AN ABSTRACT FOR THE THESIS OF

Stephanie A. Sherraden for the Master of Science degree in

Biological Sciences presented on 8 November 2002 .

Title: Mussel assemblages in a developing oxbow and a newly-cut channel of the Neosho River, Kansas

Abstract approved: *[signature]*

I compared freshwater mussel assemblages (Bivalvia: Unionidae) in a developing oxbow (old channel) and a newly-cut (new) channel of the Neosho River, Neosho County, Kansas, during 2001. I sampled mussels at approximately 1.5 km intervals, totaling 19 sites in the old channel and seven sites in the new channel, by groping substrate from bank to bank in a zigzag fashion along a 100 m reach. I found 1,239 live individuals of 20 mussel species in the old channel and 20 live individuals of six species in the new channel. Mussel abundance, diversity, and current species richness were significantly greater in the old channel than in the new. Abundance, diversity, and historic and current species richness all declined significantly from upstream to downstream in the old channel. Historic richness was greater than current richness in the old channel, but both decreased from upstream to downstream at the same rate. Loss of historic species from the old channel was no different from that in the rest of the Neosho River in Kansas; however, a decrease in lotic species will likely occur as the channel continues to evolve into an oxbow. Canonical correspondence analysis illustrated mussel assemblage variation with environmental differences between the old and new channels, and a substrate compaction, substrate composition, and depth gradient in the old channel,

including lotic species in flowing waters with sand and gravel substrate and lentic species in still waters with silt substrate.

MUSSEL ASSEMBLAGES IN A DEVELOPING OXBOW AND A NEWLY-CUT

CHANNEL OF THE NEOSHO RIVER, KANSAS

A Thesis

Presented to

The Department of Biological Sciences

EMPORIA STATE UNIVERSITY

In Partial Fulfillment

of the Requirements for the Degree

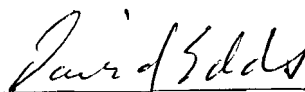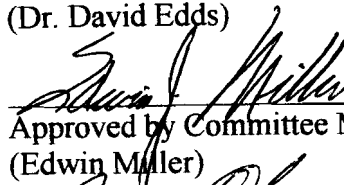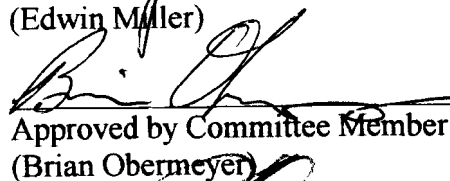Master of Science

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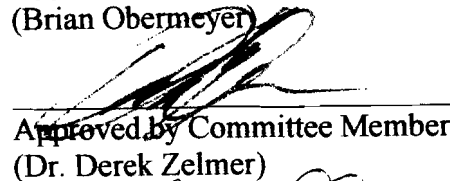
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Stephanie Ann Sherraden

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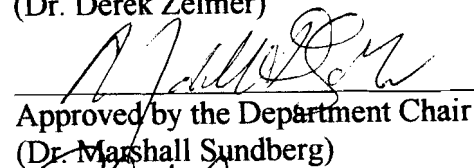(Dr. David Edds)

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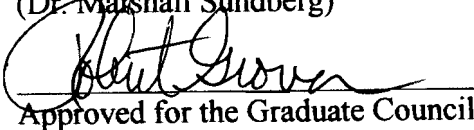Approved by Committee Member
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Approved for the Graduate Council

ACKNOWLEDGMENTS

PREFACE

My thesis will be submitted for publication to *The American Midland Naturalist* and is formatted for that journal.

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INTRODUCTION

Little information exists regarding freshwater mussel (Bivalvia: Unionidae)

assemblages in oxbows or newly-cut river channels. Only Cooper (1984) has published

data on mussels in oxbow habitats, formed when river meanders are cut off from the main

channel. No published studies have examined mussels in newly-cut river channels.

A 28.5 km meander of the Neosho River in Neosho County, Kansas (Figure 1), is

becoming isolated from the main channel. Original land surveys completed in 1866

indicated the east, or new, channel of the river was a 10.5 km slough that apparently

flowed only during flood events. The west, or old, channel remained the dominant

channel until massive flooding in 1951 (Roy Carter, pers. comm.) switched the majority

of flow to the new channel. At low discharge (less than approximately 8.5 m^3/s), the old

channel now ceases to flow, and is temporarily transformed into lentic habitat.

Downstream portions of such developing oxbows are often blocked by sediments

deposited as the meander is redirected (Reid, 1961). If the old channel does become an

oxbow lake, substantial changes in its mussel fauna will likely occur. Species adapted to

lotic conditions would be eliminated, with a persistence of lentic-tolerant species, and an

overall decrease in species richness. In two oxbows isolated from the Mississippi River,

Cooper (1984) found only five mussel species, all of which were lentic-tolerant,

including *Pyganodon grandis, Ligumia subrostrata, Anodonta suborbiculata, Quadrula*

apiculata, and Toxolasma parvus.

