July in a flow-through aquarium (D. Edds, Emporia State University, pers. comm.). Neosho madtoms may have spawned beneath larger substrata in upstream reaches of riffle heads, or in pool areas too deep to seine during June.

Estimation of Neosho madtom population size was considered a priority in the species' recovery plan (USFWS, 1991). Because YOY appeared in July, and the age 1 year class diminished thereafter, accuracy of estimates by mark-recapture decreases after August. By using captures occurring before August on the riffle with the most recaptures, accuracy of the estimate is optimized, though assumptions are violated. Schnabel's formula yielded a population estimate of 41.6 - 53.4 Neosho madtoms/100 $m^2$ at one riffle site in the study area, an upstream location for this species' range. The Schnabel estimate was higher than overall densities and the depletion estimate likely because of the violation of assumptions. Species specific densities for Neosho madtoms reported in previous studies (Moss, 1981, 1983) are within or below the range of this estimate.

Moss (1981, 1983) collected N. placidus from the Neosho River in Kansas by electroshocking at night, and calculated species specific densities ranging from 15.0 to 77.3 Neosho madtoms/100 $m^2$, and mean overall density of 11.7 Neosho madtoms/100 $m^2$. Species specific density estimates by Wenke et al. (1992), who sampled by kick-seining during daylight hours, ranged from 6.3 to 75 Neosho madtoms/100 $m^2$ with mean overall density of 6.8 Neosho madtoms/100 $m^2$. My overall density mean of 3.3 Neosho madtoms/100 $m^2$, and species specific density mean of 15.5 Neosho madtoms/100 $m^2$ are comparable to, though lower than, those expressed in these studies, and are not different among seasons, suggesting again that Neosho madtoms do not seasonally disperse from riffles. My independent estimate of density by depletion removal using electroshocked kick sets during daylight hours produced a density estimate (21.8 ± 3.5) above the range of densities calculated from kick sets alone, and similar to estimates given by Moss (1981; 1983) and Wenke et al. (1992). Neosho madtom densities at my study site may be low as a result of higher stream discharge in 1992, compared to previous years, or may indicate smaller populations in this upstream area of the species' distribution.

It appears that Neosho madtoms seldom move among riffles, though more intensive marking efforts may better quantify their degree of inter-riffle movement. Little inter-riffle movement suggests populations may be limited in distribution, a prospect relevant to the conservation biology of the species.

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# Chapter 3

# Seasonal Variation of Pool and Riffle Fish Assemblages in the Cottonwood River, Kansas

Quantification of spatial and temporal variation in fish assemblages is fundamental to understanding assemblage structure and function. Knowledge of spatial and temporal variation in fish assemblages is important in design of sampling methodology and assessments of anthropogenic perturbations of aquatic systems (Angermeier, 1985; Matthews, 1990; Poff and Ward, 1990; Meador and Matthews, 1992).

Spatial and temporal variation in fish assemblages have been investigated separately and as interacting components in both marine (Moore and Reis, 1983; Grossman, 1986; Choat et al., 1988) and freshwater environments (Hall and Werner, 1977; Bell and Hoyt, 1980; Gelwick, 1990; Gelwick and Matthews, 1990; Matthews, 1990; Meador and Matthews, 1992). Reef fishes show marked spatial variation enhanced by seasonal effects (Choat et al., 1988), whereas intertidal assemblages exhibit temporal stability (Grossman, 1986). Fish assemblages of natural lakes show temporal and spatial variability (Hall and Werner, 1977; Keast, 1978; Tonn and Magnuson, 1982, Stang and Hubert, 1984). Kushlan (1976) documented temporal variability dependent on water level fluctuations in freshwater marshes, and Gelwick and Matthews (1990) demonstrated spatial and temporal variability in assemblages of littoral zone reservoir fishes.

The study of spatial and temporal variability in stream fish assemblages is currently an active area of ecological research. Ross et al. (1985) found that fish assemblages from benign streams showed greater temporal stability than those from harsher environments. Matthews (1990) concluded that riffle fish assemblages in Virginia exhibited more spatial than temporal variation. Meador and Matthews (1992) showed fish assemblages in an intermittent prairie stream were also influenced more by spatial than temporal variation. Gelwick (1990) investigated spatio-temporal variability of stream fish assemblages in greater detail by comparing riffles and pools, and found that riffles varied more seasonally, whereas pools showed more spatial variation. These investigations were conducted by sampling reaches encompassing multiple stream orders ranging from ca. 6 - 60 km in length. "Breaks" in longitudinal patterns of stream fish assemblages are known to occur within as well as between stream orders (Matthews, 1986), however no studies have compared spatio-temporal variability in riffle and pool assemblages on a short, contiguous stream reach where commonly observed patterns of longitudinal zonation are absent. Is the relative magnitude of spatial versus temporal variability of stream fish assemblages the same over short stream reaches as on long stream distances?

