AN ABSTRACT OF THE THESIS OF

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Title: Unionidae (Bivalvia) of the Arkansas River System of SE Kansas and SW Missouri: Species of Concern, Historical Change, Commercial Harvesting, and Sampling Methods.

Abstract approved: Carl W Prophet

Freshwater mussel assemblages were examined at 99 sites between 1993 and 1995 in the Arkansas River System of southeast Kansas and southwest Missouri. Emphasis was placed on five mussel species that are candidates for adding to the federal list of threatened and endangered species. These species are the Neosho mucket (*Lampsilis rafinesqueana*), Ouachita kidneyshell (*Ptychobranchus occidentalis*), western fanshell (*Cyprogenia aberti*), rabbitsfoot (*Quadrula cylindrica*), and elktoe (*Alasmidonta marginata*). I also evaluated (i) historical change of mussel assemblages in southeast Kansas, (ii) the effectiveness of a mussel harvest refuge located on the Neosho River, and (iii) differences in sampling results between quantitative and qualitative methods.

From a total of 15,068 mussels of 35 species, I caught 1421 candidate mussels, *viz.*, 1301 *L. rafinesqueana*, 83 *P. occidentalis*, 29 *C. aberti*, seven *Q. cylindrica*, and one *A. marginata*. Habitat utilized by these species was principally shallow riffles and runs. Relatively silt-free and moderately compacted gravel was the most utilized substratum.

Disparity between species represented by extant specimens and species represented by weathered valves revealed a significant decrease in species richness in several Kansas streams. My findings also indicated substantial range reductions in Kansas, with many populations small and isolated, and consisting of mostly aged individuals.

I also evaluated the Neosho River mussel harvest refuge, located from the Neosho Falls dam, Woodson County, downstream 6.1 km to the confluence of Rock Creek, Allen County. Eight sites were selected, four within and four outside refuge boundaries, and were sampled quantitatively during summer 1994. Forty 1-m^2 quadrats were chosen randomly at each site within a 10 x 100 m area of riffle habitat, with 10-15 cm of substrate excavated from each quadrat. From these sites, 744 mussels of 20 species were caught, including 11 species on the Kansas list of threatened and endangered species. Three harvestable species, *Amblema plicata, Quadrula metanevra*, and *Quadrula quadrula,* failed to show significant differences in the percentage of legal-sized specimens between refuge and non-refuge sites. Moreover, unionid densities and species richness were generally lower at refuge sites. However, shell length of *Q. metanevra* was significantly greater at refuge versus non-refuge sites, and two species legally harvestable through 1991 also yielded significantly larger specimens at refuge sites.

Finally, I compared quadrat samples with timed snorkel searches in describing unionid community structure at nine Neosho River sites. At each site, snorkel searches were employed in a 10 x 100 m stretch. Following identification and sizing, mussels were returned to their original location, and 40 1-m^2 quadrat samples were taken from the same stretch. A total of 786 mussels was caught from over 12 h of snorkel searches, and 896 from 360 1-m^2 quadrats. Evaluations of species diversity and relative abundance were not significantly different between methods; however, snorkel searches revealed significantly fewer species, and were less effective in detecting small mussels.

UNIONIDAE (BIVALVIA) OF THE ARKANSAS RIVER SYSTEM OF SE KANSAS AND SW MISSOURI: SPECIES OF CONCERN, HISTORICAL CHANGE, COMMERCIAL HARVEST, AND SAMPLING METHODS

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PREFACE

My thesis was initiated by the U.S. Fish and Wildlife Service's (USFWS) naming of several freshwater mussel species native to southeast Kansas and southwest Missouri as federal candidates (Species of Concern) for future protective listing (*i.e.*, threatened or endangered status). These species are the Neosho mucket, *Lampsilis rafinesqueana* Frierson, 1927; Ouachita kidneyshell, *Ptychobranchus occidentalis* (Conrad, 1836); western fanshell, *Cyprogenia aberti* (Conrad, 1850); rabbitsfoot, *Quadrula cylindrica* (Say, 1817); and elktoe, *Alasmidonta marginata* Say, 1818. Prompted by the alarming decline of these species and other unionids throughout North America, the USFWS and the Kansas Department of Wildlife and Parks (KDWP) provided the initial funding and support for my research.

My thesis is a collection of four chapters that examine (i) the distribution, abundance, and ecology of mussel assemblages in southeast Kansas and southwest Missouri, (ii) historical change of southeast Kansas unionids, (iii) the impact of commercial musseling in the Neosho River, Kansas, and (iv) quantitative versus qualitative sampling methods. These subjects are divided into four autonomous manuscripts or chapters, and are written in the style specified for future submittance to scientific journals. Therefore, the format varies from one chapter to the other and some background information is repeated.

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Chapter 1

FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) OF SPECIAL CONCERN IN THE VERDIGRIS, NEOSHO, AND SPRING RIVER BASINS OF KANSAS AND MISSOURI

Abstract. I examined freshwater mussel assemblages at 99 sites between 1993 and 1995 in the Arkansas River System of southeast Kansas and southwest Missouri. Emphasis was placed on the distribution, relative abundance, and habitat use of five unionid species that are candidates for future federal listing (Species of Concern): *Lampsilis rafinesqueana* Frierson, 1927; *Ptychobranchus occidentalis* (Conrad, 1836); *Cyprogenia aberti* (Conrad, 1850); *Quadrula cylindrica* (Say, 1817); and *Alasmidonta marginata* Say, 1818. From a total of 99 sites, I caught 15,068 mussels of 35 species, including 1301 *L. rafinesqueana*, 83 *P. occidentalis*, 29 *C. aberti*, seven *Q. cylindrica*, and one *A. marginata*. The three most abundant species caught in the present study were *Amblema plicata* (Say, 1817), *Quadrula metanevra* (Rafinesque, 1820), and *Quadrula pustulosa* (Lea, 1831); however, species abundance rankings varied from stream to stream, with *L. rafinesqueana* being the most abundant species collected in the Spring River. Except for *A. marginata,* which is a peripheral species, my findings indicate population and range reductions in Kansas for these targeted species; a rarity of weathered shell material made it difficult to evaluate unionid persistence in Missouri streams.

Candidate mussels were found principally in shallow riffles and runs (mean depths ranged from 25.0 to 33.7 cm), with gravel being the most utilized substratum. Current speeds where the targeted mussels were found varied greatly between streams. However, silt deposition at locales where these targeted species were caught was predictively low, and the substrate was moderately compacted.

INTRODUCTION

Prompted by diminishing freshwater mussel populations, five species native to the Arkansas River System of southeast Kansas and southwest Missouri were added as candidates (Species of Concern) for possible addition to the list of U.S. Endangered and Threatened Wildlife and Plants (Federal Register, 1984; 1991; 1994). These candidates are the Neosho mucket (*Lampsilis rafinesqueana* Frierson, 1927); Ouachita kidneyshell [*Ptychobranchus occidentalis* (Conrad, 1836)]; western fanshell [*Cyprogenia aberti* (Conrad, 1850)]; rabbitsfoot [*Quadrula cylindrica* (Say, 1817)]; and elktoe (*Alasmidonta marginata* Say, 1818).

Lampsilis rafinesqueana is endemic to the Arkansas River System (Neosho, Spring, and Verdigris river basins) in Missouri, Arkansas, Oklahoma, and Kansas (Johnson, 1980; Gordon and Brown, 1980; Oesch, 1984; Mather, 1990; Stewart, 1992). Although populations of *L. rafinesqueana* persist within these states, its range has declined (Cope, 1979; Metcalf, 1980; Mather, 1990; Stewart, 1992; Obermeyer *et al.*, 1996; Clarke and Obermeyer, 1996). *Ptychobranchus occidentalis* is confined primarily to the Arkansas, Black, Red, St. Francis, and White river systems (Johnson, 1980); however, it also has a limited distribution in the Meramec River Basin of Missouri (Buchanan, 1980; Oesch, 1984). *Cyprogenia aberti* is native to the Arkansas, Black, St. Francis, Ouachita, and White river systems in Arkansas, Kansas, Missouri, and Oklahoma, as well as above the Ozark Uplift in the Meramec River Basin of Missouri (Johnson, 1980; Harris and Gordon, 1987; Oesch, 1984; Stewart, 1994). Although *C. aberti* is considered extirpated in Oklahoma (Mather, 1990), it is currently found in 14 streams in Arkansas, five in Missouri, and three in Kansas (Stewart, 1994). *Quadrula cylindrica,* or

Orthonymus [Agassiz (1852)] *cylindrica* as Davis and Fuller (1981) proposed due to its dissimilarity with other members of *Quadrula* Rafinesque, 1820 (see also Hoggarth, 1986), is native to the Ozarkian and Cumberland faunal regions (Johnson, 1980) of 13 states (Williams *et al.*, 1993), perhaps reaching its greatest abundance in the Black River System of Arkansas (D.H. Stansbery, Ohio State University, personal communication). A subspecies, *Q. cylindrica strigillata* (Wright, 1898), which is considered by some as an ecomorph (*e.g.*, Simpson, 1914; Gordon and Layzer, 1989; Clarke and Obermeyer, 1996) (but see Ortmann, 1920:293), occurs in the Clinch, Powell, and Holston rivers (Ortmann, 1920; Yeager and Neves, 1986). *Alasmidonta marginata* is widely distributed throughout eastern North America, being found in 22 states and one Canadian Province: Ontario (Clarke, 1981; Williams *et al.*, 1993).

The objectives of this study were to assess the distribution, abundance, and habitat use of these five candidate species in the Arkansas drainage system in eastern Kansas and southwest Missouri (*i.e.*, Neosho, Verdigris, and Spring river basins). Distributions were compared with past populations based on historical accounts and dead shell material. The overall unionid assemblage was also noted within the study area to compare candidate versus non-candidate persistence in the region.

STUDY AREA

The Neosho and Verdigris river basins are situated within the tallgrass prairie ecoregion in southeast Kansas. Cross and Collins (1995) termed the lotic waters of these two basins as Ozark-border streams, and characterized them as having the greatest habitat diversity for fishes in Kansas. The greatest richness of Kansas' unionid fauna also occurs within these two basins—37 species (Obermeyer *et al.*, 1996). Both basins are primarily agricultural, with native rangeland in many headwater reaches, whereas extensive cultivation occurs on and near the flood plains of tailwater reaches. Chert-gravel, derived of Permian and Pennsylvanian limestones (Wilson, 1984; Aber, 1992), is the dominant substratum of shallow habitats. Principal streams of the Neosho and Verdigris basins along with their respective drainage area (km^2) in Kansas follow: the Neosho (15,000) and Cottonwood (4,940) rivers of the Neosho River Basin, and in the Verdigris Basin, the Verdigris (8,690), Fall (2,290), and Elk (1,820) rivers (Fig. 1). Despite their size, these streams are subject to periodic flow interruptions during severe droughts (Deacon, 1961; Geiger *et al.*, 1995; Miller and Obermeyer, 1996). Recent flow disruptions have resulted from the construction and operation of several federal flood-control impoundments: Council Grove Lake and John Redmond Reservoir (Neosho River), Marion Lake (Cottonwood River), Fall River Lake (Fall River), Toronto Lake (Verdigris River), and Elk City Reservoir (Elk River) (Fig. 1).

Streams in the Spring River Basin, excluding the North Fork Spring River, which is a prairie stream (Davis and Schumacher, 1992), originate from the northwestern flank of the Ozark Uplift. The basin's flow is generally westward until reaching Kansas, where it is diverted southward into Oklahoma (Davis and Schumacher, 1992), eventually joining the Neosho River (Fig. 1). The Spring River basin drains approximately 5415 km^2 of southwest Missouri, and an additional 1370 km^2 in southeast Kansas (Davis and Schumacher, 1992). Streams examined in the Spring River Basin included the Spring and North Fork Spring rivers, and Shoal and Center creeks. These streams differ from Ozark-border streams by having lower turbidity, richer aquatic faunas (Cross and Collins, 1995),

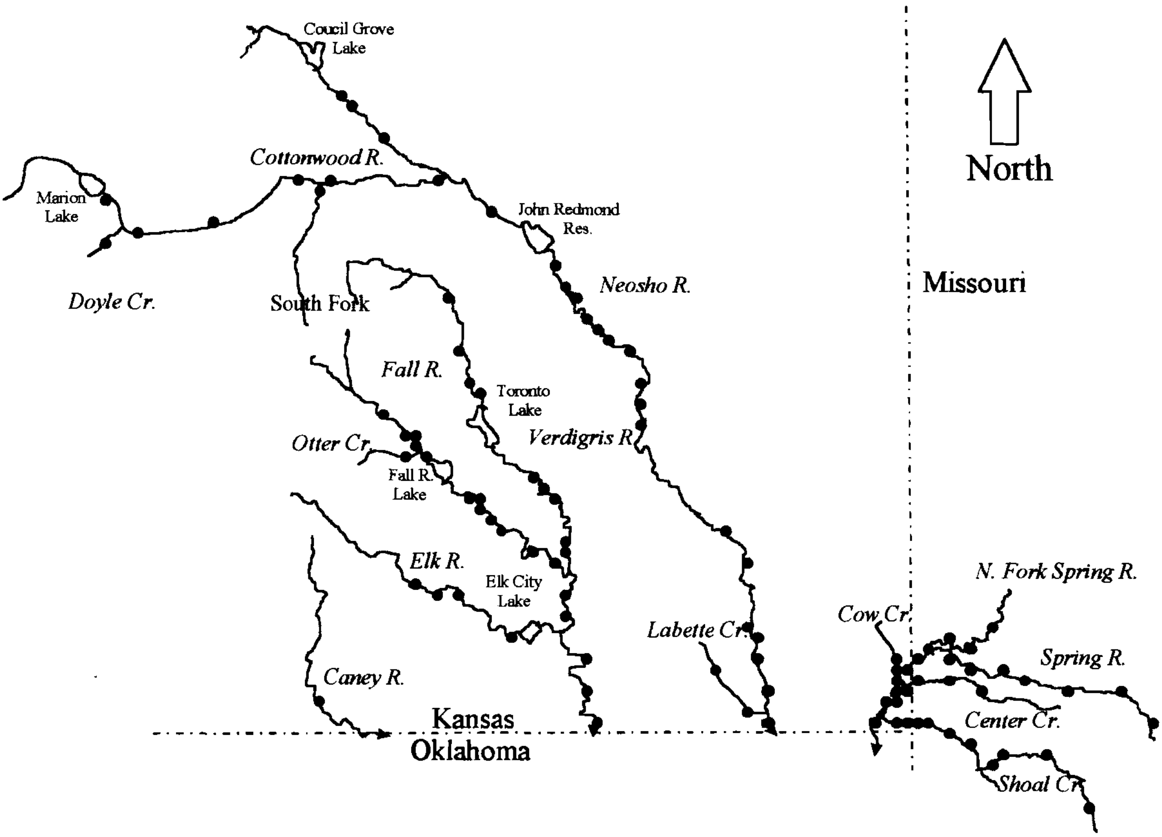

Fig. 1. Map showing sampling sites in southeast Kansas and southwest Missouri.

and sustained flows during droughts from headwater springs. Land-use in several of these streams also differs from the Neosho and Verdigris basins in that a significant proportion of the drainage area is forested (*e.g.*, 45% for Shoal Creek; Davis and Schumacher, 1992). In addition, extensive lead and zinc mining has occurred, which has especially affected the lower Spring River and Shoal Creek in Kansas and Center Creek in Missouri (Kansas Department of Health and Environment, 1980; Davis and Schumacher, 1992). Furthermore, these streams lack the large flood-control impoundments that have altered streams in the Neosho and Verdigris basins (Obermeyer *et al.*, 1996). The assemblage of Spring River basin mussels differs from that of the Neosho and Verdigris river basins with five additional species: *Alasmidonta marginata; Alasmidonta viridis* (Rafinesque, 1820); *Fusconaia ozarkensis* (Call, 1887); *Toxolasma lividus* (Lea, 1831); and *Venustaconcha pleasi* (Marsh, 1891) (Gordon and Brown, 1980; Cope, 1985; Obermeyer *et al.*, 1995). Also, four species are absent in the Spring River Basin: *Ellipsaria lineolata* (Rafinesque, 1820), *Truncilla donaciformis* (Lea, 1827), *Truncilla truncata* Rafinesque, 1820, and *Megalonaias nervosa* (Rafinesque, 1820).

METHODS

SAMPLING

Sampling sites were confined to streams in the Arkansas River Basin with known accounts of one or more of the targeted species. An attempt was made to space sites evenly within each stream; however, the rarity of suitable habitat in some stream stretches and/or the difficulty in securing legal access sometimes made this impossible. I also tried to sample sites examined by previous surveyors; unfortunately, many of these sites lacked geo-referencing.

To locate live mussels, I used snorkel and face-mask in shallow water (15 cm to < 1 m) with adequate visibility, whereas at depths exceeding 1-m, SCUBA was used. Mussels were located both by tactile cues (groping) and by visual cues during snorkeling and SCUBA searches. I also searched shorelines for unionids that had become stranded from receding water levels, or that could be located visually in shallow water. Sampling was concentrated in riffles and runs; however, several deeper runs and pools were also examined to assess usage of these habitats. All searches described were timed to quantify sampling effort; sampling effort ranged from 40 min to nine hours depending on quantity and quality of habitat. Weather conditions, water levels, and time constraints also influenced sampling effort.

I also quantitatively examined 14 sites in Kansas (Neosho = 9, Spring = 2, Fall = 3) using a 1-m^2 quadrat; a total of 505 quadrats were sampled at these sites. Quadrats were placed along measured coordinates chosen randomly, with the substrate excavated to a depth of 10-15 cm.

To seek evidence of young recruits, substrate was dredged with a shovel and transferred it to a 1-m^2 sieve (6 mm mesh) supported by a floating 15 cm PVC pipe frame. Dredging ceased when the weight of the substrate caused the frame to sink. The substrate was then sieved in an attempt to locate small mussels. The number of sieve samples examined at each site varied between 0 and 21.

To supplement historical records, I conducted qualitative searches of dead shell material with identifiable features. The presence of each species was recorded and divided into three categories: fresh, worn, and relic. Shells classified as fresh had bright, unfaded nacre and intact periostracum, with the exception of normal umbonal erosion. Worn shells exhibited considerable erosion of the periostracum and faded or mottled nacre. Relic shells were highly weathered without any remains of the periostracum; these ranged from whole valves to identifiable fragments.