Objectives of my study were to assess mussel assemblages in this developing

oxbow and newly-cut channel. Given the relatively recent development of the new

Figure 1. Map of study sites in the Neosho River, Neosho County, Kansas, 2001.
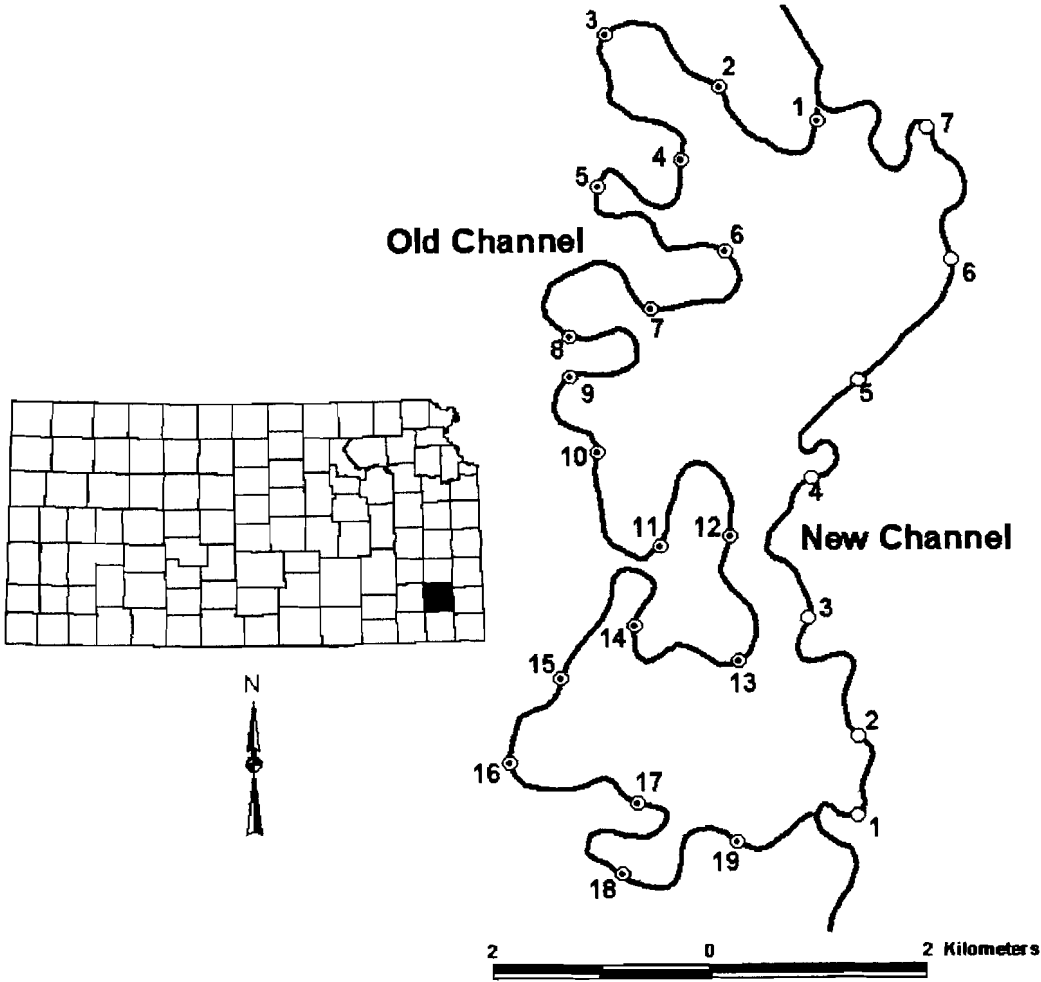
channel, I hypothesized that abundance, species diversity, and current mussel species richness would be greater in the old channel than in the new. Due to the potential deterioration of habitat quality downstream in the old channel, I hypothesized that current richness would be less than historic richness, and that abundance, diversity, and current mussel species richness would decrease downstream. Given the change to more lentic conditions, I hypothesized that sites in the old channel would have lost more mussel species than free-flowing sites in the Neosho River surveyed by Obermeyer (1996). To investigate differences in habitat at sites in the old channel, I examined relationships between distance downstream and 17 environmental variables. I used canonical correspondence analysis to analyze patterns of mussel species' distributions associated with habitat variation.