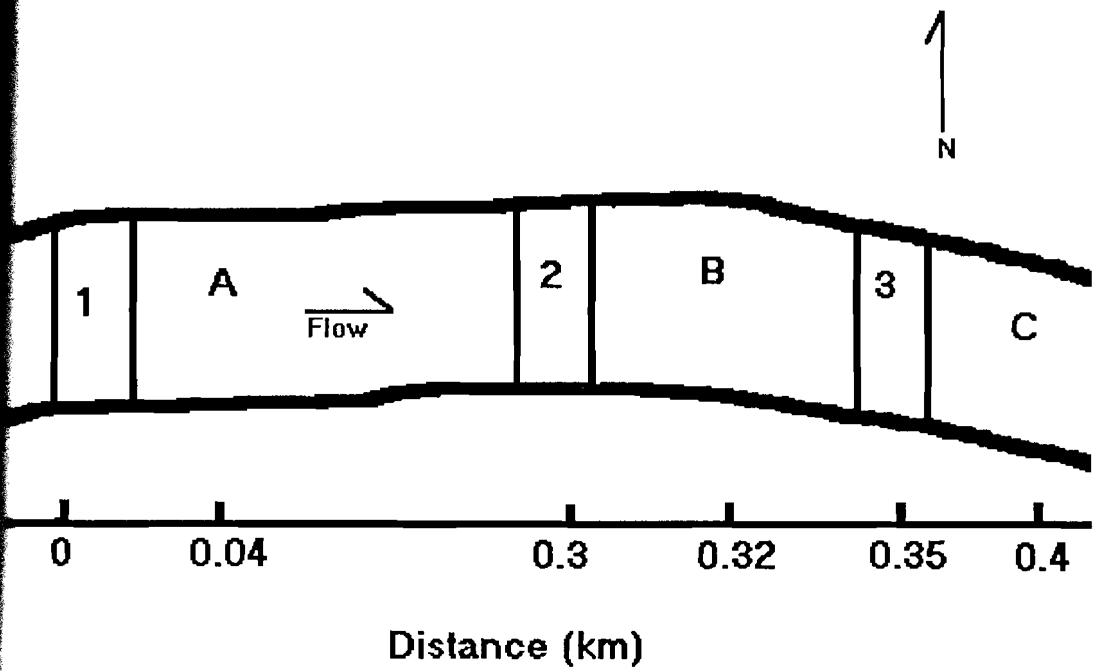
The purposes of my study were to: 1) examine spatial and temporal variation of stream fish assemblages on a contiguous series of riffles and pools over a short stream reach in Kansas; 2) assess amounts of spatial and seasonal variation in riffle and pool assemblages independently; 3) determine environmental factors associated with assemblage variation; and 4) identify fishes exhibiting spatial or seasonal variation in riffles and pools.

MATERIALS AND METHODS--My study was conducted on a series of riffles and pools over a 0.4 km stretch of the Cottonwood River in Chase County, Kansas, NW 1/4 S28 T19S R8E. The Cottonwood River is a fourth order, low gradient prairie stream with a mean width of 30 m at this locality, and a predominant substratum of chert gravel. According to data from a U. S. Geological Survey gaging station located 17 km downstream from the study site, mean discharge from February to October 1992 was 24.8 $m^3/s$, with peak discharge in November at 85.8 $m^3/s$.

I sampled six sites, three riffles (1 - 3) and the pool immediately downstream (A - C) from each riffle (Fig. 1). Riffle 2 was constructed of quarried limestone gravel by the Kansas Department of Wildlife and Parks in February 1992 as habitat restoration in an area dredged of gravel in 1988 (Chapter 1). I sampled monthly from March 1992 to February 1993, on the 15th of each month (± 8 days). High water precluded access to all sites in December, riffle 3 in November and February, and pool A in February, thus a total of 63 samples was taken.

Figure 1.

Series of riffles and pools on the Cottonwood River, Chase Co., Kansas, sampled March 1992 through February 1993. Numbers are riffles and letters are pools.


N
1
A
Flow
2
B
3
C
0
0.04
0.3
0.32
0.35
0.4
Distance (km)

Fishes were collected during daylight hours with a double-weighted, 4.7-mm mesh (4.6 m x 1.8 m) seine. To standardize pool samples, a field assistant and I seined each pool for 20 minutes, covering as much area as possible, along approximately 20 - 50 m of shoreline, depending on pool size. On riffles, fishes were collected by kick-seining at five, evenly spaced, 8-$m^2$ areas along a transect across the riffle, a process completed in approximately 20 minutes. Seine width was modified to 4 m, and gravel disturbance by two "kickers" began 2 m from the seine poles. During high water, sampling was limited to within 8 m of the shoreline, when we sampled five evenly spaced points from downstream toward the upstream area of the riffle.

Fishes collected on riffles were identified and returned live to the water. Pool fishes were preserved in 10% formalin for subsequent identification because the large number captured made field counts and identification impractical. To characterize environmental features at each site, I measured total hardness, total alkalinity, dissolved oxygen, and water temperature with a Hach water analysis kit, model AL-36B. At each transect point on riffles, and at five evenly spaced points on transects through pools, I measured water depth, current at 60% depth, percentage composition rock, cobble, gravel, sand, and silt substratum, and substratum embeddedness. Current was measured with a Teledyne Gurley pygmy current meter (no. 625), and depth with a calibrated wading rod. I sampled substratum with a shovel (Grost et al., 1991), and made visual estimations of substratum composition according to a modified Wentworth scale (Cummins, 1962; Hynes, 1970). I coded substratum embeddedness on a scale from one, very loose substrate, to three, very heavily embedded (100% silt). Seasons were coded from one to four, for winter, spring, summer, and fall, respectively. Variance in depth, substrate composition, current speed, and embeddedness were included in analyses as measures of habitat heterogeneity.