Except for a few specimens collected for reference, live unionids were identified in the field, measured with either a dial caliper or an aluminum plate shell-sizer (see Obermeyer, 1996), and returned to their original location. Reference shells from 1994 sites are deposited at the Ohio State University Museum of Zoology in Columbus, Ohio, and vouchers from 1995 sites will be housed at the Kansas Biological Survey, University of Kansas, Lawrence. Nomenclature follows Turgeon *et al.* (1988); however, subspecies are not recognized, and subgenera *Utterbackia* Baker, 1927 and *Pyganodon* Crosse and Fischer, 1893 were elevated to generic status over *Anodonta* Lamarck, 1799, based on Hoeh (1990).

HABITAT CHARACTERIZATION

At specific locales where candidates were found, I made visual estimates for three substrate variables: substrate compaction, silt deposition on the substrate, and percent composition of substrate types. Substrate compaction was coded as 0, 1, or 2, with 0 being loose, 1 being moderately compacted, and 2 being very compacted. Substrates were divided into five approximate size classes: mud (< 0.8 mm), sand (0.8 mm to 4 mm), gravel (4 mm to 50 mm), cobble (50 mm to 290 mm), and boulder (> 290 mm) (modified from Platts *et al.*, 1983). I coded the degree of silt deposition from 0 to 3, where 0 characterized a clean substrate, 1 had a detectable silt layer, 2 was moderately covered with silt, and 3 was heavily silt-laden. Current speed and water depth were measured for each candidate specimen with a pygmy Gurley current meter no. 625 at 60% and 100% depth.

RESULTS

DISTRIBUTION AND ABUNDANCE

From a combined effort of 505 1-m^2 quadrats and nearly 200 hours of qualitative sampling from 99 sites in the Arkansas River system (Neosho River Basin = 30; Verdigris River Basin = 32; Spring River Basin = 37), I caught 15,068 mussels representing 35 species (Table 1). *Corbicula fluminea* (Müller, 1774), a recent invader, was also found in all streams sampled in this study. Over 9% of my catch consisted of candidate species, with 1301 *Lampsilis rafinesqueana*, 83 *Ptychobranchus occidentalis*, 29 *Cyprogenia aberti*, seven *Quadrula cylindrica*, and one *Alasmidonta marginata* being collected. I also caught an additional candidate in Shoal Creek, *Toxolasma lividus* (Rafinesque, 1831). The most abundant species caught was *Amblema plicata* (Say, 1817), representing 18.9% of the total catch, followed by *Quadrula metanevra* (Rafinesque, 1820) representing 18.2% and *Quadrula pustulosa* (Lea, 1831) representing 11.8%. However, species rank varied among basins and streams; *Q. metanevra, A. plicata*, and *Q. pustulosa* were the most common species in the Neosho River Basin, *A. plicata, Q. pustulosa*, and *Q. metanevra* were the three most numerous species in the Verdigris River Basin, and *L. rafinesqueana, Fusconaia flava* (Rafinesque, 1820), and *Elliptio dilatata* (Rafinesque, 1820) were the most common species in the Spring River Basin (Table 1).

Table 1. Tally of unionid mussels collected in 1993-95 from the Neosho, Spring, and Verdigris river basins in southeast Kansas and southwest Missouri, and the contribution of each stream.

		Neosho Basin				Spring Basin				Verdigris Basin				
		Neosho River	Cottonwood River	S. Fork Cotton. R.	Labette Creek	Spring River	N. Fork Spring R.	Center Creek	Shoal Creek	Verdigris River	Fall River	Elk River	Otter Creek	Caney River
Species	No. sites:	21	6	1	2	20	3	3	11	14	12	4	1	1
Alasmidonta marginata	**1**	-	-	-	-	1	-	-	wd	-	-	-	-	-
Alasmidonta viridis	**1**	-	-	-	-	d	-	-	1	-	-	-	-	-
Amblema plicata	**2844**	1274	d	wd	91	94	132	wd	47	688	461	57	d	d
Cyprogenia aberti	**29**	Lr	-	-	-	13	-	-	-	11	5	wd	-	Lr
Ellipsaria lineolata	**87**	80	-	-	-	Lr	-	-	-	7	Lr	-	-	-
Elliptio dilatata	**539**	179	d	wd	-	280	23	1	56	Lr	-	-	-	-
Fusconaia spp.	**1300**	334	1	wd	12	372	26	d	68	219	217	51	wd	d
Lampsilis cardium	**499**	103	d	d	-	54	27	13	54	106	128	14	d	d
Lampsilis rafinesqueana	**1301**	32	wd	Lr	-	1192	12	d	26	5	34	wd	-	wd
Lampsilis siliquoidea	**23**	Lr	-	-	-	8	12	2	Lr	wd	d	wd	wd	1
Lampsilis teres	**71**	16	d	wd	5	1	7	-	Lr	16	20	6	wd	wd
Lasmigona complanata	**151**	14	d	d	16	3	3	-	-	78	29	8	d	d
Lasmigona costata	**31**	3	wd	wd	-	28	wd	wd	-	wd	wd	wd	Lr	Lr
Leptodea fragilis	**172**	113	6	d	3	Lr	-	-	-	24	23	3	d	d
Ligumia recta	**wd**	wd	wd	wd	-	wd	-	-	wd	wd	wd	wd	wd	Lr
Ligumia subrostrata	**18**	d	d	wd	2	2	1	-	9	wd	4	d	d	d
Megalonaias nervosa	**209**	198	-	-	-	Lr	-	-	-	8	3	-	-	-
Obliquaria reflexa	**490**	292	d	-	9	wd	-	-	-	133	47	9	-	-
Pleurobema coccineum	**421**	30	wd	-	-	335	-	wd	7	40	9	wd	wd	-
Potamilus ohiensis	**5**	3	d	-	-	-	-	-	-	2	-	d	-	d
Potamilus purpuratus	**183**	103	d	1	6	1	-	-	-	29	23	20	d	d
Ptychobranchus occidentalis	**83**	wd	wd	wd	-	45	2	-	6	11	19	wd	wd	wd
Pyganodon grandis	**14**	2	d	-	1	2	2	d	d	d	7	d	wd	d
Quadrula cylindrica	**7**	2	wd	-	-	5	-	-	wd	wd	wd	-	-	-
Quadrula metanevra	**2748**	1786	wd	-	-	15	-	-	1	658	288	d	-	-
Quadrula nodulata	**42**	12	Lr	wd	-	Lr	-	-	-	24	6	-	-	-
Quadrula pustulosa	**1779**	537	5	d	30	243	13	wd	d	388	485	78	d	d
Quadrula quadrula	**683**	274	18	1	53	60	34	-	wd	130	84	29	d	d
Strophitus undulatus	**162**	7	d	d	-	14	68	1	2	35	24	11	wd	d
Toxolasma lividus	**3**	-	-	-	-	-	-	-	3	-	-	-	-	-
Toxolasma parvus	**3**	Lr	-	-	-	-	-	-	Lr	1	1	-	-	1
Tritogonia verrucosa	**893**	354	29	d	16	76	33	-	-	160	189	35	1	d
Truncilla donaciformis	**62**	25	d	d	d	-	-	-	-	8	29	d	-	Lr
Truncilla truncata	**6**	d	wd	-	-	Lr	-	-	-	6	wd	wd	-	d

Table 1 continued

		Neosho Basin				Spring Basin				Verdigris Basin				
Species		Neosho River	Cottonwood River	S. Fork Cotton. R.	Labette Creek	Spring River	N. Fork Spring R.	Center Creek	Shoal Creek	Verdigris River	Fall River	Elk River	Otter Creek	Caney River
Uniomerus tetralasmus	**d**	d	-	-	d	-	-	-	Lr	Lr	-	wd	-	Lr
Utterbackia imbecilis	**d**	Lr	-	-	-	-	-	-	d	Lr	d	-	-	d
Venustaconcha pleasi	**208**	-	-	-	-	120	61	7	20	-	-	-	-	-
Totals	**15068**	5773	59	2	244	2964	456	24	300	2787	2135	321	1	2

d = dead (recent), wd = weathered dead, Lr = literature record. *Fusconaia* spp. represent *Fusconaia flava* and *F. ozarkensis* complex.

Although *Lampsilis rafinesqueana* was the forth most abundant species collected in this study (8.6% of total catch), most of these individuals (1192 = 91.6%; Fig. 2) were collected from the Spring River, representing 40.2% of the Spring River catch. This species was found at 13 of 20 Spring River sites, from downstream of state highway 97 bridge near Stott City, Lawrence County, Missouri, to just upstream from the confluence of Turkey Creek, Kansas (Fig. 3). In Shoal Creek, 26 *L. rafinesqueana* were collected at five of 11 sites, but only in the Missouri portion of this stream. Two of three North Fork Spring River sites yielded 12 *L. rafinesqueana* specimens. This species was not collected alive in Center Creek, but one recently dead specimen was recovered. In the Neosho River, 32 *L. rafinesqueana* were caught alive at seven of 21 sites, representing 0.6% of this river's catch; these were all found downstream from John Redmond Reservoir (Fig. 3). In the Verdigris River, a total of five *L. rafinesqueana* were caught at four of 14 sites (0.2% of total Verdigris catch), all four of these sites were located downstream from Toronto Lake and upstream from the confluence of the Elk River (Fig. 3). Thirty-four *L. rafinesqueana* were caught at five of 12 sites in the Fall River between Fall River Lake and near the confluence of the Verdigris River (Fig. 3); representing 1.7% of the total catch from this stream. Although weathered shells were observed at sites in the Cottonwood (4), Caney (2) and Elk (4) rivers, live or recently dead specimens were not found.

Young *Lampsilis rafinesqueana*, both live and freshly dead, were found at few sites. Based on external estimations of annuli, most of the Verdigris and Neosho basin specimens were over 20 years old. Only three of the specimens caught in these two basinswere estimated to be of young age (6-10 years). Spring River Basin specimens were

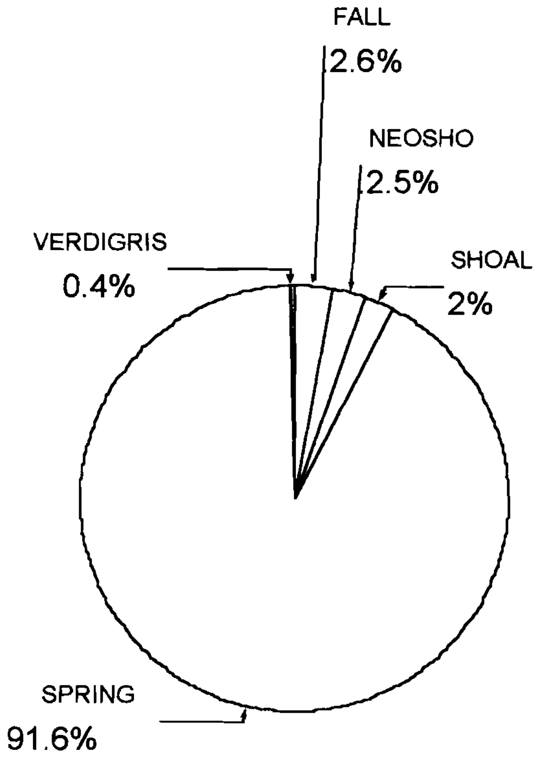

Fig. 2. Proportion of *Lampsilis rafinesqueana* collected from the Neosho, Verdigris, Fall, and Spring rivers and Shoal Creek in southeast Kansas and southwest Missouri.

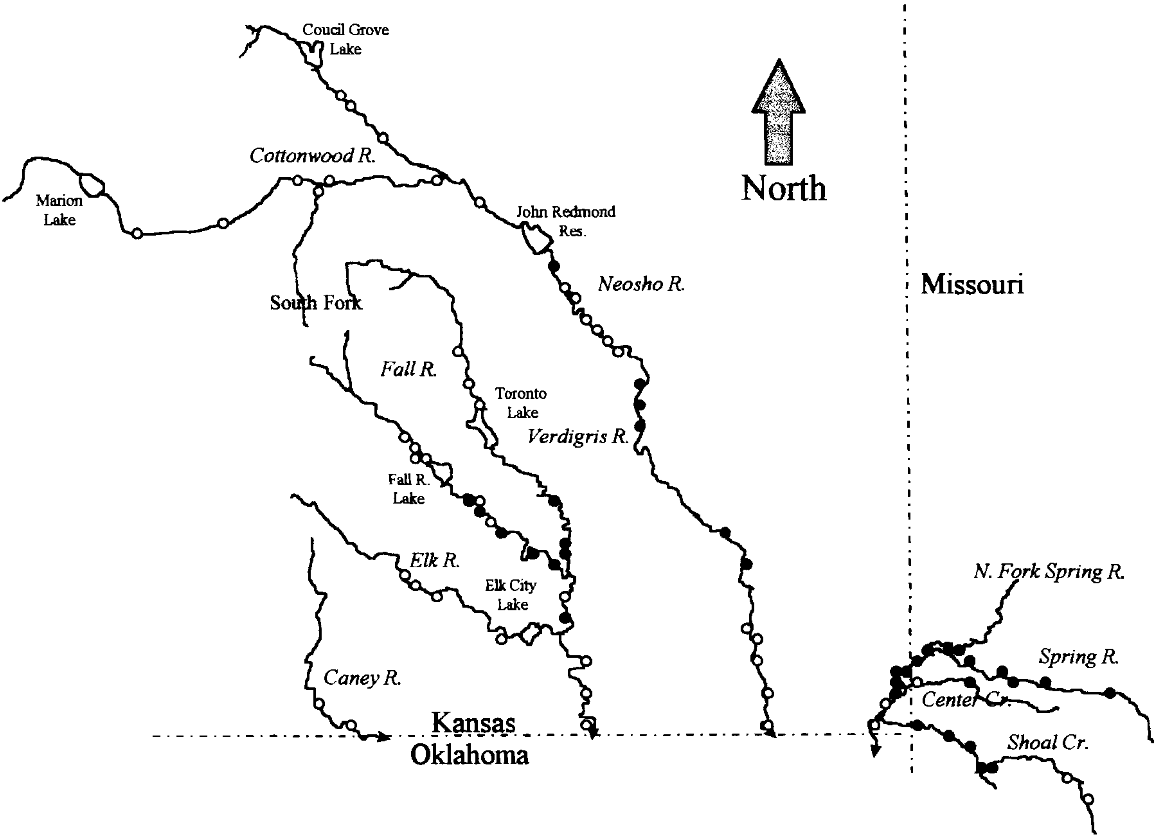

Fig. 3. Site locales of *Lampsilis rafinesqueana* collected in the Neosho, Spring, and Verdigris river basins in southeast Kansas and southwest Missouri. Solid circles represent sites where live and/or recently dead specimens were found, whereas open circles represent sites that yielded only weathered and/or relic valves.

comprised mostly of two or three cohorts between 8 and 20 years of age; the youngest *L. rafinesqueana* specimens collected alive or as recently dead specimens were four years old, the smallest being a recently dead specimen from Shoal Creek that measured 16 by 32 by 49 mm, breadth, height, and length, respectively. In the Neosho and Verdigris basins, mean length for caliper-measured *L. rafinesqueana* was 131.2 mm (SD = 12.96; Fig. 4), with specimens ranging from 94 to 163 mm in length. Spring River *L. rafinesqueana*, which were measured with the aluminum shell-sizer, averaged 110.8 mm (SD = 11.10; Fig. 5), whereas caliper-measured Shoal Creek specimens were considerably smaller ($\bar{x}$ = 72.5 mm, SD = 8.73; Fig. 5).

Ptychobranchus occidentalis ranked 19th in relative abundance from collections in the three basins. This species was not collected alive in the Neosho River, despite abundant weathered valves at several Neosho River sites. In the Verdigris River, 11 *P. occidentalis* were caught at four sites (Fig. 6), comprising 0.4% of this stream's total catch. Nineteen specimens were collected at six Fall River sites (Fig. 6), representing 0.9% of unionids captured in this stream. In the Spring River, I collected 45 *P. occidentalis* alive at 10 stations, representing 1.5% of the catch (Fig. 6). I also caught two specimens at one site in the North Fork of the Spring River, and six individuals at a Shoal Creek site in Missouri (Fig. 6). In the Cottonwood, Elk, Caney, South Fork rivers, only weathered shell material of this species was noted.

Most *Ptychobranchus occidentalis* specimens were over seven years old; the youngest *P. occidentalis* collected was a recently dead three-year-old specimen (9 mm wide, 20 mm tall, and 41 mm long) caught at a Fall River site. Mean shell length for

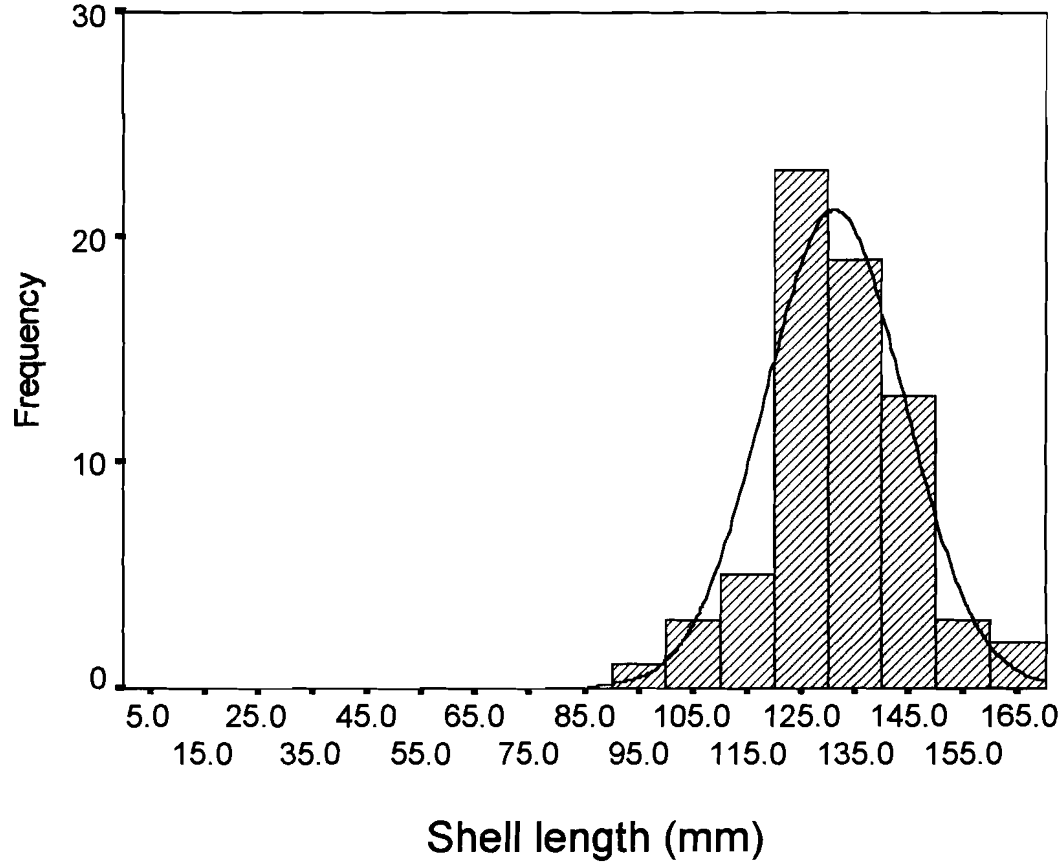

Fig. 4. Size frequency of *Lampsilis rafinesqueana* collected from the Neosho and Verdigris river basins in Kansas.