MATERIALS AND METHODS

Mussel Sampling.—From July 10 to August 17, 2001, I sampled 19 sites in the old channel and seven in the new channel (total n = 26), spaced at approximately 1.5 km intervals. I secured landowner permission at each site, and located a reach with gravel substrate within 250 m upstream and downstream. I semi-quantitatively sampled mussels (current and historic) within a 100 m reach by groping the substrate from bank to bank in a zigzag pattern starting at the downstream end of the reach. Such surveys are the most efficient and economical method of estimating richness and abundance of freshwater mussels (Miller and Payne, 1993; Obermeyer, 1998). I used an accessory breathing apparatus (hookah rig) (Pioneer 275, Brownie's Third Lung, Ft. Lauderdale, Florida) to dive for mussels in water deeper than 1 m. I kept mussels in mesh bags until the end of

the survey at a given site, then identified and counted all individuals and redistributed them throughout the reach. I also haphazardly searched the shoreline along the 100 m reach for historic mussel valves and recorded each species found. I obtained global positioning system coordinates with a Garmin 12XL GPS unit (Garmin International, Romsey, Hampshire, United Kingdom). I deposited vouchers of extant species in the University of Kansas Natural History Museum. Scientific names follow those of Turgeon *et al.* (1998).

Habitat Assessment.—Before each site was sampled, I assessed habitat at six transects spaced every 20 m along the 100 m reach. At n designated points (where n = channel width divided by 20) (Gallagher and Stevenson, 1999), I measured water depth, silt deposition, substrate compaction, and substrate composition. I also measured water temperature and Secchi depth at one point for each site.

I coded silt deposition as 0 (clean substrate), 1 (detectable silt), 2 (moderately covered by silt), or 3 (heavily covered by silt), and coded substrate compaction as 0 (loose), 1 (moderately compacted), or 2 (heavily compacted) (Obermeyer, 1996). I divided substrate into five approximate size classes: silt (< 0.8 mm), sand (0.8 mm to 4 mm), gravel (4 mm to 50 mm), cobble (50 mm to 290 mm), and bedrock (solid rock bottom) (modified from Platts *et al.*, 1983), and visually and physically estimated percent of substrate comprised by each class (Bain, 1999).

To facilitate comparison of habitat among sites, I conducted a second set of measurements from August 24 to 26, 2001. I measured water depth, velocity, silt deposition, and substrate compaction at one-quarter, half, and three-quarters width at the

six transects established during mussel sampling. I measured water depth with a meter stick or thalweg pole, and velocity at 60% depth from the surface with a Global Flow Probe FP101 current meter (Global Water, Gold River, California). One time at each site, I measured hardness using a Hach kit model AL-36B (Hach Company, Loveland, Colorado) and temperature, pH, dissolved oxygen, conductivity, TDS (total dissolved solids), and salinity using a Hydrolab Surveyor 4 with a Data Sonde 4a (Hydrolab Corporation, Austin, Texas).

Data Analysis.—I compared mussel abundance, Shannon diversity (log_{10}), and current species richness (number of species) between the two channels with analysis of variance (ANOVA). I used regression analysis to test whether abundance, diversity, and historic and current richness decreased from upstream to downstream in the old channel. I compared elevation of the regression line of historic species richness versus distance downstream with that of current richness to determine if the number of mussel species in the old channel was less than that found historically. I compared slope of the regression of historic richness versus distance downstream with that of current richness to test whether they varied at the same rate. I compared the loss of historic species at sites in the old channel with that from 16 sites surveyed by Obermeyer (1996) in the lower Neosho River using analysis of covariance (ANCOVA), with the number of live species found at each site as a covariate.

I used Spearman correlation analysis to examine correlations between distance downstream and measured environmental variables in the old channel. To identify the best predictors of a downstream habitat gradient in the old channel, I used stepwise

multiple regression (forward selection) to model influence of the measured environmental variables on distance downstream.

For both channels, and the old channel alone, I used principal component analysis (PCA) to summarize categories of substrate composition (Table 1). For both channels, PCA Axis 1 (PCA1) loadings were negative for silt and sand (fine) substrate and positive for bedrock, cobble, and gravel (coarse) substrate. PCA2 was negatively associated with silt, bedrock, and cobble substrate, and positively associated with gravel and sand substrate. For the old channel alone, PCA1 loadings were negative for silt and positive for gravel, sand, bedrock, and cobble substrate. PCA2 was negatively associated with gravel and sand, and positively associated with cobble, bedrock, and silt substrate. I used PCA1 and PCA2 scores in subsequent analyses.

For both channels together, and the old channel alone, I used canonical correspondence analysis (CCA) to examine species-environment relationships. CCA produces an ordination diagram where points represent species and sites, and arrows represent environmental variables. The trajectory and length of the arrows represent the direction and magnitude of correlations of environmental variables with species' distributions (ter Braak 1986). I did not include old channel sites 13 and 19 in CCA because only one mussel was found at each, and these sites were considered outliers by PC-Ord (McCune and Mefford, 1999) outlier analysis. New channel sites 1, 4, and 7 were not included in CCA because no live mussels were found at those sites. *Pyganodon grandis* and *Truncilla donaciformis* were not included in CCA because they were found at only one site each, and rare species can obscure analysis of the overall data set (Gauch, 1982).

Table 1. Eigenvector loadings for substrate composition variables for the first two principal component axes for both channels and old channel alone.