I examined fish assemblage structure with canonical correspondence analysis (CCA), a direct multivariate technique that produces simultaneous ordinations for species, samples, and environmental variables, such that species and sample scores are linear combinations of measured environmental variables (ter Braak, 1986, 1988b; ter Braak and Prentice, 1988). CCA ordination diagrams show the approximate distribution of species and sites with respect to environmental gradients, and indicate how fish assemblage structure varies with environmental factors. The direction and magnitude of correlation of environmental variables with axes is illustrated by the trajectory and length of vectors representing those variables. Species-environment correlations are correlations of site scores that are weighted mean species scores with site scores that are linear combinations of environmental variables, and express how well environmental variables explain assemblage variation (ter Braak, 1986, 1988a). I performed three CCA analyses, one for the overall fish assemblage (six sites), one for riffles, and one for pools. Species occurring in less than 5% of samples were omitted from analyses, following Gauch (1982), and relative abundances of fish species and other percentage data were arcsine $x^{\frac{1}{2}}$ transformed. Two environmental variables, water temperature and variance in percentage silt substratum, had negligible variance and were omitted from analyses.

To determine significance of correlations between environmental variables and CCA axes, I used the Bonferroni correction, which controls experimentwise error rate in series of correlations (Miller, 1981). Correlation coefficients of environmental variables were considered significantly correlated with an axis at $P < 0.05/19 = 0.0026$. Significance of ordinations was assessed with Monte Carlo permutation tests (ter Braak, 1988a).

I used axis scores obtained from correspondence analysis (CA) of all six sites, and riffles and pools independently, in two-way analyses of variance (ANOVA) (GLM, SAS Institute, 1985) among sites and seasons to evaluate amounts of spatial and temporal variation in fish assemblages (Gelwick, 1990). CA, or reciprocal averaging, is an indirect method of gradient analysis which produces ordinations of sites irrespective of environmental variables

(Gauch, 1982; ter Braak, 1988a). I used Bartlett's test for homogeneity of variances (HOV) (Pimentel and Smith, 1985) to assess variances of CA axis scores, and Ryan-Einot-Gabriel-Welsch multiple F (REGWF) tests (SAS Institute, 1985) to determine differences among sites and seasons in ANOVA. Parametric ANOVA was performed on log-transformed CA scores for riffles and pools. Kruskal-Wallis ranked ANOVA was used to examine variation in scores for the overall assemblage, and in the seasonal relative abundance of fishes in riffles and pools. The amount of spatial and temporal variation in riffles and pools was assessed by comparing the number of groups distinguished as significantly different in REGWF tests. To calculate confidence intervals, and thereby further quantify variation on riffles and pools, I bootstrapped (Diaconis and Efron, 1983; Efron and Gong, 1983; Bruce, 1992) coefficients of variation (CV) for species in each habitat.

Autocorrelation, the lack of independence between consecutive samples or between adjacent sites, may affect time series data and influence analyses by imposing bias that results from samples too close in space or time (Lewis, 1978; Matthews, 1990). To assess the degree of independence between samples over space and time, I examined product moment correlations for spatially adjacent sites, nonadjacent sites, and sequential and nonsequential samples (Matthews, 1990; Meador and Matthews, 1992), and used t-tests (TTEST, SAS Institute, 1985) to determine differences. There was no difference between consecutive and nonconsecutive samples ($P > 0.70$), or adjacent and nonadjacent sites ($P > 0.20$), thus autocorrelation did not influence these data.

RESULTS--Thirty-nine fish species were collected, and of the 30 retained in analyses, 22 were collected in riffles and 29 in pools. Species absent from riffles were: *Dorosoma cepedianum*, *Pimephales promelas*, *Carpiodes carpio*, *Ictiobus bubalus*, *Fundulus notatus*, *Lepomis macrochirus*, *L. megalotis*, and *Pomoxis annularis*. *Noturus placidus* was absent from pools. Species occurring in < 5% of samples were *Lepisosteus osseus*, *Cyprinus carpio*, *Phoxinus erythrogaster*, *Semotilus atromaculatus*, *Moxostoma erythrurum*, *Noturus flavus*, *Pylodictis olivaris*, and *Aplodinotus grunniens*.