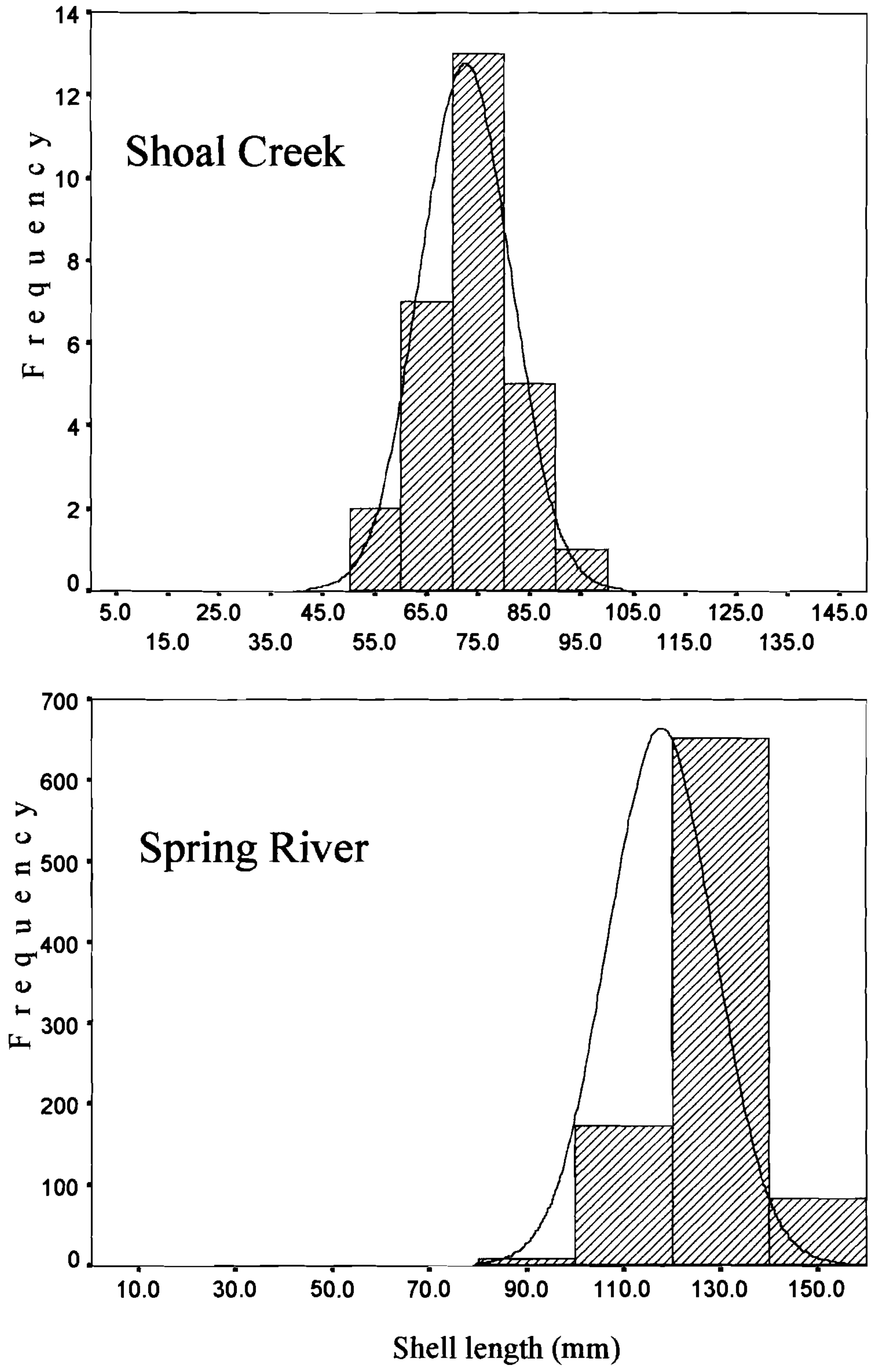

Fig. 5. Frequency of sizes of *Lampsilis rafinesqueana* collected from the Spring River (sized with aluminum plate shell sizer) versus Shoal Creek (caliper-sized).

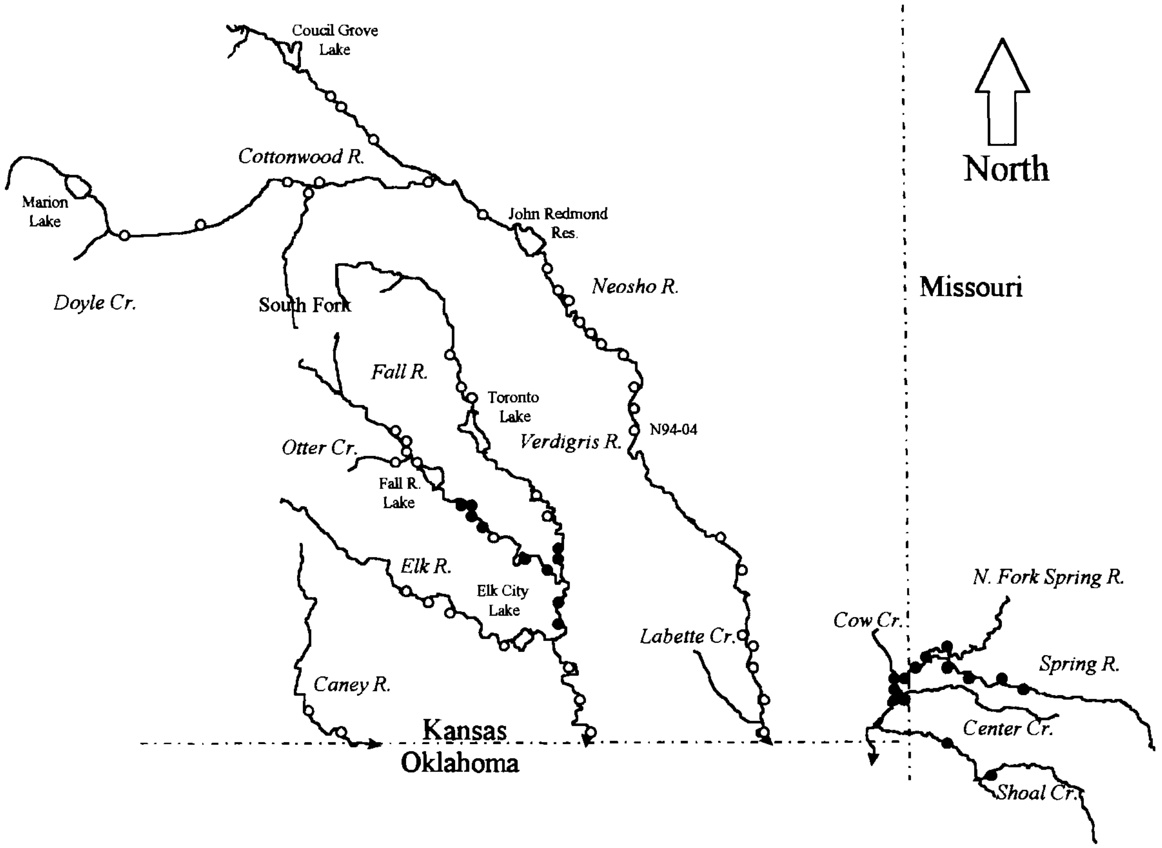

Fig. 6. Site locales of *Ptychobranchus occidentalis* collected in the Neosho, Spring, and Verdigris river basins in southeast Kansas and southwest Missouri. Solid circles represent sites where live and/or recently dead specimens were found, whereas open circles represent sites that yielded only weathered and/or relic valves.

P. occidentalis was 90.2 mm (SD = 20.74) in the Verdigris Basin of Kansas (Fig. 7), whereas Spring River Basin specimens were slightly larger ($\bar{x}$ = 97.4 mm, SD = 16.17) (Fig. 7).

Cyprogenia aberti was collected alive in only three streams, representing 0.2% of my total catch. In the Verdigris River, I collected 11 *C. aberti* at five sites (Fig. 8). In the Fall River, five live specimens were found at three sites (Fig. 8). And, in the Spring River, 13 specimens were caught at four sites. I also found one relic *C. aberti* valve from the Elk River, Kansas (Fig. 8). Although *C. aberti* has been documented in the Neosho River (Call, 1885a; Scammon, 1906), I was unable to find evidence of this species, either recent or weathered valves, in this stream. Only four *C. aberti* were caught that were less than five years old, all measuring less than 45 mm in length; the smallest one measured 16 mm wide, 26 mm tall, and 34 mm long. A Verdigris River site also yielded a young freshly dead specimen found in exposed gravel, which was estimated to be three years old and measured 15 by 35 by 44 mm [width (W), height (H), and length (L), respectively]. Shell length of live specimens from the Spring, Fall, and Verdigris rivers ranged from 34 to 81 mm ($\bar{x}$ = 61.0, SD = 13.40) (Fig. 9).

Extant representatives of *Quadrula cylindrica* were found only in the Neosho and Spring rivers. In the Neosho River, I collected two living specimens from two sites, as well as two recently dead articulated specimens with desiccated softparts at one of these sites (Fig. 10). Although freshly dead specimens of this species have been found in recent years in this stream (C. H. Cope, Kansas Department of Wildlife and Parks, personal communication), these individuals are the first *Q. cylindrica* specimens reported alive from the Neosho River since 1912 (Isely, 1925). Relic *Q. cylindrica* valves were

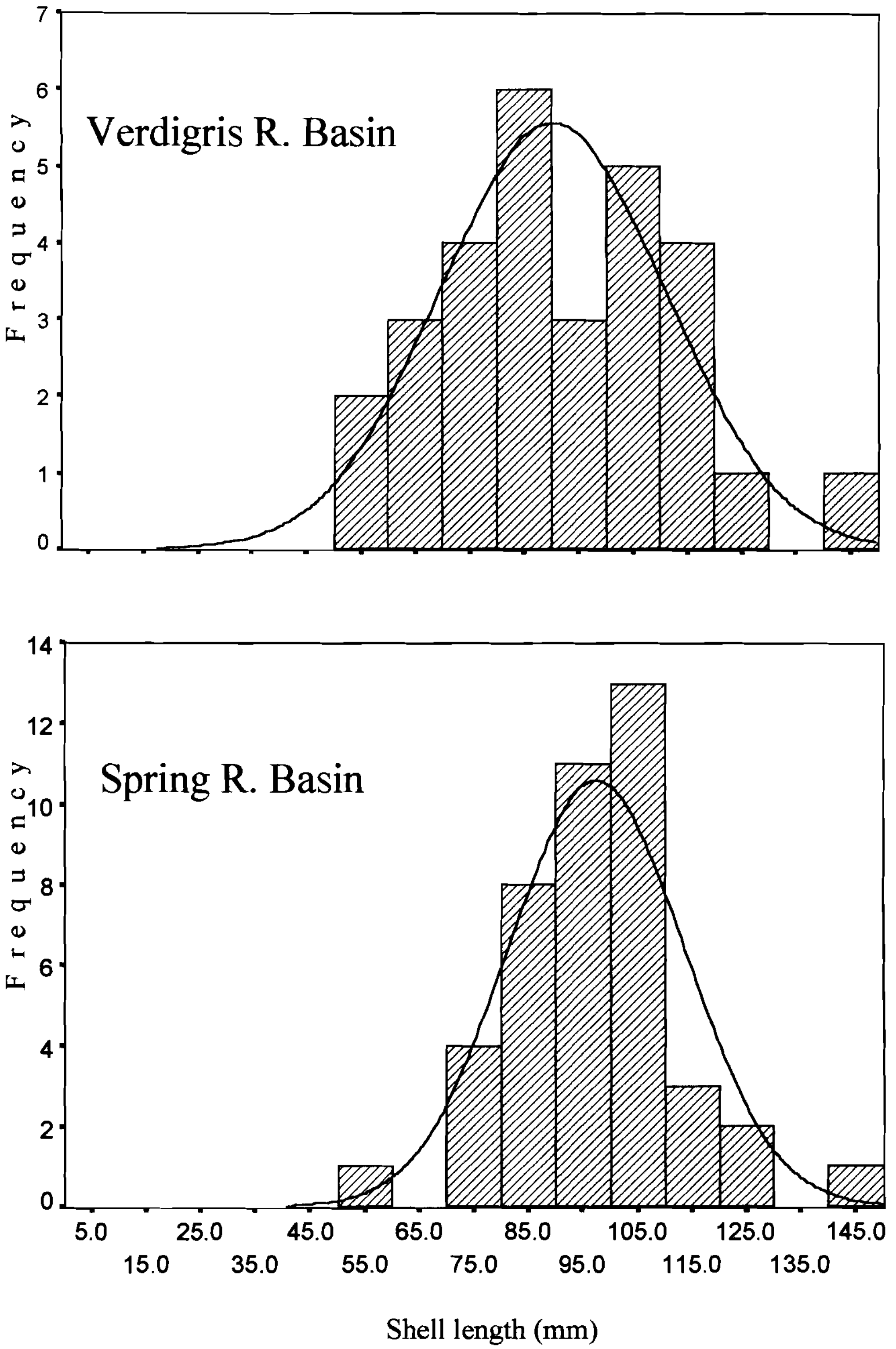

Fig. 7. Size frequency of *Ptychobranchus occidentalis* collected in the Verdigris (*i.e.*, Verdigris and Fall rivers) and Spring (Spring River and Shoal Creek) river basins.

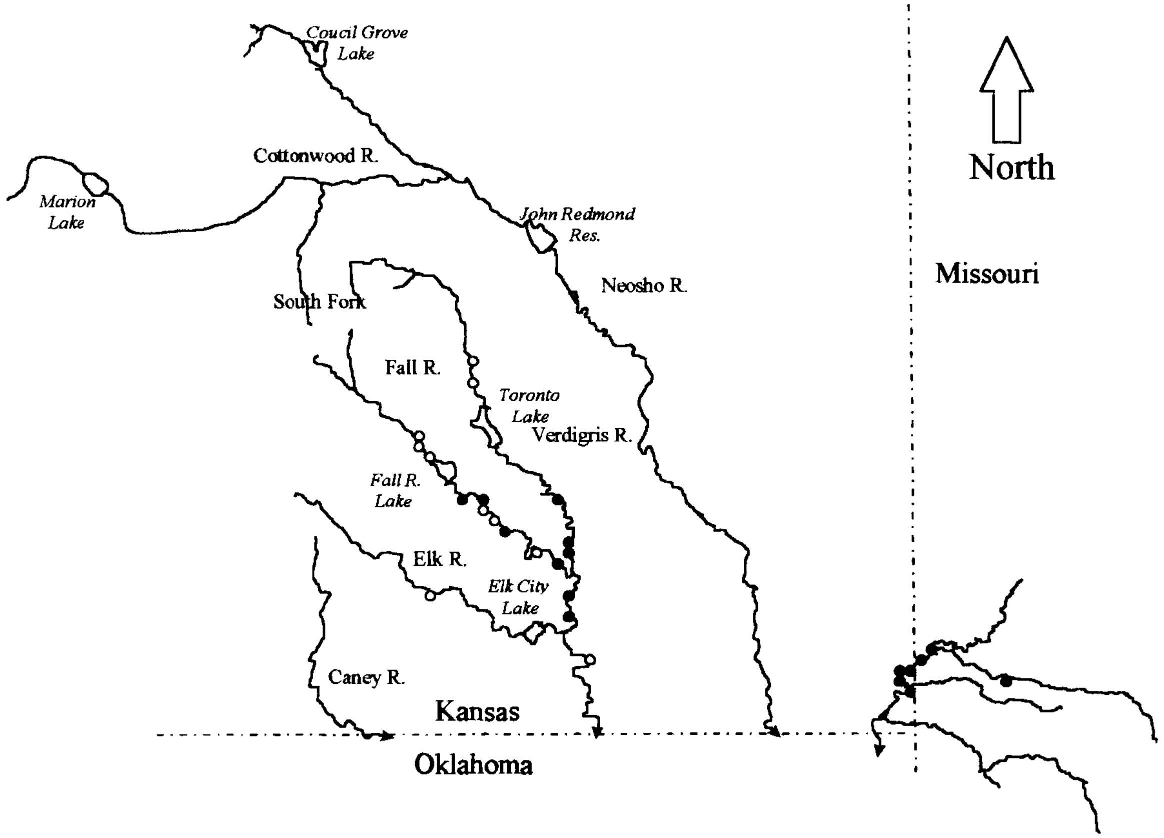

Fig. 8. Site locales of *Cyprogenia aberti* collected in the Neosho, Spring, and Verdigris river basins in southeast Kansas and southwest Missouri. Solid circles represent sites where live and/or recently dead specimens were found, whereas open circles represent sites that yielded only weathered and/or relic valves.