Variable	Both channels		Old channel	
	PCA1	PCA2	PCA1	PCA2
Silt	-0.534536	-0.439351	-0.634190	0.069608
Sand	-0.250811	0.571174	0.443687	-0.326450
Gravel	0.066299	0.670666	0.459491	-0.397976
Cobble	0.545571	-0.079295	0.295944	0.610220
Bedrock	0.591035	-0.157005	0.319735	0.598190

I used the following environmental variables in the CCA analyses: PCA1, PCA2, and Secchi depth from the first set of habitat collections; and velocity, depth, silt deposition (siltdep), substrate compaction (scomp), temperature, pH, dissolved oxygen, salinity, and hardness from the second set of habitat collections. I did not use conductivity and TDS in analyses because they are surrogates of salinity, and the three were multicollinear ($r = 0.93$ to 0.99, $P < 0.0001$). Monte Carlo simulations (9,999 permutations) were used to test significance of individual axis eigenvalues, with random number seed generation based upon time of day.

I square-root transformed abundance for ANOVA, and relativized and arcsine square-root transformed abundance for CCA. I $\log_{10} (n + 1)$ transformed depth, pH, and substrate compaction to improve normality for CCA; normality of other variables was not improved by transformation, so analyses were performed on untransformed values. I used Shapiro-Wilk tests and examined graphs of residuals to assess normality and homogeneity of variances.

Statistical analyses were performed with SAS (SAS Version 8, SAS Institute Inc., Cary, North Carolina) and SPSS (SPSS for Windows, Version 7.5.1, SPSS Inc., Chicago, Illinois). Canonical correspondence analyses were conducted with PC-Ord software (Version 4 for Windows, MjM Software Design, Gleneden Beach, Oregon).

RESULTS

I found 1,239 live individuals of 20 species in the old channel and 20 live individuals of six species in the new channel (Table 2). Mussel abundance ranged from 1 to 255 at sites in the old channel, and from 0 to 11 at sites in the new channel. Shannon

Table 2. Mussel species and abundances at 19 sites in the
old channel (old) and seven sites in the new channel (new)
of the Neosho River, Neosho County, Kansas, 2001.
Abbreviations refer to species in figures 3 and 4.

Scientific Name	Abbrev.	No. Old	No. New
Megalonaias nervosa	Mnerv	258	
Quadrula pustulosa	Qpust	210	
Quadrula quadrula	Qquad	199	7
Amblema plicata	Aplic	186	2
Tritogonia verrucosa	Tverr	74	2
Fusconaia flava	Fflav	65	
Pleurobema sintoxia	Psint	59	
Quadrula metanevra	Qmeta	47	
Ellipsaria lineolata	Eline	33	
Obliquaria reflexa	Orefl	29	
Leptodea fragilis	Lfrag	24	6
Potamilus purpuratus	Ppurp	15	2
Elliptio dilatata	Edila	14	
Lasmigona complanata	Lcomp	8	
Quadrula nodulata	Qnodu	7	
Lampsilis teres	Ltere	4	
Lampsilis cardium	Lcard	3	
Potamilus ohiensis	Pohie	2	1
Pyganodon grandis	Pgran	1	
Truncilla donaciformis	Tdona	1	
Total No. Individuals		1,239	20

diversity ranged from 0 to 1.01 in the old channel, and from 0 to 0.44 in the new channel.

Current richness ranged from 1 to 16 in the old channel, and from 0 to 4 in the new

channel. Two sites in the old channel had only one species, and three sites in the new

channel had no species. I found 27 historic species (dead valves) in the old channel and

14 in the new channel. *Lampsilis rafinesqueana, Ligumia recta, Ptychobranchus*

occidentalis, Quadrula cylindrica, Strophitus undulatus, Truncilla truncata, and

Utterbackia imbecillis were found only as dead valves in the old channel; none of these

was found in the new channel.

Mussel abundance (F = 8.87; df 1, 24; P = 0.0065), diversity (F = 12.76; df 1, 24;

P = 0.0015), and current richness (F = 11.15; df 1, 24; P = 0.0027) were all greater in the

old channel than in the new channel. In the old channel, mussel abundance (r^2 = 0.22,

P = 0.025) (Figure 2a), diversity (r^2 = 0.41, P = 0.002) (Figure 2b), historic richness

(r^2 = 0.35, P = 0.004) (Figure 2c), and current richness (r^2 = 0.35, P = 0.004) (Figure 2c)

all decreased significantly from upstream to downstream. The regression lines for

historic and current richness versus distance downstream had different elevations

(t = -5.60, df 35, P < 0.0005), indicating that historic richness was greater than current

richness in the old channel. Slopes of the lines were not significantly different (t = 0.41,

df 34, P > 0.25), showing that both decreased from upstream to downstream at the same

rate.