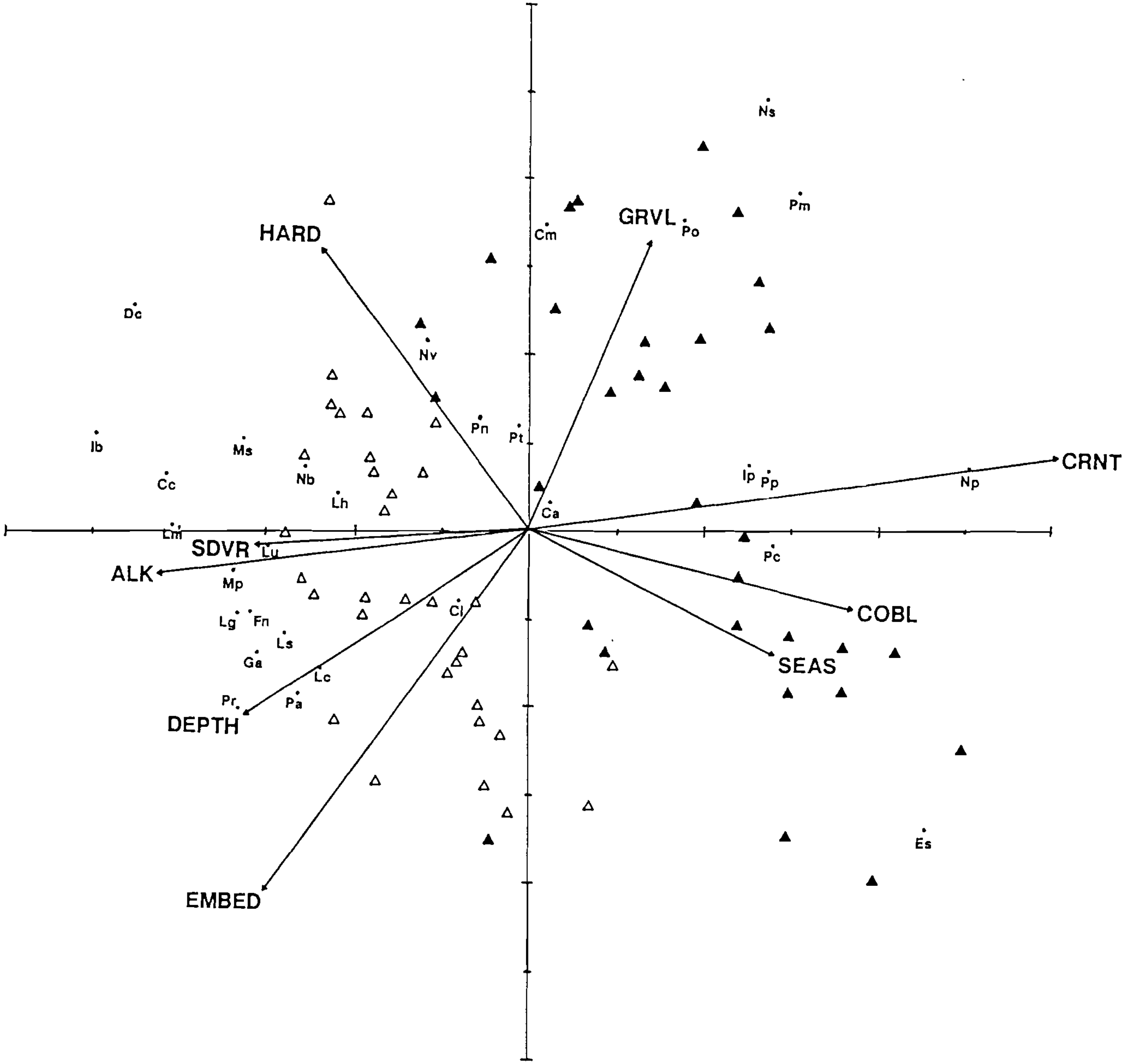
Total number of fishes captured in pools was 13,356, and in riffles, 2575. Total number of fishes was highest in spring and lowest in fall for both pools (3801 and 2791) and riffles (878 and 529). Number of pool species collected was highest in summer (26), whereas number of riffle species was equally high (18) in spring and summer. Twenty-one pool species were collected in winter, 23 in fall, and 24 in spring. Fifteen species were collected on riffles in winter and fall.

CCA of six sites produced an ordination with the first four axes significant ($P < 0.001$, $F = 8.67 - 12.84$), and explaining 36.7%, 16.9%, 10.3%, and 8.6% of assemblage variability, respectively. Because the first two axes explain the greatest portion of variation and are ecologically interpretable, I will limit my discussion to these ordinations. CCA 1, with a length of 3.9 standard deviation units (SD), had a species-environment correlation of 0.88, indicating nearly one complete change of species (Gauch, 1982), showed distinct separation of riffle and pool sites (Fig. 2). *Etheostoma spectabile*, *Noturus placidus*, *Phenacobius mirabilis*, *Percina caprodes*, and *P. phoxocephala*, "riffle species", scored highest, whereas "pool species", *Ictiobus bubalus*, *Dorosoma cepedianum*, *Carpiodes carpio*, and *Lepomis macrochirus*, scored lowest. Current speed, percentage cobble substratum ($P < 0.001$), and season ($P < 0.002$) were positively correlated with CCA 1 scores, and total alkalinity, water depth, variance in percentage sand substratum, and substrate embeddedness ($P < 0.001$) were negatively associated with this axis (Fig. 2). CCA 1 primarily demonstrates differences in riffle-pool assemblages based on depth, current, and substratum gradients, but also indicates seasonal influence.

CCA 2 represents a gradient of substratum embeddedness

Figure 2.

Ordination of CCA 1 and CCA 2 for overall fish assemblage (six sites) on Cottonwood River, Kansas, March 1992 through February 1993. Scale in SD units is 1:1 for sites, 1:2 for environmental variables, and 1:3 for species scores, with tick marks every 0.5 SD units. Open triangles = pools; closed triangles = riffles; vectors = environmental variables; points = species. Abbreviation codes are given in Appendix.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and composition, and also demonstrates seasonal influence. Fishes scoring highest on CCA 2 were Notropis stramineus, Phenacobius mirabilis, and Percina copelandi; Etheostoma spectabile, Pimephales promelas, and Pomoxis annularis scored lowest on this axis (Fig. 2). The species-environment correlation for CCA 2 was 0.80, and axis scores were positively correlated with percentage gravel substratum and water hardness, and negatively correlated with substratum embeddedness ($P < 0.001$) (Fig. 2).