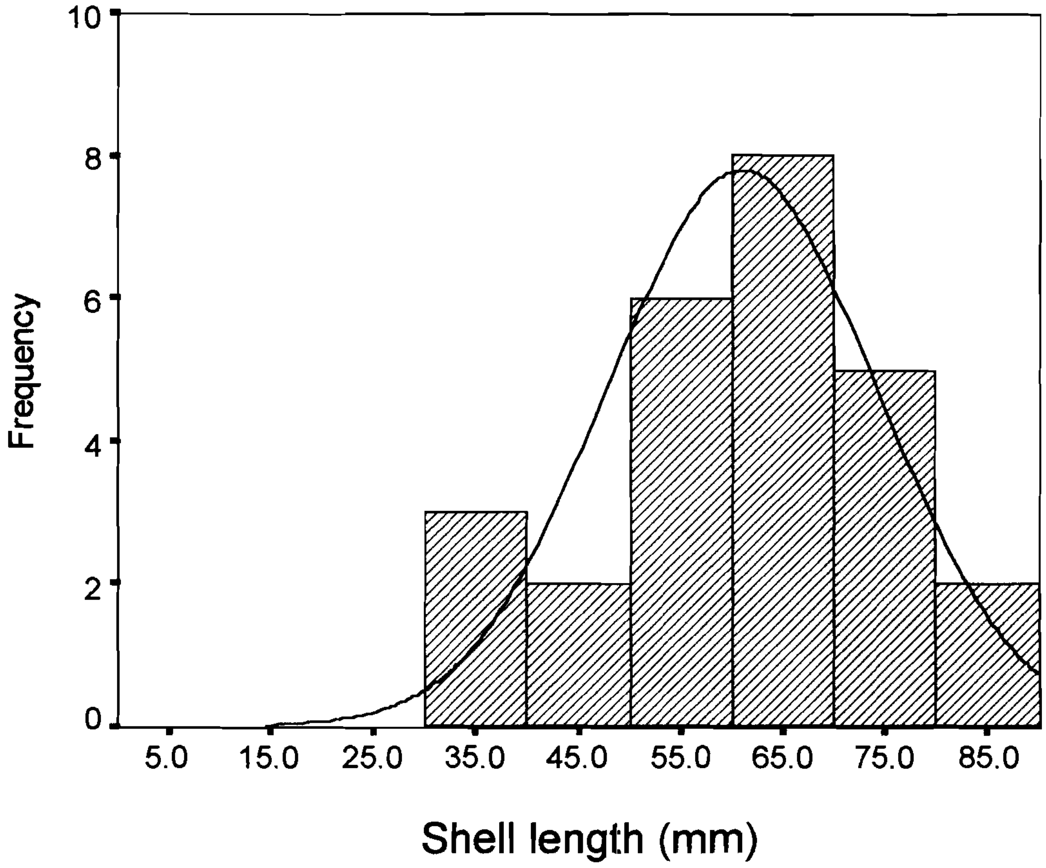

Fig. 9. Size frequency of *Cyprogenia aberti* caught from the Verdigris, Fall, and Spring rivers in southeast Kansas and southwest Missouri.

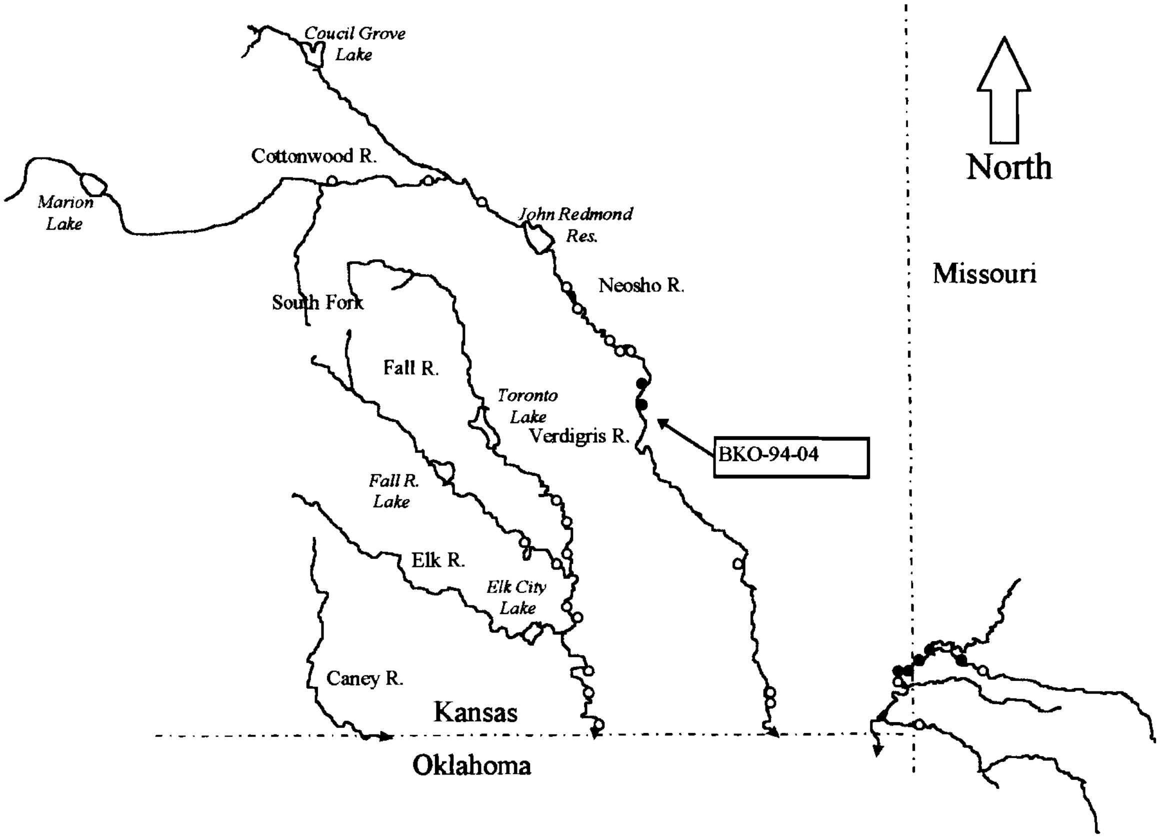

Fig. 10. Site locales of *Quadrula cylindrica* collected in the Neosho, Spring, and Verdigris river basins in southeast Kansas and southwest Missouri. Solid circles represent sites where live and/or recently dead specimens were found, whereas open circles represent sites that yielded only weathered and/or relic valves.

also found at nine additional sites Neosho River sites. In the Spring River, I caught a total of five specimens from one site in Kansas and two sites in Missouri (Fig. 10). Relics were collected from one Shoal Creek site in Missouri, which represents the first evidence of this species in Shoal Creek. The establishment of new stream records for *Q. cylindrica* was also made for the Fall and Cottonwood rivers, with relic valves collected at two sites in each of these streams. Although Isely (1925) reported live *Q. cylindrica* in the Verdigris River in 1912, I found only relic valves of the species at eight of my 14 sites.

I estimated that three *Quadrula cylindrica* specimens from the Neosho River (two recently dead and one alive) were in their sixth year of growth (78, 86, and 87 mm long); an additional live specimen was estimated to be over 10 years old (113 mm long). A rather large specimen (recently dead valve) of this species, which measured 127 mm in length, was also recovered at one of these sites (BKO-94-04; Fig. 10). In the Spring River, *Q. cylindrica* specimens ranged from 74 to 109 mm in length ($\bar{x}$ = 93.0; SD = 12.71).

Only one *Alasmidonta marginata*, which measured 30, 38, and 73 mm (W, H, L), was caught during the study—from a Kansas Spring River site. Weathered shells of this species were recovered at two additional Spring River sites in Kansas and one weathered valve was found at a Shoal Creek site in Missouri, which is the first account of this species in Shoal Creek.

HABITAT USE

Lampsilis rafinesqueana was collected most often in shallow riffles and runs with a predominantly gravel substratum (Table 2; Fig. 11); however, there was a substantial

Table 2. Observed habitat use [mean (SD)] of candidate mussels from Arkansas Basin streams (KS and MO) during 1994-1995.

			Current speed (cm/s) at:		Substrate character (%):						
Stream	N	Depth (cm)	100% depth	60% depth	Mud	Sand	Gravel	Cobble	Boulder	Compaction	Siltation
Lampsilis rafinesqueana											
Fall R.	34	34.1(20.9)	12.4 (10.7)	13.2 (8.3)	0.7 (1.8)	11.7 (12.3)	48.4 (22.5)	37.6 (24.3)	1.5 (4.2)	1.2 (0.6)	1.3 (0.5)
Verdigris R.	5	26.2 (18.9)	3.2 (4.6)	5.2 (7.3)	11 (16.3)	11 (5.7)	52 (18.2)	27 (17.2)	-	1.0 (0.0)	1.6 (0.5)
Neosho R.	32	39.6 (22.2)	16 (13.8)	27 (25.4)	3.3 (6.6)	14.9 (13.7)	41.3 (20.0)	35.9 (24.6)	4.4 (14.4)	1.1 (0.4)	1.4 (0.5)
Spring R.	258	33.0 (11.7)	43.5 (19.3)	72.4 (27.1)	1 (3.3)	16.4 (16.9)	74.3 (16.6)	-	-	1.0 (0.0)	0.2 (0.4)
Shoal Cr.	20	59.4 (15.4)	20.4 (11.5)	42.2 (28.4)	0.3 (1.1)	17.1 (7.1)	74.5 (14.8)	8.3 (16.9)	-	0.9 (0.4)	0.1 (0.2)
Ptychobranchus occidentalis											
Fall R.	17	17.5 (12.8)	12.2 (11.9)	14.1 (10.6)	1.8 (3.3)	15.3 (12.2)	62.0 (19.5)	13.9 (12.1)	6.9 (20.7)	0.9 (0.2)	1.2 (0.6)
Verdigris R.	9	19.0 (8.1)	13.2 (10.3)	18.6 (14.4)	2.6 (2.7)	15.3 (4.5)	73.2 (8.9)	8.9 (7.8)	-	1.0 (0.0)	1.3 (0.5)
Spring R.	12	41.0 (17.7)	26.8 (19.8)	44.4 (27.9)	1.0 (1.8)	24.6 (25.2)	69 (24.1)	5.4 (6.6)	-	0.9 (0.3)	0.3 (0.5)
Shoal Cr.	4	73.5 (4.0)	34.9 (7.1)	97.1 (6.4)	0.0 (0.0)	11.8 (2.4)	82.0 (3.6)	7.5 (5.0)	-	1.3 (0.3)	0.0 (0.0)
Cyprogenia aberti											
Fall R.	5	29.6 (17.6)	8.4 (7.9)	16.8 (12.1)	0.2 (0.5)	14.2 (15.2)	18.4 (25.3)	45.2 (29.5)	22.0 (31.9)	1.0 (0.0)	1.2 (0.5)
Verdigris R.	9	26.5 (26.9)	17.1 (18.1)	20.9 (19.6)	4.1 (6.0)	12.6 (8.6)	7.3 (6.1)	75.1 (15.7)	-	0.8 (0.4)	1.5 (0.5)
Spring R.	3	37.3 (10.7)	27.2 (17.0)	65 (35.8)	-	30.0 (35.0)	1.7 (2.9)	68.3 (33.3)	-	0.7 (0.6)	0.3 (0.6)
Quadrula cylindrica											
Neosho R.	2	12.5 (13.4)	27.5 (16.3)	38.0 (31.1)	0.5 (0.7)	7.0 (4.2)	60.0 (8.5)	32.5 (3.5)	-	1.0 (0.0)	1.0 (0.0)
Spring R.	5	44.2 (16.6)	23.8 (9.14)	56.2 (31.9)	-	20.0 (12.7)	80.0 (12.7)	-	-	0.9 (0.2)	0.2 (0.4)

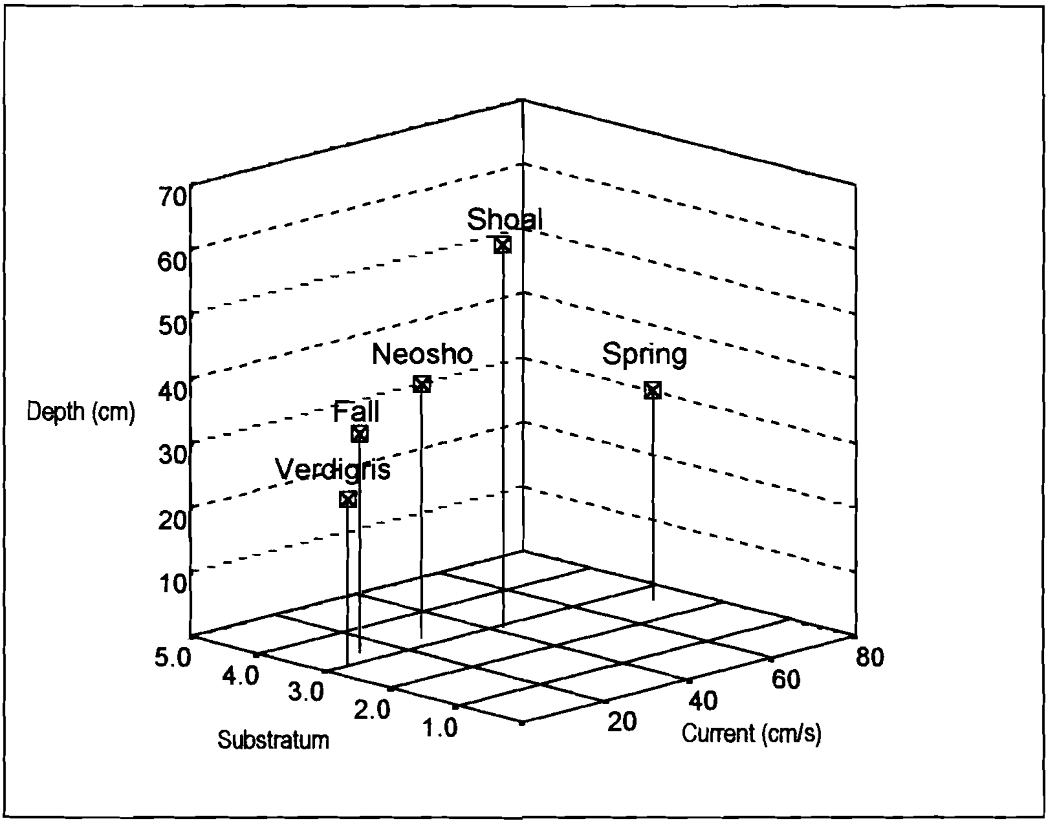

Fig. 11. Three-dimensional ordination plot of habitat measurements taken for *Lampsilis rafinesqueana* in southeast Kansas and southwest Missouri (Shoal Creek only). The substratum value is the proportion of mud (1), sand (2), gravel (3), cobble (4), and boulder (5). Current velocities were taken at depths of 60%.

difference in habitat use by *L. rafinesqueana* in the Spring River and Shoal Creek compared to that of the Neosho, Fall, and Verdigris rivers (Table 2; Fig. 11). For instance, mean current speed (60% depth) at locales utilized by *L. rafinesqueana* was 51.8 cm/s higher in the Spring River (in Kansas) than in other Kansas streams in this study. At 100% depth, flows were 30.2 cm/s higher (Table 2). The mean coded value for silt deposition at *L. rafinesqueana* sites in the Spring River was 0.2 (SD = 0.4) compared to 1.4 (SD = 0.5) in the Neosho, Verdigris, and Fall rivers (Table 2). These data are likely skewed due to the uniqueness of the Spring River compared to other Kansas streams (Cross and Collins, 1995), and because of greater *L. rafinesqueana* densities in the Spring River. For example, 67 *L. rafinesqueana* were caught in one 1-m^2 quadrat (located at a depth of 28 cm with current speeds of 90 and 68 cm/s at 60 and 100% depth, respectively, in clean, moderately loose substrate consisting of 10% sand, 80% gravel, and 10% cobble); whereas the species was found only sporadically in other Kansas streams.

Like *Lampsilis rafinesqueana, Ptychobranchus occidentalis* exhibited a high degree of variation in habitat use among streams (Table 2; Fig. 12). Because of the rarity of *Cyprogenia aberti* and *Quadrula cylindrica,* I was unable to discern a difference between streams, that is, they were generally confined to shallow riffles and runs in predominantly clean, moderately compacted gravel-sand substrata throughout the study area (Table 2). The single live specimen of *Alasmidonta marginata* was collected from a swift riffle with current speeds of 72 and 33 cm/s, 60 and 100% depth, respectively, at 54 cm depth in a predominantly cobble substratum (6% sand, 15% gravel, and 79% cobble).

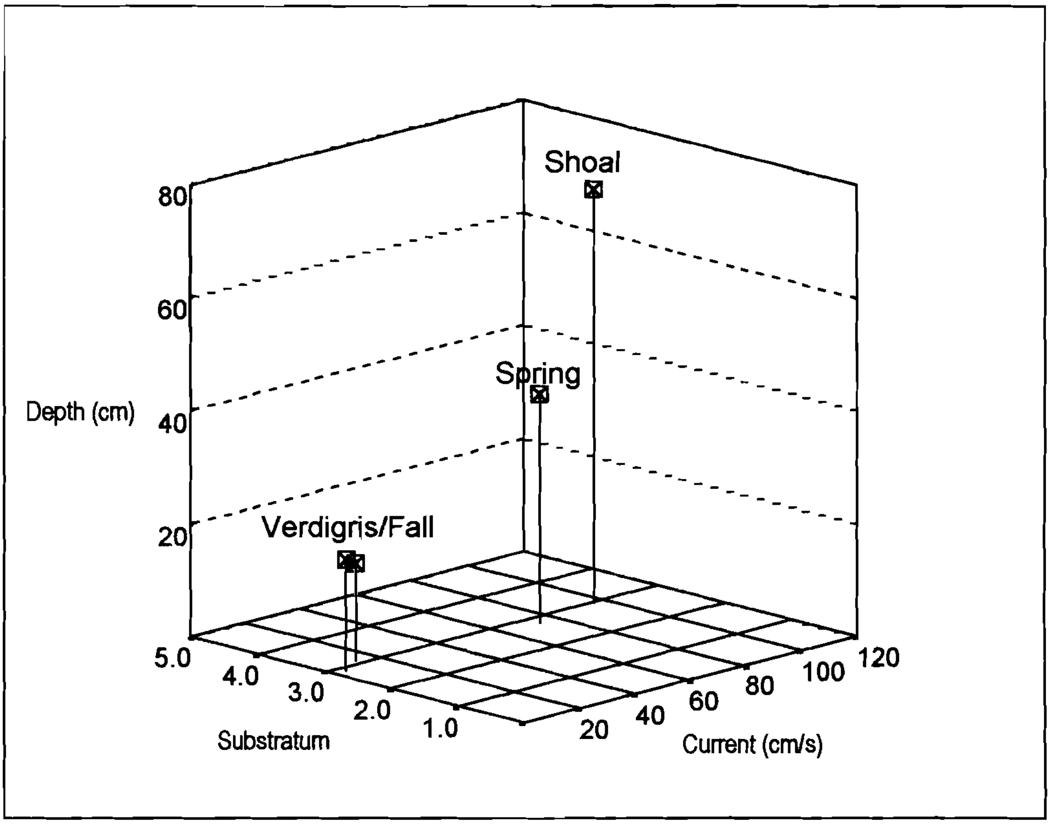

Fig. 12. Three-dimensional ordination plot of habitat measurements taken for *Ptychobranchus occidentalis* in southeast Kansas and southwest Missouri. The substratum value is the proportion of mud (1), sand (2), gravel (3), cobble (4), and boulder (5). Current velocities were taken at depths of 60%.