PCA1 (r = -0.85, P < 0.0001), silt deposition (r = 0.61, P = 0.0052), and

temperature (r = 0.57, P = 0.0104) from the first habitat collection, and depth (r = 0.68,

P = 0.0015), dissolved oxygen (r = -0.64, P = 0.0032), silt deposition (r = 0.46,

Figure 2. Mussel abundance ($r^2 = 0.22$, P = 0.025) (a), species diversity ($r^2 = 0.41$, P = 0.002) (b), and historic (□ dashed line) ($r^2 = 0.35$, P = 0.004) and current (■ solid line) ($r^2 = 0.35$, P = 0.004) mussel species richness (c) versus distance downstream in the old channel of the Neosho River, 2001. Dashed square ▨ point represents both historic and current richness.

a

b

c
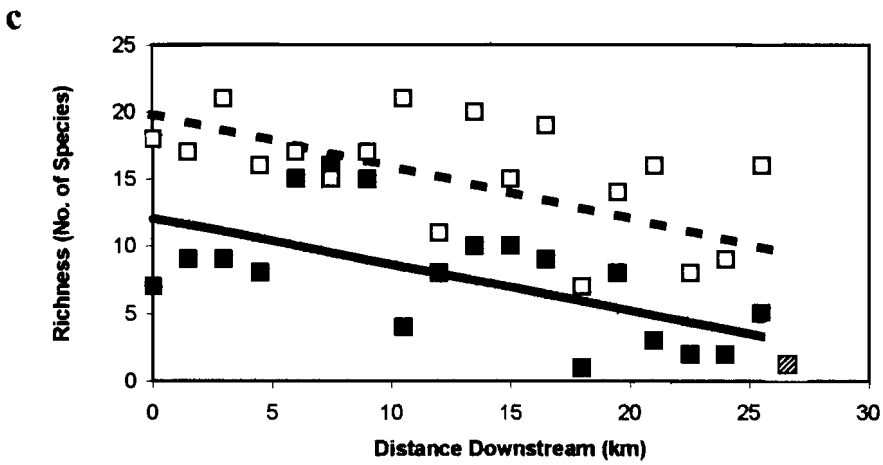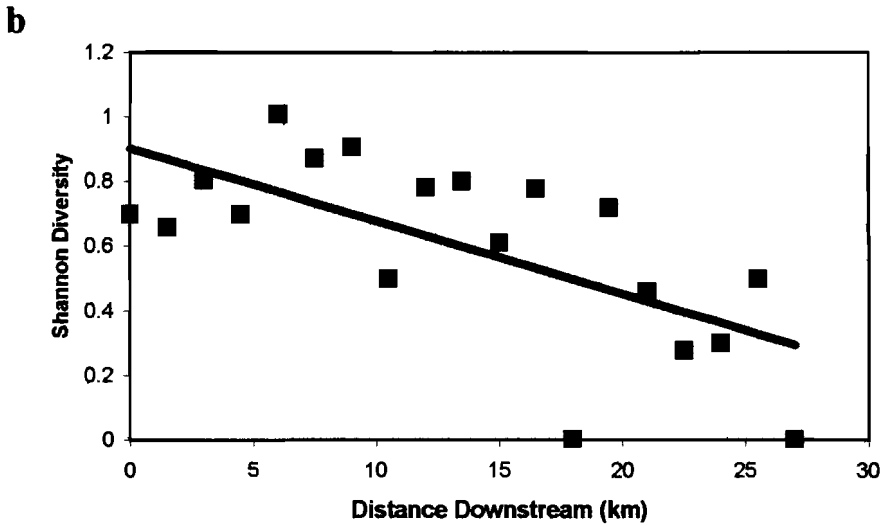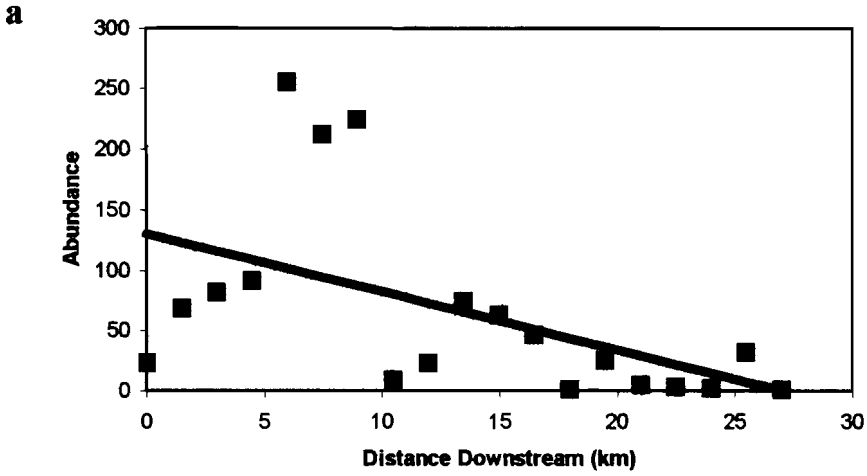
P = 0.0490), and pH (r = -0.46, P = 0.0497) from the second habitat collection were significantly correlated with distance downstream in the old channel. None of the other measured habitat variables was significantly correlated with distance downstream (r = -0.44 to 0.43, P = 0.0596 to 0.7889). PCA1 and dissolved oxygen were the best indicators of a habitat gradient in the old channel (model r^2 = 0.79, P < 0.0001).