Kruskal-Wallis ranked ANOVA of CA scores for all sites showed differences among sites and seasons on both axes, and no interaction effects on either axis. Pools were significantly different from riffles ($P < 0.0001$) on CA 1 (Table 1). Winter samples were different from spring and summer, and fall different from spring ($P < 0.002$) on CA 1. On CA 2, three broadly overlapping groups of sites resulted from REGWF tests, and fall and winter samples were different from spring ($P < 0.003$) (Table 1).

Bootstrapping CV's of riffle and pool species' relative abundance produced 95% confidence intervals of 207.8% - 277.0% for pools, and 237.7% - 349.4% for riffles. Although these ranges overlap, the range of variation for riffles was 42.5 units larger than that for pools.

Pools--CCA 1 and CCA 2 accounted for 26.1% and 12.3%, respectively, of the variation among pool samples. CCA 1

Table 1. Seasonal differences in CA axis scores for overall analysis (six sites) and pools and riffles independently, on the Cottonwood River, Kansas, March 1992 through February 1993. Seasons and sites are listed in decreasing score order from left to right, and lines indicate those not significantly different in Ryan-Einot-Gabriel-Welsch multiple F tests. W = winter, F = fall, P = spring, S = summer, ns = not significant.

| Analysis | CA 1 | P > F | CA 2 | P > F |
|---|---|---|---|---|
| All Sites: | W F S P | 0.002 | F W S P | 0.003 |
| | 1 3 2 B A C | 0.0001 | A C B 2 1 3 | 0.01 |
| Pools: | F W S P | 0.01 | W P F S | 0.03 |
| Riffles: | W F S P | 0.002 | ns | |

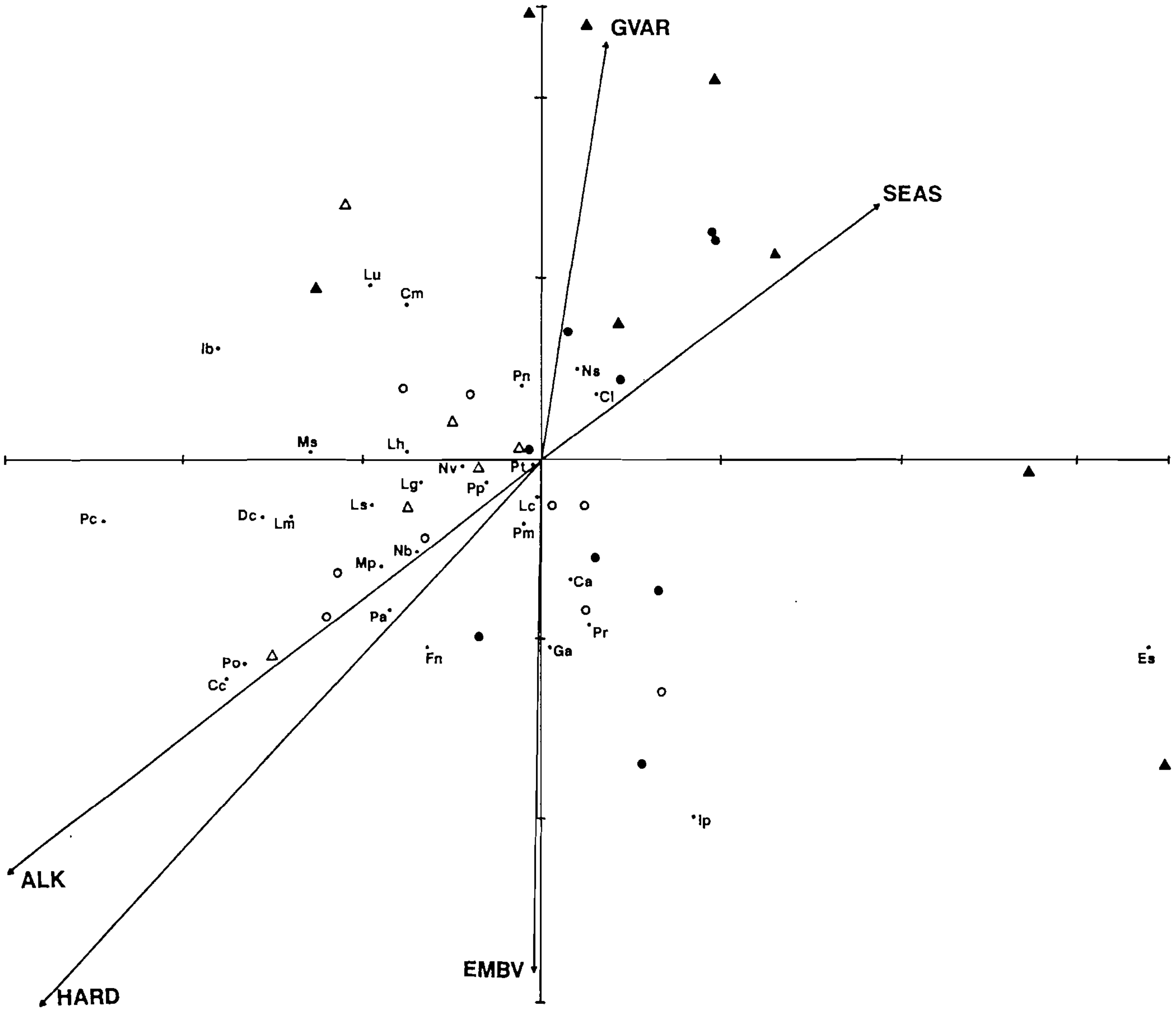
suggests a seasonal gradient (Fig. 3), and spans 5.0 SD units. No environmental variables were significantly correlated with this axis. Highest scoring species on CCA 1 were *Etheostoma spectabile*, *Ictalurus punctatus*, *Cyprinella lutrensis*, and *Pimephales promelas*. Lowest scoring species were *Percina caprodes*, *Ictiobus bubalus*, and *Carpiodes carpio*. CCA 2 was significantly negatively correlated with water hardness ($P < 0.003$), a factor that varies seasonally. On CCA 2, *Lythrurus umbratilis*, *Ictiobus bubalus*, and *Pimephales notatus* scored highest, whereas *Ictalurus punctatus*, *Carpiodes carpio*, and *Percina copelandi* scored lowest. Species-environment correlations for CCA 1 and CCA 2 were 0.94 and 0.92, respectively, indicating the measured environmental variables explained most of the variation among samples.