DISCUSSION

Habitat descriptions for freshwater mussels have often been generalized, with a broad range of possibilities (Gordon and Layzer, 1989). For example, *Quadrula cylindrica* occurring in medium to large streams is cited as preferring sand-gravel substrates in 6-10 feet of water (Parmalee, 1967; Cummings and Mayer, 1992) with a detectable current (Parmalee, 1967). However, in smaller streams the species is considered a riffle species, being most often found near shore in cobble substratum with a slack current (Stansbery, 1974) or, as Gordon and Layzer (1989) reported, in close proximity to the swiftest flows. Anecdotal habitat preference of *Ptychobranchus occidentalis* is gravel substratum in riffles with depths between 2.5 and 75 cm in a slow to moderate current (Buchanan, 1980; Oesch, 1984). Gordon and Layzer (1989) stated that two congeners, *P. fasciolaris* (Rafinesque, 1820) and *P. subtentum* (Say, 1825), prefer shallow riffles in moderate to swift currents. *Cyprogenia aberti* is described as preferring shallow water (7-45 cm), with mud, sand, and gravel substrates (Murray and Leonard, 1962; Buchanan, 1980; Oesch, 1984). *Alasmidonta marginata* is reported to prefer riffles in cobble-gravel and gravel-sand substrates in medium to large rivers (Clarke, 1981; Cummings and Mayer, 1992), with a preference for moderate to swift currents (Gordon and Layzer, 1989). And finally, Oesch (1984) described the habitat use of *Lampsilis rafinesqueana* in Missouri as shallow water with a moderate current in fine to medium gravel.

Detailed habitat descriptions for many unionids such as those just mentioned are difficult because of broad microhabitat tolerances (Strayer, 1981; Kat, 1982; Gordon and Layzer, 1989; Strayer and Ralley, 1994), and because of site-specific preferences (Strayer,

1981) due to macro-scale variation (*e.g.*, hydrologic variability) among sites (Strayer and Ralley, 1994). Habitat use of mussels caught in the present study, including candidate species, was also variable when compared among different streams (Figs. 11 and 12), which makes it difficult to extrapolate habitat suitability indices from one stream to another. Habitat use on a broader scale, however, was more predictable; that is, mussels were most often found in shallow riffles and runs at depths less than one meter, with stable and moderately compacted substrata, predominantly gravel, and with a minimum of silt. Deeper, more silt-laden habitats (*i.e.*, pools) revealed a decrease in species richness and abundance of unionids, including the absence of candidate species. Sites that were unstable (*i.e.*, loose, shifting substrata) were especially low in unionid numbers.

I found the habitat use of *Lampsilis rafinesqueana* to be particularly intriguing. In the Neosho, Verdigris, Spring, and North Fork of Spring rivers, this species was found most often in riffle habitat, usually in a swift current. However, in Shoal Creek, the species was found most often in habitats near shore or out of the strongest current. Mather (1990) and C.C. Vaughn (Oklahoma Biological Survey, personal communication) found a similar trend in another Ozarkian stream, the Illinois River in Oklahoma, and described *L. rafinesqueana*'s habitat preference in this stream as backwater areas. Nonetheless, mean current speed of *L. rafinesqueana* in Shoal Creek was greater than from other streams sampled in this study (Table 2; Fig. 12), probably because Shoal Creek is a high gradient stream (Davis and Schumacher, 1992). The rarity of *L. rafinesqueana* in mid-channel flows in Shoal Creek might be due to greater disruptions of the substrate, especially during spates, than other streams sampled in this study. Despite *L. rafinesqueana*'s inability to colonize extremely unstable habitats, this species seemed more adapted to unstable habitats than most other unionids. I observed that individuals of *L. rafinesqueana* in the Spring River and Shoal Creek often had their foot well extended into the substrate, especially in loose gravel. Kat (1982) similarly noted that *Elliptio complanata* (Lightfoot, 1786) used its foot to maintain a viable position in unstable habitats (*i.e.*, soupy mud). Foot extension of *L. rafinesqueana* was not noted, however, in prairie streams of the Neosho and Verdigris basins and in the North Fork Spring River, except for specimens in the process of moving. Foot anchoring by *L. rafinesqueana* in the Spring River Basin was probably due to swifter average current speeds in association with *L. rafinesqueana* in the Spring River Basin versus Neosho and Verdigris basins (Fig. 11), and because substrates in the Spring River and Shoal Creek were less compacted than those in the prairie streams mentioned.

The ability of *Lampsilis rafinesqueana* to securely anchor itself in gravel substrates might help explain why it was the dominant species at a number of sites in this study. This phenomenon was especially noticeable at a Spring River site in Kansas (Fig. 13). Quadrats (1-m^2) sampled at this site with current speeds > 50 cm/s (at 60% depth) and with a high percentage of loose gravel substratum revealed a greater proportion of *L. rafinesqueana* than other species [*e.g.*, 67 of 69 in one quadrat (6); Fig. 13]; but in slower and more stable habitats, the species was less dominant. The narrow band of habitat where densities of *L. rafinesqueana* were greatest, in which many individuals were completely buried under gravel, may represent the optimal microhabitat of this species. Conversely, aggregation of mussels at this site may be a response to help stabilize their habitat (substrate). It might also represent a zone of recent migration between the exposed gravel bar and unstable, torrent habitat.

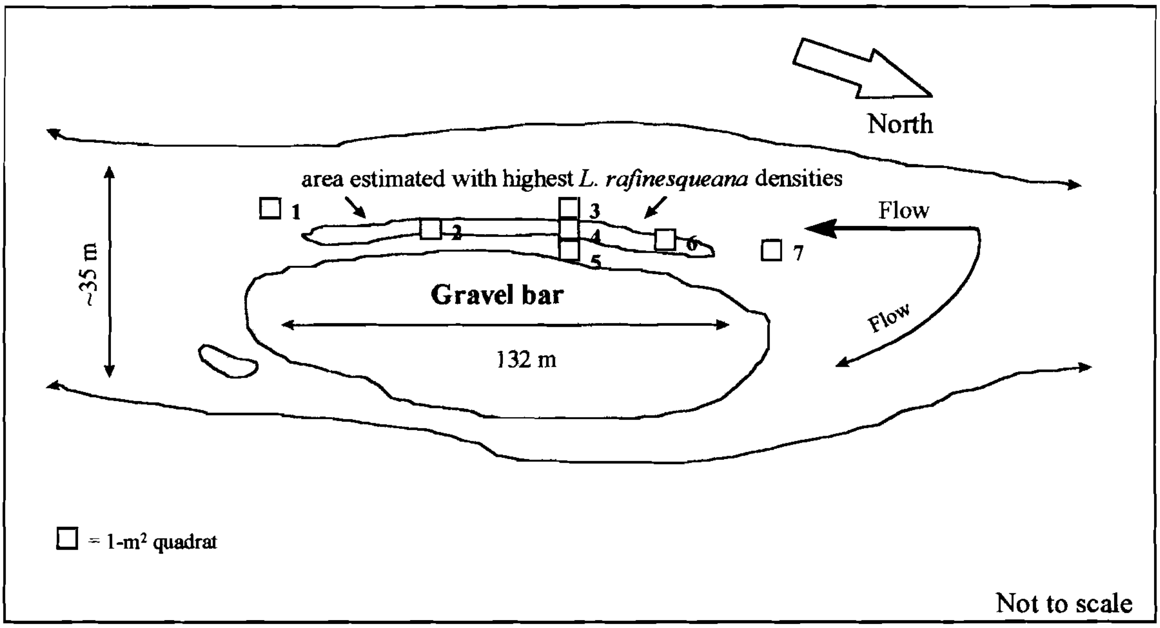

Fig. 13. Spring River site (BKO-94-48), Cherokee, Co., Kansas, illustrating habitat preference of *Lampsilis rafinesqueana*. Quadrat depth, current speed (60% depth), and the proportion of *L. rafinesqueana* follow: **1** = 18 cm, 73 cm/s , 6/15; **2** = 16-33 cm, 70 cm/s, 44/48; **3** = 48-76 cm, 120 cm/s, 11/11; **4** = 25-47 cm, 82 cm/s, 63/68; **5** = 1-25 cm, 36 cm/s, 16/19; **6** = 9-28 cm, 90 cm/s, 67/69; **7** = 20 cm, 90 cm/s, 0/0.

I suspect that *Lampsilis rafinesqueana* originated in Ozarkian streams—perhaps in the Spring River Basin—rather than streams in the western half of its range. I base this hypothesis on (i) the inferred foot anchoring adaptation of *L. rafinesqueana* to high-gradient habitats in the Spring River Basin and (ii) its darkly pigmented mantle lure (personal observations), which would be advantageous in attracting host fishes in clear water streams; prairie streams of its western range were probably more turbid historically. Moreover, climate and stream flow patterns in the Verdigris and Neosho river basins in Kansas and Oklahoma have been highly variable since the Pleistocene (Frye, 1955; Aber, 1985; 1992), whereas streams arising from the Ozark plateau have been more stable (J.S. Aber, Emporia State University, personal communication). Thus, the present day range of *L. rafinesqueana* may be receding to its center of origin.

Lampsilis rafinesqueana has apparently become extirpated from five Kansas streams: the Elk, Big Caney, Cottonwood, and South Fork of the Cottonwood rivers, and Shoal Creek (Cope, 1979; 1985; Metcalf, 1980; Obermeyer *et al.*, 1996), and currently remains in the Verdigris, Fall, Neosho, and Spring rivers (Cope, 1979; 1983; 1985; Miller, 1993; Obermeyer *et al.,* 1995; 1996) (Fig. 3). In addition to its range decline in Kansas, *L. rafinesqueana* has apparently become less abundant (Obermeyer, *et al.*, 1996). It is presently listed by KDWP in Kansas as endangered. In Missouri, *L. rafinesqueana* is confined to the Spring and Elk river basins (Johnson, 1980; Gordon and Brown, 1980; Oesch, 1984; Clarke and Obermeyer, 1996), and is state-listed as rare (Anonymous, 1994). Despite the decline of *L. rafinesqueana* in Kansas (Obermeyer *et al.*, 1996), the relative abundance of this species may have increased in the Spring River since Branson's (1967) survey. For example, he collected only 15 "muckets" at one of my Spring River sites in Kansas, whereas I found 112 live *L. rafinesqueana* [note: his identifications of *Actinonaias ligamentina* (Barnes, 1823) were likely *L. rafinesqueana*]. Presently, the species is probably more abundant in the Spring River from Carthage, Missouri, to near the confluence of Center Creek, Kansas, than anywhere else throughout its range. Although *L. rafinesqueana* remains within its historic range in Missouri, Branson (1967) recovered the species at sites further upstream than from my sites in both the Spring River and Shoal Creek, perhaps indicating a slight decrease in range. In the Kansas portion of the Spring River, *L. rafinesqueana,* as well as most other riverine mussel species, is apparently extirpated downstream from Turkey Creek (Fig. 3). Nonetheless, I collected this species at a riffle in the Spring River immediately downstream from the confluence of Center Creek that was previously devoid of mussels (Cope, 1985; Stewart, 1992; Obermeyer *et al.,* 1995), which may indicate improving stream conditions (Clarke and Obermeyer, 1996).

Ptychobranchus occidentalis has experienced the largest reduction in range in Kansas of the five candidate species targeted in this study (Obermeyer *et al.,* 1996). Ten Kansas streams have historic records for this species: the Cottonwood, South Fork of the Cottonwood, Elk, Fall, Big Caney, Neosho, Spring, and Verdigris rivers, and Otter (Greenwood County) and Cedar (Chase County) creeks (Popenoe, 1885; Call, 1885c; 1885d; 1886; Scammon, 1906; Isely, 1925; Branson, 1966a; Branson, 1967; Liechti and Huggins, 1977; Schuster, 1979; Schuster and DuBois, 1979; Cope, 1979; 1983; 1985; Metcalf, 1980; Miller, 1993; Obermeyer *et al*., 1996). However, extant representatives have been recovered recently from only four Kansas streams: the Neosho, Spring, Fall, and Verdigris rivers (Branson, 1966a; Frazier, 1977; Liechti and Huggins, 1977; Schuster, 1979; Schuster and DuBois, 1979; Cope, 1979; 1983; 1985; Miller, 1993; Obermeyer *et al.*, 1996). Furthermore, *P. occidentalis* may have since become extirpated in the Neosho River (Obermeyer *et al.*, 1995). Presently, *P. occidentalis* is listed as threatened in Kansas. In the Spring River Basin, *P. occidentalis*, which is listed in Missouri as a watch species (Anonymous, 1994), was uncommon in this study. This observation agrees with the contention of Oesch (1984) and Buchanan (1980) that *P. occidentalis*, although widely distributed in the southern-half of Missouri, is uncommon at any one locale.

Cyprogenia aberti is listed in Kansas as endangered. This species is known to have occurred historically in the Fall, Elk, Verdigris, Neosho, Spring rivers (Popenoe, 1885; Call, 1885a; 1885b; 1886; 1887a; Scammon, 1906; Murray and Leonard, 1962; Branson, 1966b; Liechti and Huggins, 1977; Cope, 1979; 1983; 1985; Miller, 1993; Obermeyer *et al.*, 1996); however, it presently occurs in only the Verdigris, Fall, and Spring rivers, and is considered rare with a patchy distribution (Obermeyer *et al.*, 1996). In Ozarkian streams of Missouri and Arkansas, Oesch (1984) and Harris and Gordon (1987) reported that *C. aberti* was locally abundant, especially in the Spring (White River system) and Caddo (Ouachita River system) rivers in Arkansas (Harris and Gordon, 1987). Oesch (1984) reported that *C. aberti* was rare in the Meramec system. I found the species uncommon in the Spring River Basin as well. Currently, *C. aberti* is listed in Missouri as rare (Anonymous, 1994).

A taxonomic note of *Cyprogenia aberti* is worth mentioning here regarding conchological differences between *C. aberti* from the Arkansas River system (Verdigris, Fall, and Spring rivers) and those from the White River system (personal observations). Call (1885a) described specimens from Kansas as *Unio popenoi,* based on comparisons between Kansas (Neosho and Verdigris rivers) and Arkansas (St. Francis and Saline rivers) specimens. However, Call later disregarded *U. popenoi* since the type specimen for *C. aberti* was collected in the Verdigris River (Scammon, 1906). Specimens that I have examined from the Spring River in Arkansas (Black River Basin) appear to be an intermediate form between *C. aberti* and *C. stegaria* (Rafinesque, 1820), based on specimens from the Clinch River (*C. stegaria;* OSUM) and Arkansas River system specimens (*C. aberti*) (also *cf.* Johnson, 1980).

Oesch (1984) reported that *Quadrula cylindrica* is restricted in Missouri to the Black, St. Francis, and Spring rivers. However, it also occurred historically in Center Creek (Utterback, 1915) as well as Shoal Creek. In Kansas, Obermeyer *et al.* (1996) stated that *Q. cylindrica*'s continued persistence in the state is questionable, with extant representatives limited to a few locales in the Spring and Neosho rivers (Cope, 1985; Obermeyer *et al.*, 1996). Its current distribution contrasts greatly with its past presence in the Neosho, Cottonwood, Spring, Verdigris, and Fall rivers as well as Shoal Creek (Popenoe, 1885; Call, 1885b; 1885d; Scammon, 1906; Isely, 1925; Obermeyer *et al.*, 1996). Clarke and Obermeyer (1996) remarked that the species has exhibited a similar trend of decline throughout most of its range in eastern North America. *Quadrula cylindrica* is presently state-listed as endangered in both Kansas and Missouri.

Oesch (1984) described *Alasmidonta marginata* as widely distributed in the southern-half of Missouri, but noted that it is uncommon at any one locale. *Alasmidonta marginata* was first documented in Kansas by Branson (1966a), who found three live specimens in the Spring River in 1964. Although additional specimens have since been collected in the Spring River (Obermeyer *et al.*, 1995), the only other stream record for *A.*

marginata in Kansas is from the Marais des Cygnes River, Franklin County, which is based on a recently dead specimen collected in 1983 (Distler and Bleam, 1987). The recovery of only one live *A. marginata* and the rarity of fresh shell material collected in the present study raises concern for the species since earlier surveyors (Branson, 1967; Cope, 1985) found the species in Kansas more frequently and at more sites.

Young recruits of these candidate species as well as other mussels were noticeably lacking at most sites. Although individuals less than 20 mm in length are difficult to locate regardless of sampling technique (Neves and Widlak, 1987), I noted a rarity of young mussels from most of my substrate sieve samples from habitats often utilized by juveniles (Isely, 1911; Clarke, 1986; Neves and Widlak, 1987).

Because of low recruitment in the study area, future investigations of reproductive biology of these species, such as fish hosts and host availability, is important. Fortunately, the breeding biology of all of these species has been explored to varying degrees, although knowledge regarding potential host fishes is not complete. In fact, no one has yet identified a potential host for *Cyprogenia aberti*, although glochidial cysts were noted on goldfish (*Carassius auratus*) for up to 5 hours following their ingestion of *C. aberti* conglutinates (Chamberlain, 1934); subsequent examinations of glochidial cysts were not made to determine host suitability. Gravid females of *C. aberti* have been found with all stages of embryological development throughout the year (Call, 1887b); however, Chamberlain (1934) observed that the species released conglutinates in late winter, apparently in response to warmer water temperatures.

The reproductive biology of *Quadrula cylindrica* is based mostly on Tennessee populations of *Q. c. strigillata,* except for a brief breeding record by Utterback

(1915:149). Yeager and Neves (1986) found *Q. c. strigillata* to be tachytictic, with the bigeye chub (*Notropis amblops*), spotfin shiner (*Cyprinella spiloptera*), and whitetail shiner (*C. galactura*) potential hosts based on artificial infestations. Although *Q. c. cylindrica* and *Q. c. strigillata* may represent phenotypic plasticity of the same species (Gordon and Layzer, 1989; Clarke and Obermeyer, 1996), it is possible that host specificity varies between eastern populations, especially of *Q. c. strigillata*, and those in Kansas and Missouri. Further evidence of host differences is suspected because in the Neosho River, where small populations of this species remain, suitable hosts identified by Yeager and Neves (1986) are believed absent (Cross, 1967; F.B. Cross, University of Kansas, personal communication).

Two potential hosts have been identified for *Lampsilis rafinesqueana*: smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*M. salmoides*) (Barnhart *et al.*, 1996); M.C. Barnhart (Southwest Missouri State University, personal communication) suspects that spotted bass (*M. punctulatus*) would also serve as a host, although this species has not been tested. *Lampsilis rafinesqueana* is a bradytictic breeder (Barnhart *et al.*, 1996), and females, like other Lampsilines, attract potential hosts with a mantle lure (Johnson, 1980; Oesch, 1984; Barnhart *et al.*, 1996), with July and August being the period of most frequent mantle display (personal observations).