Comparison of my collections in the old channel to 16 sites surveyed by Obermeyer (1996) in the lower Neosho River, Kansas, showed that the number of live species was significantly associated with the number of historic species (F = 18.55, df 1,32; P = 0.0001), with no significant interaction among sites (F = 0.51, df 1,31; P = 0.4817). When the number of live species at sites was controlled for as a covariate, there was no significant difference in the number of historic species at my sites versus those of Obermeyer (F = 1.69, df 1,32; P = 0.2026). Thus, in general, decreased flows in the old channel have not caused mussel species to be lost at a greater rate than at other sites in the Neosho River.

CCA of all sites (both channels together) (Figure 3) showed only CCA1 significant (P = 0.0009). CCA1 accounted for 24.1 % of the variation in species' distributions and had a gradient length of 3.1 standard deviations. CCA1 represents a gradient of new to old channels, with four of the six highest scores being new channel sites (falling to the right of the ordination diagram), and the 15 lowest scores being old channel sites (falling to the left of the jointplot). *Potamilus ohiensis*, *Leptodea fragilis*, *Potamilus purpuratus*, *Quadrula quadrula*, and *Tritogonia verrucosa* scored highest on CCA1, and were species typical of mussel assemblages at sites in the new channel.

Figure 3. Canonical correspondence analysis jointplot of sites, mussel species, and environmental correlates at four sites from new channel (n) and 17 sites from old channel (o) of the Neosho River, 2001. Only environmental correlates with jointplot scores greater than 0.325 are shown. (See Table 2 for species' abbreviations).
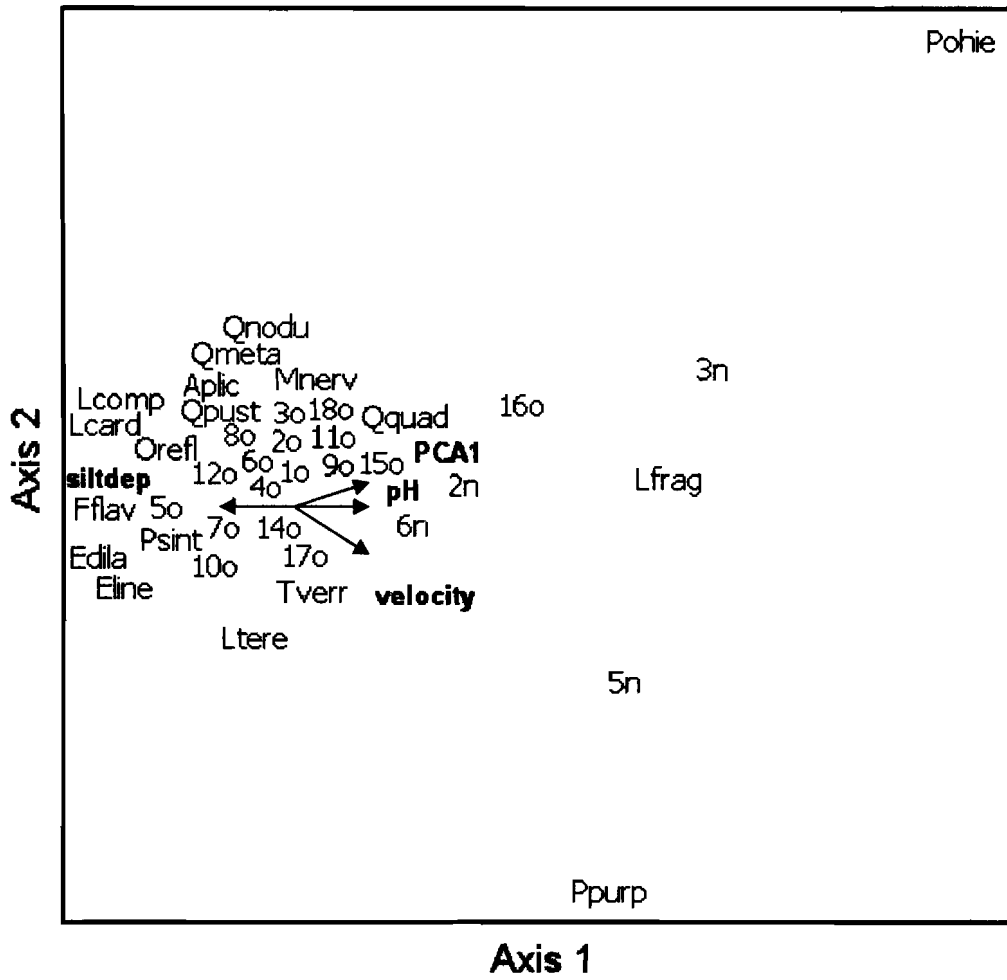
Elliptio dilatata, Ellipsaria lineolata, Pleurobema sintoxia, Lampsilis cardium,
Fusconaia flava, Obliquaria reflexa, Lasmigona complanata, Quadrula pustulosa,
Quadrula metanevra, Quadrula nodulata, Lampsilis teres, and *Megalonaias nervosa*
scored lowest on CCA1, and were characteristic species of mussel assemblages at sites in
the old channel. pH, PCA1, and velocity were positively associated with mussel
distributions in the new channel, while silt deposition was positively associated with
species' distributions in the old channel (Figure 3). CCA1 was significantly correlated
with pH, silt deposition, PCA1, depth, PCA 2, and velocity (Table 3).