Two-way ANOVA showed seasonal differences on both CA axes, no differences among the three pools, and no interaction effect of space x time on either axis. The REGWF test resulted in two groups of seasons for both CA 1 and CA 2 scores. Fall and winter samples were different from spring ($P < 0.01$) on CA 1, and winter and spring were different from summer ($P < 0.03$) on CA 2 (Table 1).

Ten of the 29 pool species (34%) showed seasonal variation in relative abundance (Table 2). These included four centrarchids, three cyprinids, two percids, and one poeciliid, and accounted for 12% of the total number of

Figure 3.

Ordination of CCA 1 and CCA 2 for pools in the Cottonwood River, Kansas, March 1992 through February 1993. Scale in SD units is 1:1 for sites, 1:6 for environmental variables, and 1:1.8 for species scores, with tick marks every SD unit. Closed triangles = winter, closed circles = fall, open triangles = spring, open circles = summer; vectors = environmental variables; points = species. Abbreviation codes are given in Appendix.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fishes collected in pools. Five of these species were most abundant in summer (Table 2). Three species that exhibited significant seasonal variation also scored high on pool CCA axes; Etheostoma spectabile and Pimephales promelas both scored high on CCA 1, and Lythrurus umbratilis scored high on CCA 2.

Riffles--The first two CCA axes explained 27.2% and 15.5%, respectively, of the variance among riffle samples. CCA 1 spans 4.0 SD, and represents a season and substrate gradient, whereas CCA 2 shows dissolved oxygen as an influencing factor (Fig. 4). CCA 1 was negatively correlated with water hardness ($P < 0.001$), a factor that varied seasonally. Highest scoring species were Etheostoma spectabile, Percina caprodes, and Noturus placidus; Micropterus salmoides, M. punctulatus, and Labidesthes sicculus scored lowest on CCA 1. Dissolved oxygen was negatively correlated ($P < 0.0025$) with CCA 2. Lythrurus umbratilis, Noturus placidus, Labidesthes sicculus, and Micropterus punctulatus scored highest, and Notropis buchanani, N. volucellus, and Percina caprodes scored lowest on CCA 2. Species-environment correlations for CCA 1 and CCA 2 were 0.91 and 0.93, respectively.

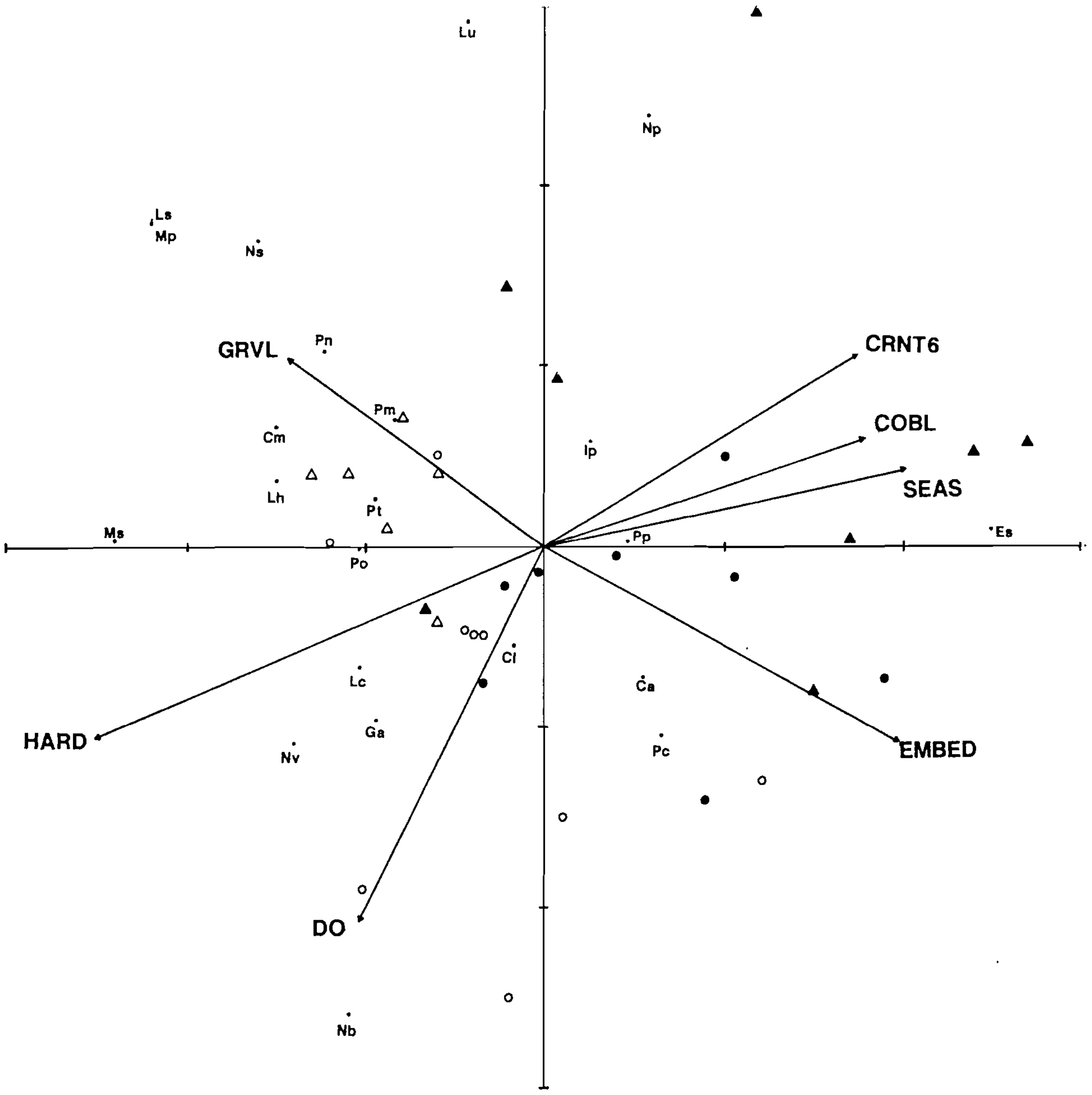
Seasonal differences in species abundance were noted for CA 1, but there was no difference among riffles and no site x season interaction. Riffle fishes exhibited the same