Ptychobranchus occidentalis is a bradytictic breeder (Johnson, 1980; Barnhart *et al.*, 1996) that releases mimetic larval packets from pleated marsupial gills in early spring (Barnhart *et al.*, 1996). The greenside, Yoke, and rainbow darters (*Etheostoma blennioides, E. juliae*, and *E. caeruleum*, respectively) are identified thus far as potential hosts (Barnhart *et al.*, 1996). Of these three species, only the greenside darter is found in the study area (*i.e.*, Spring River Basin) (Pflieger, 1975; Cross and Collins, 1995). However, M.C. Barnhart (personal communication) speculates that other darters, such as the orangethroat darter (*E. spectabile*), would also serve as suitable hosts for *P. occidentalis*.

Five potential hosts have been identified for *Alasmidonta marginata* (Howard and Anson, 1923), which is a bradytictic breeder (Ortmann, 1919; Oesch, 1984). These hosts are the northern hog sucker (*Hypentelium nigricans*), rock bass (*Ambloplites rupestris*), shorthead redhorse (*Moxostoma macrolepidotum*), warmouth (*Lepomis gulosus*), and white sucker (*Catastomus commersoni*), all of which occur in the Spring River Basin.

CONCLUSIONS

Clarke and Obermeyer (1996) recommended federal listing status for four of the five species targeted in this study; that is, all except *Alasmidonta marginata*, which is a peripheral species in the study area and is widely distributed throughout much of eastern North America (Clarke, 1981). Clarke and Obermeyer (1996) stressed the need for habitat conservation as the key element for future protection of these species, and regarded the preservation of the Spring River to be a top priority because of its diverse mussel assemblage. Furthermore, they considered the Spring River a possible refuge from the impending threat of *Dreissena polymorpha* (Pallas, 1771) (French, 1990; Ludyanskiy *et al.*, 1993) because of the rarity of headwater impoundments, which can function as upstream sources for *Dreissena* veligers (McMahon, 1991). They also regarded the Spring River an important refuge because of its tolerance of droughts due to generous spring-fed flows. In Kansas, I believe that the Verdigris and Fall rivers should also be given special protection. Despite over a century of abuse (Obermeyer *et al.*, 1996), these two streams still maintain diverse mussel assemblages in limited stretches in Kansas. However, on a larger scale, the Verdigris River Basin has experienced severe reductions to its mussel fauna, especially in Oklahoma due to dams (Mather, 1990). Thus, protection of remnant mussel populations of these two streams offers the only chance of preserving the Verdigris River system's unique genetic variability for several rare species. The speciose stretch of the Neosho described in Obermeyer *et al.* (1995) also warrants special protective measures, such as restricting commercial mussel harvesting as proposed by Obermeyer (1995).

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Chapter 2

RANGE REDUCTIONS OF FRESHWATER MUSSELS (BIVALVIA, UNIONIDAE) IN SOUTHEAST KANSAS: AN ASSESSMENT OF HISTORICAL CHANGE

Abstract. During summers 1994 and 1995, freshwater mussel assemblages were examined at 75 sites in the Neosho and Verdigris basins of southeast Kansas, with an emphasis to locate five mussel species being considered for federal listing (Species of Concern): Neosho mucket (*Lampsilis rafinesqueana*), Ouachita kidneyshell (*Ptychobranchus occidentalis*), western fanshell (*Cyprogenia aberti*), elktoe (*Alasmidonta marginata*), and the rabbitsfoot (*Quadrula cylindrica*). Approximately 13,000 mussels of 32 species were caught from qualitative (timed snorkel and SCUBA searches) and quantitative (1-m^2 quadrats) sampling. Comparisons of present distributions with weathered shell material and historical records dating to 1885 indicate substantial range reductions. For example, *Lampsilis rafinesqueana* occurred in at least nine Kansas streams historically but I found it in only four; *Ptychobranchus occidentalis*' range appears to have shrunk from 10 to three streams, *Cyprogenia aberti*'s from four to three, and *Quadrula cylindrica*'s from five to two. Furthermore, *Ligumia recta* has apparently become extirpated from the entire study area. The cumulative effect of stream degradation is suggested as the most widespread contributor of mussel declines in southeast Kansas. However, other factors, such as dams, channel alterations, over-harvesting, and episodic stochastic events, are also linked to this decline.

Introduction

Assessing historic change in freshwater mussel assemblages is often difficult because historic records were often based on non-quantifiable sampling methods. Moreover, many streams for which there are records have large temporal and spatial gaps in the data. In Kansas, assessment of the abundance of unionid populations occurring in the past century is hindered because most past surveyors (e.g. Popenoe, 1885; Call, 1885a, 1885b, 1885c, 1885d, 1886, 1887; Scammon, 1906) did not provide relative or rank abundances of species and often gave ambiguous locality descriptions. Prior to more recent work (e.g. Cope, 1983, 1985; Miller, 1993; Obermeyer et al., 1995), only Isely (1925) provided relative abundances for several species; but he sampled only two sites in Kansas. Moreover, minimal field work was conducted in Kansas between Isely's (1925) survey in 1912 and Murray and Leonard's (1962) work in the 1950s. However, weathered valves can provide some insight of the presence and relative abundances of historic mussel populations, especially in Kansas' limestone-buffered waters, and can be used to compare with extant assemblages.

I assessed unionid faunal change in the Neosho and Verdigris river basins of southeast Kansas by using weathered shell remains to supplement sparse literature and museum records. By comparing shell evidence of past mussel populations to this study's collection of live unionids, I found that range reductions had occurred in Kansas.

The study area

Kansas is located on the western edge of North America's rich diversity of freshwater mussels. The state's highest concentration of unionids is generally confined to streams in its eastern third; only eight of the 45 species of mussels for which there are historic records in Kansas occur in the western two-thirds of the state (Murray and Leonard, 1962). The southeastern third of the state, especially the Verdigris and Neosho river basins, contain the highest diversity of unionids—37 species. Important mussel streams within these two basins include the Fall, Elk, Verdigris, and Caney rivers (Verdigris Basin) and the Neosho, Cottonwood, and Spring rivers (Neosho Basin). Today there are six unionid species state-listed as endangered, four as threatened, and 12 as species in need of conservation (SINC); five of these species are federally listed as species of concern (formerly Category 2 federal candidates). In addition, four species are considered extirpated from the state, one from my study area.

The Neosho and Verdigris river basins are located in the tallgrass prairie ecoregion, formerly an extensive grassland dominated by warm season grasses with riparian forests bordering most streams. Today much of this upland prairie remains in the western half of the study area, especially in the headwaters of the Neosho River and much of the Verdigris Basin; however, many of these grasslands are degraded from intensive cattle grazing, and little remains of the bottomland prairies and riparian forests due to extensive cultivation. Upland heavy-clay soils are generally shallow with limestone and chert outcroppings of Permian and Pennsylvanian origins preventing cultivation in many areas, whereas alluvial soils predominate in the flood plain. Spring River and Shoal Creek differ in that they are derived from the Ozark Plateau and are characterized by much lower turbidities and richer aquatic faunas (Cross and Collins, 1995).

Streams in these basins have been affected by anthropogenic activities. For example, the Neosho River has lost much of its watershed grasslands except in headwater reaches and has been polluted by effluents from oilfields, feedlots, and cropland, which contrasts with Isely's (1925) description of this river in 1912 as "... a splendid clear water stream ..." It has been further modified by 15 city dams, numerous flood control impoundments, and two federal flood-control lakes: Council Grove Lake and John Redmond Reservoir. Not only have unionids been affected, with the inferred loss of three species, but these changes are also linked to a deterioration of the Neosho River fish fauna, with the presumed extirpation of the bigeye chub (*Notropis amblops*), spotfin shiner (*Cyprinella spiloptera*), northern hogsucker (*Hypentelium nigricans*), banded sculpin (*Cottus carolinae*), American eel (*Anguilla rostrata*), and chestnut lamprey (*Ichthyomyzon castaneus*) (Cross, 1967; Cross and Braasch, 1968; F.B. Cross, University of Kansas, personal communication).

Materials and methods

I surveyed 75 sites in 13 streams in the Neosho and Verdigris basins of southeast Kansas during summers 1994 and 1995, with an emphasis to document the current distribution of four unionid species: *Lampsilis rafinesqueana, Ptychobranchus occidentalis*, *Cyprogenia aberti*, and *Quadrula cylindrica*. Site selection was based on past occurrence of these four species, or sites (e.g. Cope 1979, 1983, 1985) with habitats described as suitable for them (e.g. Murray and Leonard, 1962; Oesch, 1984; Mather, 1990). Sampling stations were located on the Caney, Cottonwood, South Fork of the Cottonwood, Neosho, Verdigris, Spring, Fall, and Elk rivers, and Cow, Doyle, Labette, Otter, and Shoal creeks (Fig. 1). However, for statistical analyses, I concentrated on sites in the Neosho, Cottonwood, Spring, Verdigris, Fall, and Elk. In each of these streams, the number of extant species (live specimens and fresh valves) was tallied versus the number of species represented by weathered shells (worn and relic), and a paired *t*-test (one-tailed) was used to assess differences in species richness.

Sampling consisted of snorkel searches in shallow water (15 cm to < 1 m), whereas at depths exceeding one meter SCUBA was used. Mussels were located both by visual and tactile cues (groping). Visual searches in shallow water (< 15 cm) were also employed. All searches were timed to quantify sampling effort, which ranged from 40 minutes to nine hours. I also quantitatively sampled 505 1-m^2 quadrats at 16 sites in the Neosho, Spring, Verdigris, and Fall rivers; quadrats were placed along measured coordinates chosen randomly. Substrate was excavated in each quadrat to a depth of 10-15 cm and identified and recorded the size of all unionids found within or under the quadrat frame.

To locate small or burrowed mussels, substrate was dredged with a shovel, transferred to a floating sieve (6 mm galvanized mesh screen supported by a 1-m^2 x 15 cm diameter PVC pipe frame), and sieved. The number of sieve samples varied between 0 and 21, depending on size and quality of the site, and time or weather constraints.

In addition to collecting live mussels, I searched exposed gravel bars and banks of streams for dead shell material with identifiable features. These searches were not timed, but, rather, dead shell sampling adequacy was based on a thorough examination of areas

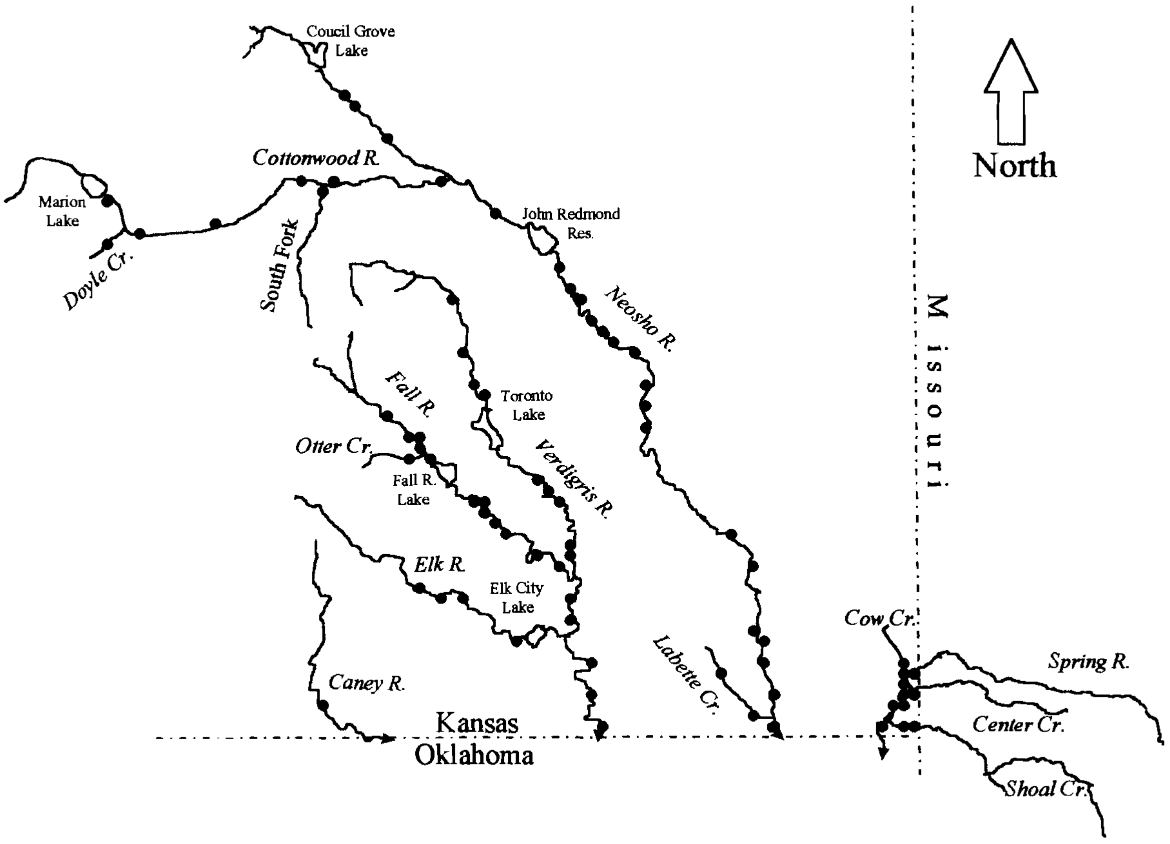

Figure 1. Map of study area in southeast Kansas.

with shell deposits (e.g. gravel bars, bank deposits). The presence of each species was noted and placed into three categories: fresh, worn, and relic. A shell classified as fresh had a bright, unfaded nacre and retained much of its periostracum, with the exception of normal umbonal erosion. A worn shell exhibited considerable erosion of the periostracum and a faded, often chalky nacre. Relic shells were highly weathered without any remains of the periostracum, and ranged from whole valves to identifiable fragments.

A representative collection of valves is held at the Ohio State University Museum of Zoology in Columbus, Ohio. A more extensive collection will be deposited at the Kansas Biological Survey, Lawrence, Kansas. Except for a few specimens collected for reference, live unionids were identified in the field and returned to their original location. Unionid nomenclature follows Turgeon et al. (1988); however, subspecies are not recognized in this paper.

Results

From the 13 streams sampled in this study, I caught 12,826 mussels of 32 species (Table 1), including 904 *L. rafinesqueana*, 64 *P. occidentalis*, 27 *C. aberti*, and three *Q. cylindrica*. Evidence of recruitment for most species was noticeably lacking from many sites, with only four sites revealing recent recruits of candidate species (< 5 yrs old): Neosho River (1), Spring River (1), and Verdigris River (2).

In the Neosho River, I sampled 21 sites and caught 5773 mussels of 24 species (Table 1). I found a significant difference ($p < 0.001$) in the mean number of extant species ($\bar{x} = 16.5$, SD = 3.45) compared to the mean number of species represented by

Table 1. Tally of unionids collected in 1993-95 from the Neosho and Verdigris River basins in southeast Kansas, and the contribution of each stream.

			Neosho Basin								Verdigris Basin				
			Neosho River	Cottonwd. River	S. Fork Cotton. R.	Doyle Creek	Labette Creek	Spring River	Cow Creek	Shoal Creek	Verdigris River	Fall River	Elk River	Otter Creek	Caney River
Species	**Totals**	No. sites:	23	6	1	1	2	7	1	2	14	12	4	1	1
Alasmidonta marginata	**1**		-	-	-	-	-	1	-	-	-	-	-	-	-
Amblema plicata	**2603**		1274	d	wd	d	91	32	-	Lr	688	461	57	d	d
Cyprogenia aberti	**27**		Lr	-	-	-	-	11	-	-	11	5	wd	-	Lr
Ellipsaria lineolata	**87**		80	-	-	-	-	Lr	-	-	7	Lr	-	-	-
Elliptio dilatata	**215**		179	d	wd	wd	-	36	-	-	Lr	-	-	-	-
Fusconaia flava	**960**		334	1	wd	wd	12	126	-	Lr	219	217	51	wd	d
Lampsilis cardium	**385**		103	d	d	-	-	32	wd	2	106	128	14	d	d
Lampsilis rafinesqueana	**904**		32	wd	Lr	-	-	833	-	Lr	5	34	wd	-	wd
Lampsilis siliquoidea	**6**		Lr	-	-	-	-	5	d	Lr	wd	d	wd	wd	1
Lampsilis teres	**64**		16	d	wd	wd	5	1	-	Lr	16	20	6	wd	wd
Lasmigona complanata	**148**		14	d	d	d	16	3	-	-	78	29	8	d	d
Lasmigona costata	**15**		3	wd	wd	-	-	12	-	-	wd	wd	wd	Lr	Lr
Leptodea fragilis	**173**		113	6	d	1	3	Lr	-	-	24	23	3	d	d
Ligumia recta	**wd**		wd	wd	wd	-	-	wd	-	Lr	wd	wd	wd	wd	Lr
Ligumia subrostrata	**7**		d	d	wd	d	2	1	-	wd	wd	4	d	d	d
Megalonaias nervosa	**209**		198	-	-	-	-	-	-	-	8	3	-	-	-
Obliquaria reflexa	**490**		292	d	-	-	9	wd	-	-	133	47	9	-	-
Pleurobema coccineum	**173**		30	wd	-	-	-	94	-	wd	40	9	wd	wd	-
Potamilus ohiensis	**5**		3	d	-	-	-	-	-	-	2	-	d	-	d
Potamilus purpuratus	**183**		103	d	1	-	6	1	-	-	29	23	20	d	d
Ptychobranchus occidentalis	**64**		wd	wd	wd	-	-	34	-	-	11	19	wd	wd	wd
Pyganodon grandis	**12**		2	d	-	d	1	1	1	-	d	7	d	wd	d
Quadrula cylindrica	**3**		2	wd	-	-	-	1	-	-	wd	wd	-	-	-
Quadrula metanevra	**2741**		1786	wd	-	-	-	9	-	-	658	288	d	-	-
Quadrula nodulata	**42**		12	Lr	wd	-	-	Lr	-	-	24	6	-	-	-
Quadrula pustulosa	**1686**		537	5	d	d	30	162	1	-	388	485	78	d	d
Quadrula quadrula	**633**		274	18	1	d	53	42	2	-	130	84	29	d	d
Strophitus undulatus	**88**		7	d	d	d	-	11	-	-	35	24	11	wd	d
Toxolasma parvus	**3**		Lr	-	-	-	-	-	-	Lr	1	1	-	-	1
Tritogonia verrucosa	**822**		354	29	d	-	16	36	2	-	160	189	35	1	d

Table 1 continued

			Neosho Basin								Verdigris Basin				
			Neosho River	Cottonwd. River	S. Fork Cotton. R.	Doyle Creek	Labette Creek	Spring River	Cow Creek	Shoal Creek	Verdigris River	Fall River	Elk River	Otter Creek	Caney River
Species	**Totals**	No. sites:	23	6	1	1	2	7	1	2	14	12	4	1	1
Truncilla donaciformis	**62**		25	d	d	-	d	-	-	-	8	29	d	-	Lr
Truncilla truncata	**6**		d	wd	-	-	-	Lr	-	-	6	wd	wd	-	d
Uniomerus tetralasmus	**d**		d	-	-	wd	d	-	-	Lr	Lr	-	wd	-	Lr
Utterbackia imbecilis	**d**		Lr	-	-	-	-	-	-	Lr	Lr	d	-	-	d
Venustaconcha pleasi	**9**		-	-	-	-	-	9	-	-	-	-	-	-	-
Totals	**12876**		5773	65	2	2	246	1500	7	4	2801	2147	325	1	3

d = dead (recent), wd = weathered dead, Lr = literature record.

weathered and relic valves ($\bar{x}$ = 20.9, SD = 2.04) (Fig. 2); two sites were excluded from this comparison because of inadequate dead shell searches. The only candidates I caught were 32 *L. rafinesqueana* from seven of 21 sites and two *Q. cylindrica* from two sites; these represent the first live records for *Q. cylindrica* from the Neosho River since Isely's (1925) survey in 1912. I also collected two recently dead articulated specimens (with desiccated softparts) at one of these sites. Only weathered shells of *P. occidentalis* were found in the Neosho River, though they were common at several sites. *Cyprogenia aberti* was not collected, either alive or as a weathered shell.