CCA of sites in the old channel (Figure 4) showed only CCA1 significant
(P = 0.0003). CCA1 accounted for 21.3 % of the variation in species' distributions and
spanned 2.2 standard deviations. CCA1 represents a substrate compaction, substrate
composition, and depth gradient. Depth, pH, and silt deposition were positively
associated with CCA1 and PCA1 was negatively associated with CCA1 (Figure 4). Sites
16, 15, 17, 18, 9, 8, 1, 14, 3, 11, and 2 scored highest on CCA1, while sites 7, 5, 10, 12, 6,
and 4 scored lowest. *Leptodea fragilis, Q. quadrula,* and *L. teres* scored highest on
CCA1, while *E. dilatata, E. lineolata, P. sintoxia, L. cardium, P. ohiensis, L. complanata,*
and *F. flava* scored lowest on CCA1. CCA1 was significantly correlated with substrate
compaction, depth, and PCA1 (Table 3). For summaries of data at each site see
Sherraden *et al.* (2002).

Table 3. Correlation coefficients between habitat variables and CCA Axis 1 of both channels and old channel alone. Correlations significant at $\alpha = 0.05$ are denoted with an asterisk.

	Both channels	Old channel
Variable	CCA1	CCA1
Secchi depth	0.286	-0.008
Hardness	-0.267	-0.094
Dissolved oxygen	0.145	0.018
Temperature	-0.108	0.086
Salinity	-0.291	-0.420
Silt deposition	-0.568*	0.053
Velocity	0.472*	-0.078
pH	0.580*	0.115
Depth	0.532*	0.585*
Substrate compaction	0.229	-0.597*
PCA1	0.567*	-0.534*
PCA2	-0.492*	0.136

Figure 4. Canonical correspondence analysis jointplot of sites, mussel species, and environmental correlates at 17 sites in the old channel of the Neosho River, 2001. Only environmental correlates with jointplot scores greater than 0.325 are shown. (See Table 2 for species' abbreviations).
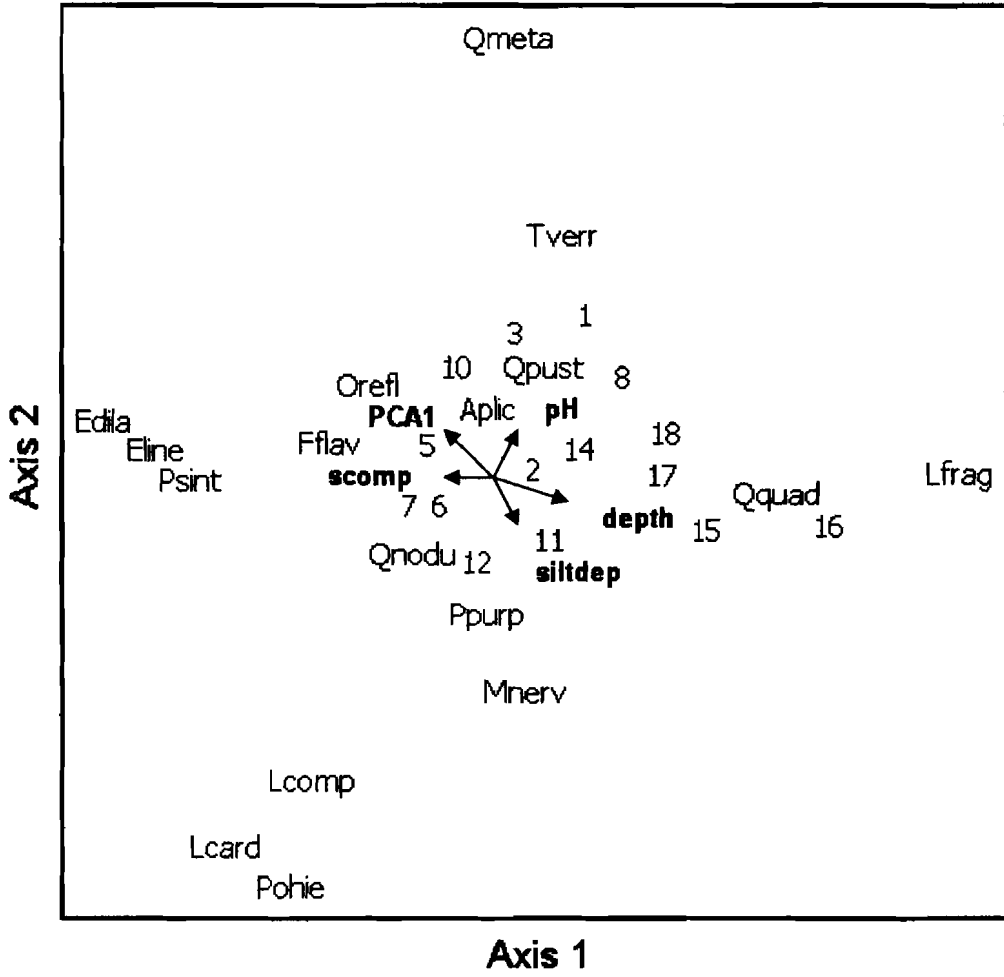
DISCUSSION