Table 2. Seasonal differences in ranked relative abundance of pool and riffle species on the Cottonwood River, Kansas, March 1992 through February 1993. REGWF = Ryan-Einot-Gabriel-Welsch multiple F test results, listing decreasing abundance from left to right; W = winter, F = fall, P = spring, S = summer.

| | Pools | | Riffles | |
|---|---|---|---|---|
| Species | REGWF | P > F | REGWF | P > F |
| *Cyprinella lutrensis* | | | F S P W | 0.002 |
| *Lythrurus umbratilis* | P W S F | 0.04 | | |
| *Notropis buchanani* | P S F W | 0.0001 | S F P W | 0.01 |
| *N.volucellus* | | | P S F W | 0.01 |
| *Phenacobius mirabilis* | | | P W F S | 0.06 |
| *Pimephales notatus* | | | P S W F | 0.02 |
| *P. promelas* | F S W P | 0.001 | | |
| *Gambusia affinis* | S F P W | 0.02 | | |
| *Lepomis humilis* | S P W F | 0.02 | P W S F | 0.01 |
| *L. macrochirus* | S P W F | 0.01 | | |
| *Micropterus salmoides* | P S W F | 0.002 | | |
| *M. punctulatus* | S P F W | 0.0001 | | |
| *Etheostoma spectabile* | F W S P | 0.01 | F W S P | 0.0001 |
| *Percina copelandi* | | | P S F W | 0.04 |
| *P. phoxocephala* | S W F P | 0.02 | | |

Figure 4.

Ordination of CCA 1 and CCA 2 for riffles in the Cottonwood River, Kansas, March 1992 through February 1993. Scale in SD units is 1:1 for sites, 1:4 for environmental variables, and 1:1.5 for species scores, with tick marks every SD unit. Closed triangles = winter, closed circles = fall, open triangles = spring, open circles = summer; vectors = environmental variables; points = species. Abbreviation codes are given in Appendix.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pattern of seasonal variation on CA 1 detected in the analysis of six sites (Table 1). Spring and summer samples were different from winter, and fall was different from spring ($P < 0.002$). There were no significant differences detected in CA 2 scores.

Eight of 22 species collected (36%) on riffles exhibited seasonal variation in abundance (Table 2). This represents 60% of the total number of fishes collected on riffles, and included five cyprinids, two percids, and one centrarchid. Five of these eight species were most abundant on riffles in spring, and four were least abundant in winter. *Phenacobius mirabilis* was the only species least abundant in summer samples.

DISCUSSION--Ichthyofaunal variation from headwaters through mid-reaches to depositional areas commonly results in distinct longitudinal zonation of stream fish assemblages (Sheldon, 1968; Smith and Powell, 1971; Hawkes, 1975), thus detection of spatial variation in fish assemblages is expected on long stream reaches that include a gamut of stream orders. However, fish faunal "breaks" occur within stream orders as well (Evans and Noble, 1979; Matthews, 1986; Edds, 1993), suggesting that spatial variation may occur on a short stream reach. Stewart et al. (1992) found markedly dissimilar fish assemblages at stations less than 1.5 km apart in a second order stream.

Matthews (1990) assessed spatial and temporal variation of riffle fish assemblages across approximately 30 km on the Roanoke River, Virginia, during warm months of one year, and found riffle assemblages varied more spatially than temporally, though some spatial variation was a result of interaction between space and time. Meador and Matthews (1992) sampled monthly for one year, and showed that, despite drastic fluctuations of water flow, intermittent stream fish assemblages in Texas (with no distinction between riffles and pools) also varied more spatially than temporally. Bell and Hoyt (1980) sampled fishes monthly at three sites over approximately 16 km for one year, and suggested temporal variation resulting from seasonal water level fluctuations and fish migrations may reduce the relative amount of longitudinal zonation detected in stream fish assemblages. Gelwick (1990), sampling monthly for one year over 6 km in Oklahoma, found temporal changes accounted for more variation in riffles, while pools showed more spatial variation. She attributed temporal variation on riffles to fluctuations in abundance of juveniles and seasonal changes in species richness.