I sampled seven sites in the Spring River and caught 1493 mussel of 23 species (Table 1). Two additional species were represented only by relic shells: *Ligumia recta* and *Obliquaria reflexa*. The mean number of species represented by weathered valves compared to extant species was not significantly different at five sites upstream from the confluence of Turkey Creek, a polluted stream (extant: $\bar{x}$ = 19.0, SD = 0.82; weathered and relic: $\bar{x}$ = 18.5, SD = 3.11; p = 0.76) (Fig. 2). I collected all four candidates including 34 *P. occidentalis*, one *Q. cylindrica*, 11 *C. aberti*, and 833 *L. rafinesqueana*, which was the most abundant species comprising 55.7% of the total catch (Table 1). In a single m^2 quadrat I found 67 *L. rafinesqueana*. However, the Spring River's rich mussel fauna is limited in Kansas to an approximate 10 km stretch, with the remaining portion decimated by pollution and dams.

In the Cottonwood River, I sampled six sites and found 59 mussels (Table 1). Several species were found only as relic shells, including *L. rafinesqueana, Lasmigona costata, L. recta, Pleurobema coccineum, P. occidentalis, Q. cylindrica*, and *Quadrula*

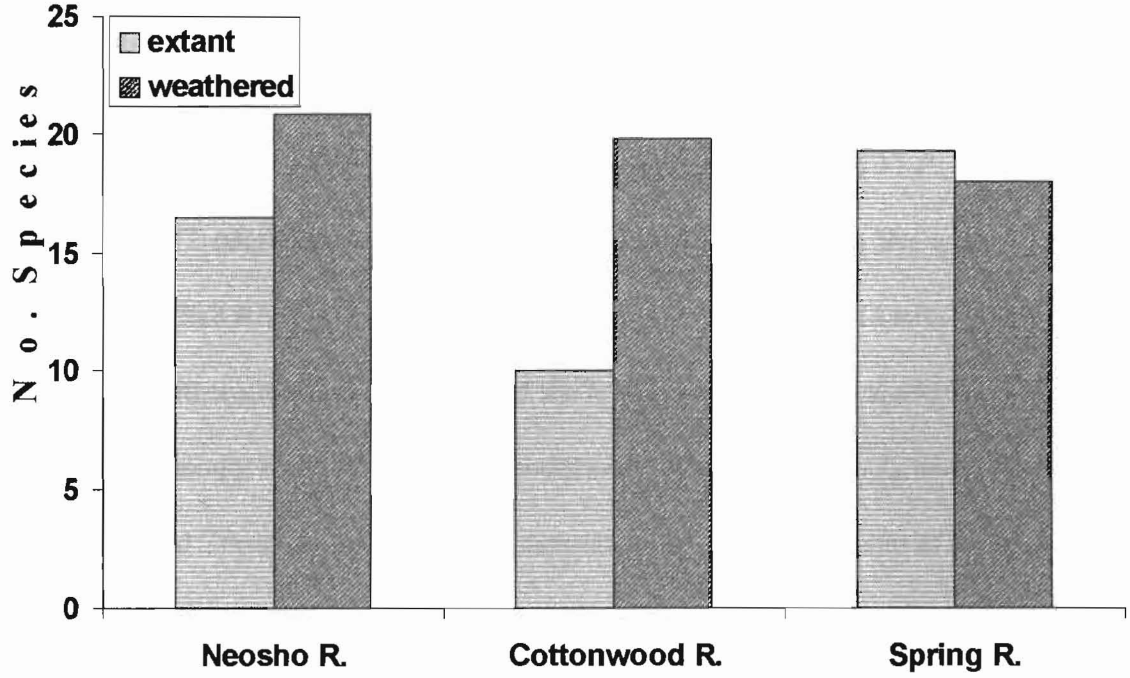

Figure 2. Comparisons of the mean number of species represented by live and recently dead specimens versus species represented by weathered and relic valves in the Neosho, Cottonwood, and Spring rivers in Kansas.

metanevra (Table 1). In addition, species typically common in other streams, such as *Amblema plicata*, often lacked extant representatives, though they were abundant as relics. The difference between the number of extant species ($\bar{x}$ = 10.0, SD = 3.22) and those represented by weathered shells at these sites ($\bar{x}$ = 19.8, SD = 3.66) was significant (p = 0.002) (Fig. 2).

Fourteen Verdigris River sites yielded 2787 mussels representing 24 species (Table 1). Four species were found only as relics: *Lampsilis siliquoidea, L. costata, L. recta*, and *Q. cylindrica*. The mean number of extant species ($\bar{x}$ = 16.8, SD = 3.62) at each site was significantly lower than the mean number of species represented by weathered valves ($\bar{x}$ = 19.1, SD = 3.06; p = 0.006) (Fig. 3). Regarding candidates, I found 11 *P. occidentalis* at four sites, 11 *C. aberti* at five sites, and five live *L. rafinesqueana* at five sites.

In the Fall River, I caught 2135 mussels of 23 species from 12 sites (Table 1). Five species either collected as weathered shells or based on historical records (Call, 1887) were missing extant representatives: *Ellipsaria lineolata, L. costata, L. recta, Q. cylindrica*, and *Truncilla truncata*. The mean number of extant species at these sites ($\bar{x}$ = 15.3, SD = 2.74) was significantly lower than the number represented by weathered valves ($\bar{x}$ = 17.5, SD = 3.78; p = 0.023) (Fig. 3). I collected living specimens of three candidate species: five *C. aberti*, 34 *L. rafinesqueana*, and 19 *P. occidentalis*. All were found downstream from Fall River Lake to its confluence with the Verdigris River, though weathered shells were found upstream from Fall River Lake.

I sampled four sites in the Elk River and caught 321 mussels of 17 species (Table1), plus I found evidence of nine additional species, including relic valves of *L.*

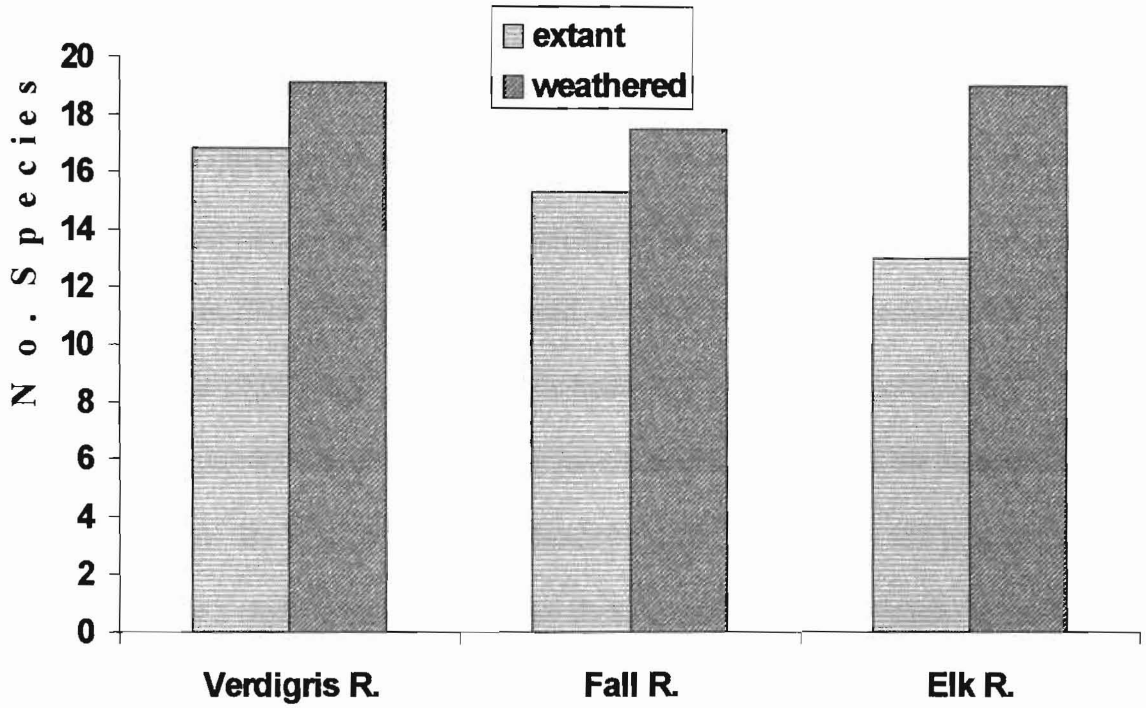

Figure 3. Comparisons of the mean number of species represented by live and recently dead specimens versus species represented by weathered and relic valves in the Verdigris, Fall , and Elk rivers in Kansas.

rafinesqueana, P. occidentalis, L. costata, and *C. aberti* (the first record of *C. aberti* for this stream). The mean number of extant species was significantly lower than that of weathered and relic species (extant: $\bar{x} = 13.0$, SD = 0.82; weathered and relic: $\bar{x} = 19.0$, SD = 0.50; $p = 0.029$) (Fig. 3).

Discussion

Evidence of the decline

Historic data of mussel densities in Kansas are not available prior to Cope's (1983) work; however, early harvest records suggest rich mussel beds in Kansas streams. For example, over 17,000 tons of shells were reportedly collected from the Neosho River through 1911 and 1912, representing about 17% of the nation's contribution to the pearl button industry in 1912 (Murray and Leonard, 1962). Coker (1919) estimated that a ton equaled 5,000 to 10,000 mussels from virgin beds—30,000 from depleted beds. Consequently, over 85 million mussels may have been harvested from the Neosho River in just this one year. By 1918, a shell blank factory in Iola, Kansas, was still processing up to 30 tons of shells a week, with many of these shells coming from the Neosho River near Leroy, Kansas (Iola Register, 6 April 1918). Isely (1925) in 1912 found densities as high as 383 mussels from a 100^2-foot sample (41.2 per m^2) in the Verdigris River in Oklahoma. His findings contrast with Miller's (1993) Verdigris River mean of 3.1 per m^2 and my mean in the Neosho River of only 2.3 unionids per m^2.

Although the four targeted candidate species were collected in my study area, their ranges have declined precipitously. For example, *P. occidentalis* was found in only three of its historic distribution of 10 streams, with extant representatives missing from numerous sites in these three streams. I found only 27 *C. aberti* from three of five streams with historical evidence of past populations, supporting Cope's (1979) assertion that this species is extremely rare in Kansas. Moreover, its distribution in these streams was patchy.

Extant representatives of *L. rafinesqueana* were found in only four of its nine historic Kansas streams. I caught 32 *L. rafinesqueana* from 21 sites in the Neosho River, whereas Isely (1925) in 1912 collected the same number from a single site. Evidence of extant populations of *L. rafinesqueana* was found at only seven of my 21 Neosho River sites, and most of my specimens were caught at only three sites located downstream from John Redmond Reservoir.

Live *Q. cylindrica* collected in this study reflect a species with a disjunct distribution, though weathered valves at many of my sites revealed a wider historical distribution in Kansas. Relic shells were also found in the Missouri portion of Shoal Creek (personal observation), suggesting its historical presence in this stream in Kansas as well. Isely (1925) collected a live *Q. cylindrica* from the Verdigris River in 1912, but I found only relic valves at eight of my 14 Verdigris River sites. I found three relic valves of *Q. cylindrica* in Fall River and one valve in the Cottonwood River, both of which are new stream records for this species. Schuster (1979) considered *Q. cylindrica* extirpated from the Verdigris River. I concur, and hypothesize that it is also extirpated from Shoal Creek and the Fall and Cottonwood rivers, as well as much of the Neosho River.

Not only were some species absent from streams, but certain stretches seemed more conducive to extirpations. For example, *P. coccineum, Q. cylindrica, Q. metanevra, P. occidentalis, L. costata, C. aberti*, and *L. rafinesqueana* were not represented by extant specimens upstream from federal impoundments in the Neosho, Verdigris, and Fall rivers; only weathered shells were found. Conversely, evidence of extant populations of *T. truncata* was found only upstream from impoundments in the Neosho and Verdigris rivers, and only weathered valves were found downstream. *Ligumia recta* was absent as an extant species from the entire study area, although weathered valves were commonly found, supporting Scammon's (1906) assessment of the species at the turn of the century as being common in southeast Kansas.

Evidence of recent reproductive success of most unionids was noticeably absent at most sites. Neves and Widlak (1987) suggested that past failures to locate juveniles < 20 mm length were probably due to inefficient or inadequate sampling. Although I may have overlooked mussels less than two months of age because of their transparent shell and small size (Neves and Widlak, 1987), my sieving of substrate from habitats known to be utilized by juveniles (Isely, 1911; Clarke, 1986; Neves and Widlak, 1987) should have yielded small mussels if they were present.

Causes for the decline

I believe the most widespread contributor of mussel declines in the study area has been the cumulative effect of stream deterioration, though certainly most streams have also been plagued by episodic stochastic events such as drought. Perhaps the broadest deleterious factor has been the influx of sediment and organic materials, primarily from agrarian activities. The presumed extirpation of *L. recta* from streams in low populated and non-industrial areas supports this conclusion.

Elevated levels of suspended solids can reduce the rate at which mussels take up oxygen and excrete nitrogen (Aldridge et al., 1987), possibly reducing the survival of brooded glochidia (Ellis, 1931) or resulting in aborted glochidia. Ellis (1936) demonstrated experimentally that covering mussels with 0.25 mm of silt interfered with respiration and feeding. Imlay (1972) similarly found that covering mussels with detritus, sand, and even grit increased mortality. Turbidity from suspended solids also lowers the productivity of unionid food organisms (Fuller, 1974), and may interfere with visually-oriented reproductive adaptations, such as mantle flaps, placentae, and conglutinates.

Excessive silt deposition can also degrade habitats. Although large, turbid rivers often support diverse mussel beds in deep habitats, Kansas streams lack an adequate current velocity in deep habitats during low flows to prevent settling of suspended silt and clay particles (note: sedimentation increases logarithmically with decreased streamflow, Platts et al., 1983). Because deep habitats in Kansas could serve as refugia during droughts, degradation of these habitats has likely resulted in greater vulnerability to mussel populations during recent droughts. Therefore, an assertion that droughts were responsible for many of the extirpations in Kansas, for example, *P. occidentalis* in the Caney River (Metcalf, 1980), may be only partly correct.

The influx of sediments and nutrients may also eliminate potential juvenile nursery areas. Several papers (e.g., Clarke, 1986; Neves and Widlak, 1987; Amyot and Downing, 1991; Sparks; in press) provide evidence that juvenile mussels can live buried within substrate interstices. However, Clarke (1986) stated that it is doubtful that mud would permit adequate circulation for a hypobenthic existence. Similarly, the influx of organic nutrients, which are linked to high coliform bacterial counts and associated dissolved oxygen deficits in Kansas streams (Kansas Department of Health and Environment, 1994), may be particularly detrimental to juvenile mussels if anoxic conditions occur within the substrate. Sparks (in press) noted stress responses (gaped valves, extended siphons, and surfacing) in juveniles of *Elliptio complanata* when subjected to dissolved oxygen levels less than 2 mg l^{-1}, and found a significant increase in mortality when juveniles were held at this DO concentration for one week. Therefore, eutrophication in Kansas streams, along with a corresponding increase in BOD, may limit recruitment.

A more recent anthropogenic factor likely detrimental to Kansas unionids is impoundments, particularly large reservoirs. Dams are not only barriers to host fishes, but the impounded stream channels are transformed from lotic to lentic environments, altering assemblages of fishes and unionids (Stansbery, 1970; 1973; Fuller, 1974; Williams et al., 1993; Layzer and Madison, 1995). Although impoundments trap sediments and may reduce downstream turbidity and siltation, Donnelly (1993) stated, " A river deficient in sediment can be expected to be erosive and to degrade its bed accordingly." Regulated releases from impoundments usually prevent flood waters from entering the downstream flood plain (high-flow channel). During potential flooding, discharge from reservoirs is often maintained at half- to full-channel capacity for extended periods. The energy of this discharge is therefore confined to the channel, rather than being distributed over the flood plain. Trimble (1983) stated that a flood plain acts as a sediment sink in most stream basins, with greater sediment uptake and transport within the stream channel, especially if banks are unvegetated and saturated. Therefore, confinement of flood waters within the channel for extended periods, combined with sediment-deficient releases, may accelerate streambank erosion. My observations of the Neosho River downstream from John

Redmond dam supports this hypothesis, and matches much of Hartfield's (1993) characterization of headcuts, with extensive bank scouring and the virtual absence of perennial streambank vegetation. Stable mussel beds in this sinuous river were most often found adjacent to rock outcroppings; unstable sites were generally low in unionid species richness and abundance. In fact, I accurately predicted the occurrence of several mussel beds in the Neosho River based solely on 7.5 minute 1:24,000 scale USGS topographical maps, which indicated areas where the Neosho River abutted higher terrain with possible stabilizing outcrops.