Mussel abundance, diversity, and current species richness were all greater in the old channel than in the new. Instream habitat in the old channel is more stable than in the new channel, where the channel is actively migrating laterally and substrate consists mostly of bedrock. Mussel abundance, diversity, and historic and current species richness declined from upstream to downstream in the old channel, suggesting that downstream sites offer poorer mussel habitat, and had poorer habitat in the recent past. The best predictors of distance downstream were fine substrate (PCA1) and low dissolved oxygen, again suggesting that downstream sites offer poor mussel habitat, given that mussel development and reproduction are dependent on substrate composition and dissolved oxygen (Polhill and Dimock, 1984; Parmalee and Bogan, 1998). Until about 1993, when floodwaters washed around it, the City of Parsons dam inundated downstream sites 13 to 19 (Roy Carter, pers. comm.). Lowhead dams can be detrimental to mussels (Dean *et al.*, 2002), slowing flow of water, increasing siltation, and stopping host fish migration (Watters, 1996).

Comparison of loss of historic species from sites in the old channel to historic loss from Obermeyer's (1996) sites in the lower Neosho River showed no significant difference, suggesting reduced flows in the old channel have not caused species to be lost from this channel at a greater rate than at other sites in the lower Neosho River. Anthropogenic alterations, including nutrient and silt loading from agricultural practices, have likely contributed to the substantial decline in the number of mussel species throughout the Neosho River (Obermeyer *et al.*, 1997). The old channel still receives flow when discharge in the main channel is greater than 8.5 m^3/s, and because changes to

lentic conditions affect recruitment and not adult survivorship, changes in the mussel fauna of the developing oxbow might take years to detect as mussels are long-lived.

Old channel sites 5-7 had the highest abundance, diversity, and current richness, although they did not have the highest historical richness. These sites had gravel substrate and had more permanent water than other upstream sites. Instream habitat at sites 1-4 was partially exposed in late August of 2001 because of low flows (pers. obs.); thus, mussels at these sites are likely in greater danger of perishing in times of drought than mussels at sites 5-7. I found several recently dead valves at Site 3 that appeared to have perished during droughty conditions in 2000.

CCA of all sites illustrated the different mussel faunas and habitats of the two channels. Mussels in the new channel were primarily associated with higher pH, coarse substrates (PCA1), higher velocity, and low silt deposition, while mussels in the old channel were primarily associated with lower pH, fine substrates, lower velocity, and high silt deposition. I found fewer individuals and species per site in the new channel than in the old channel. The newly-cut channel was unstable with mostly bedrock substrate, providing poor habitat for mussels.

Cooper (1984) found 14 mussel species in Lake Chicot, Arkansas, a flow-through oxbow of the Mississippi River with sand substrate, but only five species total in two other oxbow lakes with silt substrate and no river inflow. Three of these five were lentic species (*T. parvus*, *L. subrostrata*, and *A. suborbiculata*) not found in Lake Chicot, but present only in the oxbows with silt substrate and no inflow or outflow, demonstrating the differing mussel faunas that inhabit oxbow lakes isolated from river flow.

CCA demonstrated a substrate and depth gradient between the old and new channels, as well as within the old channel. Some areas of the old channel (those scoring high on CCA1) appear to be developing oxbow characteristics, including silty, unconsolidated substrate and deeper, lentic habitat. These areas were inhabited almost exclusively by *L. fragilis*, *Q. quadrula*, and *L. teres*, species typical of lentic conditions (Parmalee and Bogan, 1998). Other sites in the old channel (scoring low on CCA1), with less silt deposition and more consolidated substrate including sand and gravel, retain lotic species, including *E. dilatata*, *E. lineolata*, and *P. sintoxia*. Some of these lotic species will likely be lost from the old channel as it continues to evolve into an oxbow lake.

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