Sampling throughout four seasons, and using analyses similar to Gelwick (1990), I found fish assemblages on a 0.4 km stream distance exhibited primarily temporal variation and no longitudinal (spatial) variation. As expected, the most conspicuous difference in assemblages was between riffles and pools, habitats characterized by marked contrasts in current and depth. Indeed, current, depth, and substrate characteristics were significantly correlated with CCA 1. Seasonal variation among sites was evidenced by correlations of season and seasonally variable water chemistry factors on CCA 1 and CCA 2.

In analysis of riffles and pools independently, only temporal variation was detected, even though riffle quality varied (Chapter 1). Two-way ANOVA showed riffles exhibited slightly more seasonal variation than pools; riffle assemblages displayed three overlapping groups that varied among seasons, whereas pools showed only two overlapping seasonal groups. Thirty-six percent of riffle fish species had temporally variable relative abundances, compared to 34% of pool species. Bootstrapping CV's of species abundances showed riffles had a wider 95% confidence interval than did pools, although these intervals did overlap. Bootstrapped CV's for both riffles and pools showed a standard deviation of up to three times the mean, indicating a large amount of variation in these assemblages. The pattern of riffle assemblage seasonal variability was the same as that of the entire assemblage, where winter and fall samples had high CA 1 scores. Stream discharge may have influenced temporal variability (Hynes, 1970). Increases in abundance of species in fall samples, a period of high discharge, could be a function of high water, when fishes may aggregate nearer to shore, out of mid-channel areas (Ross and Baker, 1983).

Stream fishes have been described as "mobile", ranging freely over distances up to 100 km, or "sedentary", remaining in the same area for extended periods (Gerking, 1953; Funk, 1955; Deacon, 1961). Seven of 15 species that exhibited seasonal variability at my site, *Cyprinella lutrensis*, *Lythrurus umbratilis*, *Phenacobius mirabilis*, *Pimephales notatus*, *P. promelas*, *Etheostoma spectabile*, and *Percina phoxocephala*, were described by Deacon (1961) as temporally variable species in Kansas; he attributed most of the seasonal variability to the species' vagility.

Life history information for many fishes includes patterns of seasonal variation in habitat use, particularly related to spawning (e.g., Cross and Collins, 1975; Pflieger, 1975; Robison and Buchanan, 1984). Centrarchids are known to disperse into shallow shoreline areas in spring before spawning (Cross and Collins, 1975). Three species of centrarchids were more abundant in pools in spring or summer, and *Lepomis humilis* was more abundant on riffles in spring at my study site; patterns likely related to seasonal spawning movements. Increased relative abundance of *Notropis volucellus*, *N. buchanani*, *Phenacobius mirabilis*, *Pimephales notatus*, and *Percina copelandi* on riffles, and *Lythrurus umbratilis* and *Percina phoxocephala* in pools in spring may have been associated with spawning (Cross and

Collins, 1975; Pflieger, 1975).

Because temporal variation of both pool and riffle fish assemblages may be significant, even on short stream reaches, sampling regimes designed to assess assemblage structure at a site in this or similar systems may require repeated sampling over time. Considering regional differences in ichthyofauna, climate, and stream hydraulics, amounts of temporal variation would be expected to vary among drainages.

Appendix. Abbreviation codes for Figures 2 - 4.

ALK = total alkalinity, COBL = % cobble substratum, CRNT = current speed at 60% depth, DEPTH = water depth, DO = dissolved oxygen, EMBED = substratum embeddedness, EMBV = variance in embeddedness, GRVL = % gravel substratum, GVAR = variance in % gravel substratum, HARD = water hardness, SEAS = seasons, SDVR = variance in % sand substratum

Ca = *Campostoma anomalum*, Cc = *Carpiodes carpio*, Cm = *Cyprinella camura*, Cl = *C. lutrensis*, Dc = *Dorosoma cepedianum*, Es = *Etheostoma spectabile*, Fn = *Fundulus notatus*, Ga = *Gambusia affinis*, Ip = *Ictalurus punctatus*, Ib = *Ictiobus bubalus*, Ls = *Labidesthes sicculus*, Lc = *Lepomis cyanellus*, Lh = *L. humilis*, Lm = *L. macrochirus*, Lg = *L. megalotis*, Lu = *Lythrurus umbratilis*, Ms = *Micropterus salmoides*, Mp = *M. punctulatus*, Nb = *Notropis buchanani*, Ns = *N. stramineus*, Nv = *N. volucellus*, Np = *Noturus placidus*, Pc = *Percina caprodes*, Po = *P. copelandi*, Pp = *P. phoxocephala*, Pm = *Phenacobius mirabilis*, Pn = *Pimephales notatus*, Pt = *P. tenellus*, Pr = *P. promelas*, Pa = *Pomoxis annularis*.

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Habitat restoration and seasonal habitat use by Neosho madtoms (Noturus placidus), and spatio-temporal variation of stream fish assemblages in the Cottonwood River, Kansas

Title of Thesis

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11-23-92
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