Other factors, such as pollution, channelization, gravel dredging, and mussel harvesting may also contribute to mussel declines (Fuller, 1974). Pesticides and high fecal coliform counts in the Verdigris River downstream from Independence (Kansas Department of Health and Environment, 1994) may have been responsible for an observed decrease in unionid species richness and abundance. Feedlots may have caused the loss of mussel species in the Cottonwood River; numerous fish kills attributed to feedlot runoff in this stream were well documented in the 1960s (Cross and Braasch, 1968; Prophet, 1969; Prophet and Edwards, 1973). One landowner (personal communication) recalled the death of many mussels and fishes at one of my Neosho River sites, which coincided with feedlot-related fish kills in that stream. Oil and saltwater spills from oilfields have also historically plagued eastern Kansas streams with devastating results, especially in the Cottonwood River (Doze, 1926). Contamination by heavy metals from mine tailings can cause the virtual elimination of mussel populations (Fuller, 1974), which has probably contributed to the rarity of mussels in a large portion of the Spring River in Kansas. Mussel harvesting may have shifted once common species from core to satellite status

(Hanski, 1982), thus making them more vulnerable to extirpation. Perhaps this was a contributing factor to the decline of *L. rafinesqueana* in Kansas since, according to a mussel harvester active in the 1920s (A.A. Frishenmeyer, Chanute, Kansas, personal communication), the "mucket" was one of the most sought after species by the pearl button industry in Kansas. Coker (1919:28) confirmed its harvest in Kansas, relating Mr. Boepple's comment (founder of the pearly button industry) that the mucket of the Cottonwood River in Kansas reached the quality of marine shells.

Because stream conditions have apparently become less suitable for reproductive success and juvenile survival for some Kansas unionid species, density declines may further accelerate extirpations (Downing et al., 1993; Strayer et al., in press). A possible analogy for the current unionid situation is the collapse of the Pacific sardine (*Sardinops caerulea*) fishery. Each female sardine produces from 100,000 to 200,000 eggs, but less than 0.1% survive in normal years (Moyle and Cech, 1988). With large population densities, the Pacific sardine's population remained stable, even when conditions for recruitment were poor, due to its massive reproductive effort along with little intraspecific competition. However, when their population density became low due to over-fishing, the Pacific sardine was unable to rebound to historical densities and was especially vulnerable to continued exploitation and to poor recruitment conditions (Moyle and Cech, 1988). Hence, in organisms with little trophic competition, which appears to be the case in freshwater mussels (Strayer, 1981), high densities probably increase reproductive success (Downing et al., 1993) and act as a buffer during poor recruitment years.

Murray and Leonard (1962) warned that unless immediate measures were taken to curb siltation and industrial pollution, Kansas unionids faced continued extirpations. Since that warning, at least one species they considered extant, *L. recta*, is now believed extirpated from Kansas. Considering the range reduction of several Kansas species, this survey suggests that several unionids are at risk of following *L. recta*'s fate. As populations become more isolated, local extinctions may accelerate, even in pristine habitats, due to the lack of recolonization from other populations (Sjogren, 1991; Vaughn, 1993). Consequently, merely protecting remaining habitats and populations of a severely isolated species like *Q. cylindrica* may not curb their continued trend towards extirpation. To prevent other unionid species from becoming isolated, it is important to minimize stream fragmentation and identify and protect remaining populations and critical habitats. However, it is important to realize that reestablishment of depleted beds is a long-term process, even for common species in ideal habitat, and may require decades for recovery (Neves, 1993).

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Chapter 3

AN EVALUATION OF THE NEOSHO RIVER, KANSAS, MUSSEL REFUGE

ABSTRACT

This study was conducted to evaluate the Neosho River, Kansas, mussel refuge located from the Neosho Falls dam, Woodson County, downstream 6.1 km to the confluence of Rock Creek in Allen County. Eight study sites were selected, four within and four outside refuge boundaries (two upstream and two downstream). Sites were sampled quantitatively during summer 1994. At each site, forty 1-m^2 quadrats were chosen randomly and sampled within a 10 x 100 m area of selected riffle habitat. A total of 744 mussels comprising 20 species was caught, including 11 species on the state list of threatened and endangered species. Three harvestable species targeted in this study, *Amblema plicata*, *Quadrula metanevra*, and *Quadrula quadrula* failed to show significant differences in the percentage of legal-sized specimens between refuge and non-refuge sites. Moreover, unionid densities and species richness were generally lower at refuge sites. However, mean shell lengths of *Q. metanevra*, *Obliquaria reflexa*, and *Tritogonia verrucosa* were significantly greater at refuge than at non-refuge sites; the latter two species were legally harvestable through 1991. Explanations offered for the few significant differences between refuge and non-refuge sites include habitat dissimilarity, varying rates of recruitment among sites, light harvest pressure, and/or illegal harvesting at selected non-refuge sites.

INTRODUCTION

Presently, four commercial mussel species are legally harvestable in Kansas: *Amblema plicata*, *Potamilus purpuratus*, *Quadrula metanevra*, and *Quadrula quadrula*. Areas open to commercial harvest in Kansas include the Neosho, Verdigris, Fall, and Elk rivers. In the Neosho River, harvest is allowed downstream from John Redmond Reservoir, Coffey County, to the Oklahoma border, with the exception of a mussel refugium, which is located from the Neosho Falls dam, Woodson County, downstream 6.1 km to the mouth of Rock Creek in the NW¼ NW¼ Section 11, T24S, R17E, Allen County.

Three mussel refugia were established in Kansas in 1984 following the recommendation of Cope (1983) to set aside stretches of the Neosho, Verdigris, and Fall rivers as a first step in establishing state-management strategies for unionids. These refugia were selected based on historical locations of harvestable mussel beds, suitability as potential recruitment areas, and proximity to other beds (C.H. Cope, KDWP, personal communication).

Miller (1993) first assessed the state's refuge system by examining Verdigris River mussel communities within refuge sites versus sites located outside refuge boundaries. He found a significantly higher ratio of legal-sized *A. plicata* and *Q. metanevra* at refuge sites, as well as significantly more *A. plicata* at refuge sites.

The present study was designed similarly to Miller's (1993) survey to compare unionid size distributions and relative abundance at sites within and outside the Neosho River mussel refuge. Four sites were located within refuge boundaries and four were located outside. I quantitatively examined each site using 40 1-m^2 quadrats, targeting three unionid species presently harvestable: *A. plicata*, *Q. metanevra*, and *Q. quadrula*.

BACKGROUND

The Neosho River originates in Morris County and transects eight Kansas counties before it exits the state from Cherokee County. This prairie stream is approximately 775 km long; about 510 km of the Neosho occurs in Kansas and drains approximately 15,000 km^2. Thirty-five species of unionid mussels have been documented from the Neosho River in Kansas, three of which are now presumed extirpated (Obermeyer et al., 1995).

The Neosho River has experienced many anthropogenic alterations that have likely affected its mussel fauna, including nutrient and silt loading from agrarian practices; toxins from urban, agricultural, and industrial effluence; gravel mining; damming by 15 city dams and two federal reservoirs; and commercial shell-fishing. Historically, the Neosho River was the most important source for pearly products in the state. Over 17,000 tons of shells collected along the Neosho River in Kansas and Oklahoma were shipped from Kansas during 1912, representing approximately 17% of the nation's total pearly products (Coker, 1919; Murray and Leonard, 1962). Coker (1919) estimated that a ton of shells taken from virgin beds equaled 5,000 to 10,000 live mussels. Based on this estimate, over 85 million mussels were probably harvested from the Neosho River in just this one year. During 1918, a shell blank factory in Iola processed up to 30 tons of shells a week; most of these shells were collected from the Neosho River near Leroy (Iola Register, 6 April 1918). By 1920, harvest yields had declined with only 500 tons of shells processed at the Iola factory (Iola Register, 2 September 1920).

According to a musseler who was active during the late 1920s (A.A. Frischenmeyer, Chanute, Kansas, personal communication), all mussel species were harvested, either for pearl prospects or button blanks, with the most intensive shell-fishing occurring in shallow riffles. Coker (1919) noted that these shallow, accessible beds were often rapidly depleted. Total historical harvest yields from the Neosho River are difficult to estimate because harvest records do not exist for other shell blank processing factories; factories were also located at Oswego up until at least 1936 (Oswego Historical Society, personal communication), and another factory was located in Iola between 1912 and 1916 (Iola city directories, 1912; 1916). The Iola Button Company discontinued operations sometime in the 1930s or 1940s, perhaps due to depleted beds.

Demand for shells for use in the cultured pearl industry caused shell-fishing to resume in the Neosho River in the mid-1960s, with over 125 Kansas mussel harvest permits sold by KDWP in 1967 (Busby and Horak, 1993). Official harvest statistics were not kept until 1983, although buyers estimated a yield of 300 tons from Kansas in 1970 (Busby and Horak, 1993). Shellers estimated a 10-fold decrease in abundance between the 1960s and 1980s (Cope, 1983), suggesting that earlier harvest yields may have been larger than the 1970 harvest estimate. Harvest statistics for 1994 indicate that about 17 tons of shells were harvested from the Neosho, a dramatic decrease from the reported 230 tons harvested in 1991, especially because both years had similar harvest conditions (i.e., low flow). Although this decline likely indicates diminishing returns due to lower mussel population densities, it may also reflect regulations that narrowed the number of species legally harvestable, fewer licensed musselers (71 vs. 91), and the movement of musselers from streams to federal reservoirs because of high prices for 'lake' mapleleafs, *Q. quadrula.*

In 1978, the state's first attempt at regulating shell-fishing began with a 1.75-inch minimum length limit (Busby and Horak, 1993). Beginning in 1979, listed species (i.e., endangered, threatened, and species in need of conservation (SINC)) were given legal protection under the state's "Nongame and Endangered Species Conservation Act" (KAR 115-15-1 and 115-15-2). In 1981, size regulations were changed from the 1.75-inch length limit to a 3-inch minimum length limit. The number of legally harvestable species was narrowed in 1992 from all non-listed species to the current four: *A. plicata*, *Q. metanevra*, *Q. quadrula*, and *P. purpuratus*. Following the 1991 harvest, size regulations were changed from a 3-inch length limit to the present 2.75-inch minimum shell height limit for *Q. metanevra*, and 3-inch minimum shell height limits for *A. plicata*, *Q. quadrula*, and *P. purpuratus* (KAR 115-17-6 to 115-17-9).

MATERIALS AND METHODS

Four sampling stations were selected within the refuge and four were chosen outside the refuge boundary: two upstream and two downstream. Non-refuge sites were selected based on habitat similarities (e.g., site stability, depth, and substrate) with refuge sites; however, non-refuge sites similar to refuge sites were difficult to locate and were situated as much as 48 river km upstream and 29.5 km downstream from the refuge (Fig. 1). All selected sites consisted of shallow riffle and run habitats with cobble-gravel-sand substrata; each site consisted of at least a 100 m long reach with a mean depth less than one meter.

I quantitatively sampled unionids at these eight sites in the Neosho River during June and July 1994 using a 1-m^2 steel rod quadrat placed at measured coordinates chosen randomly within a 10 x 100 m stretch. Coordinates located on bedrock slabs were rejected and another random coordinate was chosen. Forty quadrats were sampled at each site. In each quadrat, I excavated the substrate by hand to a depth of 10-15 cm. Live unionids collected within quadrats were identified to species, and length, height, and width were measured with a dial caliper. Following measurement and identification mussels were returned to the river to their approximate original location.

Species diversity was calculated at each site by using Shannon's index, $\log_2$ (Zar, 1984), and tested for significant differences between refuge and non-refuge sites with a two-sample t-test. *Amblema plicata*, *Q. metanevra*, and *Q. quadrula* were sorted into two size classes (legal- and under-sized shells) and were tested for independence between refuge and non-refuge sites using the log-likelihood G-statistic (Zar, 1984). Two-sample t-tests were used to compare mean densities of legal-sized unionids, as well as to assess significant differences in shell lengths between refuge and non-refuge sites for *A. plicata*, *Q. metanevra*, *Q. quadrula*, and four additional species legally harvestable before 1992. Statistical analyses were performed at the 0.05 level of significance.

Nomenclature follows Turgeon et al. (1988), however, subspecies are not recognized and the subgenus *Pyganodon* is elevated to generic status over *Anodonta* based on Hoeh (1990). A representative collection of voucher shells from these sites is housed at The Ohio State University Museum of Zoology in Columbus, Ohio.

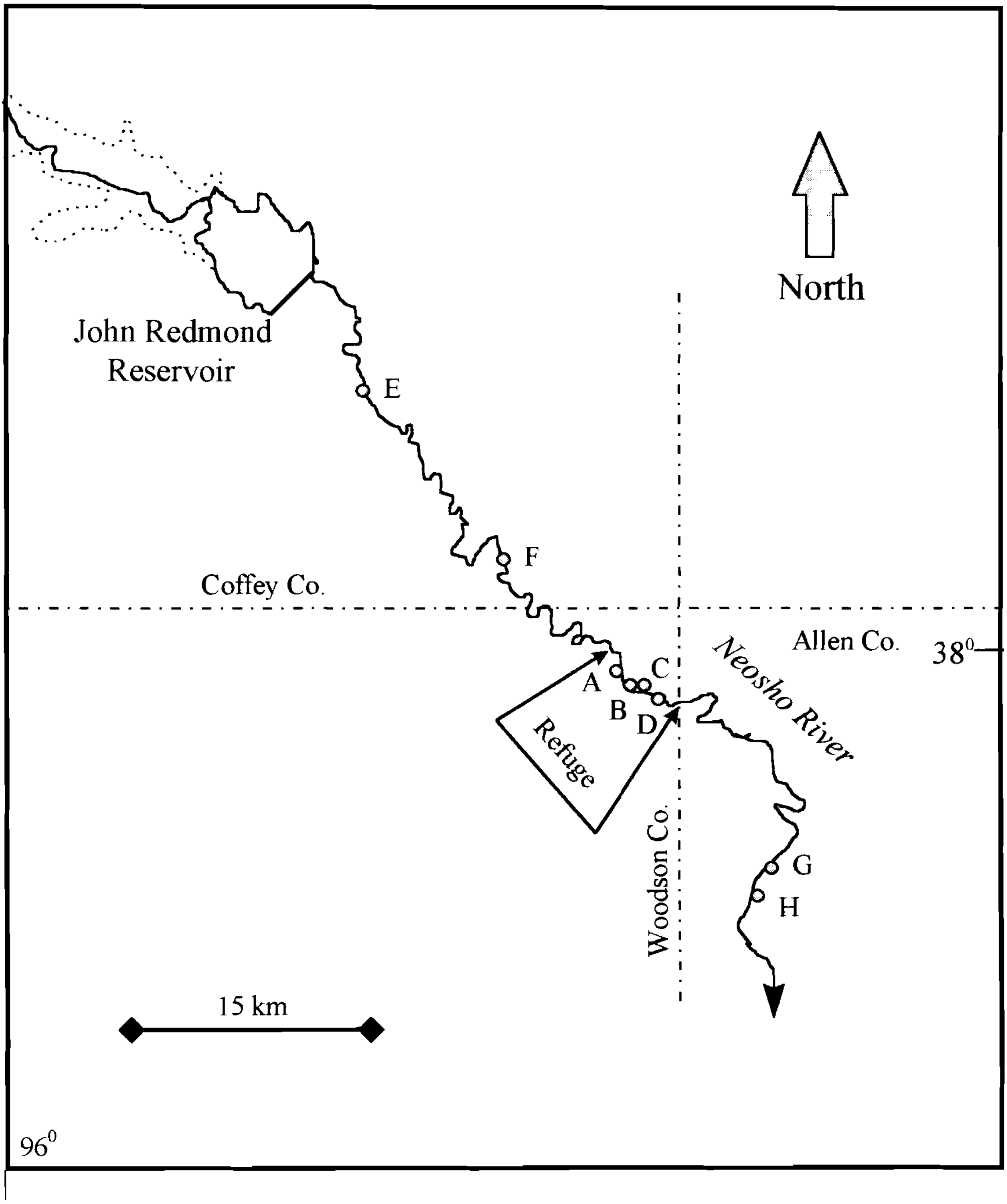

Figure 1. Map of refuge and non-refuge study sites on the Neosho River, Kansas.

RESULTS

A total of 744 live unionids, representing 20 species, including 11 state-listed species (i.e., endangered, threatened, or SINC), was caught from 320 1-m^2 quadrats (Table 1). Four additional species were represented either by recently dead specimens or live specimens caught in non-quantitative searches at the eight study sites. The most abundant species caught in quantitative searches was *Q. metanevra* (n = 388), comprising 52.1% of the total catch, followed by *Q. pustulosa* (n = 70) and *Elliptio dilatata* (n = 48), with 9.4% and 6.5%, respectively (Table 1). *Amblema plicata* and *Q. quadrula* were ranked fifth (n = 33) and eighth (n = 18), with 4.4% and 2.4% of the total catch, respectively (Table 1). The overall mean density of unionids per 1-m^2 quadrat was 2.3 (SD = 1.0; range = 0-12).

Despite the presumed protection from mussel harvesting at refuge sites, only 39.8% (n = 296) of the total catch of mussels during this study came from these sites, whereas 60.2% (n = 448) came from non-refuge sites (Table 1). Mean density of mussels at refuge sites (1.9 per m^2) was lower than at non-refuge sites (2.8 per m^2); however, the difference between mean densities was not significant ($p = 0.188$). Site H yielded the most species (17), including two Kansas endangered species, *Lampsilis rafinesqueana* and *Quadrula cylindrica*, whereas refuge site D revealed the fewest species, nine (Table 2). Despite these differences, Shannon's index of species diversity was similar at refuge ($\bar{x}$ = 2.4, SD = 0.4) and non-refuge ($\bar{x}$ = 2.4, SD = 0.8) sites ($p = 0.908$). Summaries of collections are presented in Table 2. Harvestable species were generally more abundant at non-refuge sites: 60.8% of *Q. metanevra*, 51.5% of *A. plicata*, and 55.6% of *Q. quadrula*

Table 1. Total number of each unionid species collected, ranking, and percent composition from eight refuge and non-refuge sites in the Neosho River, Kansas, 1994.

	In-refuge	Out-refuge	Total	% Composition	Cumulative %
Quadrula metanevra monkeyface	152	236	388	52.1	52.1
Quadrula pustulosa pimpleback	23	47	70	9.4	61.5
Elliptio dilatata *spike	25	23	48	6.5	68.0
Obliquaria reflexa three-horn wartyback	25	21	46	6.2	74.2
Amblema plicata threeridge	16	17	33	4.4	78.6
Tritogonia verrucosa pistolgrip	8	23	31	4.2	82.8
Fusconaia flava *Wabash pigtoe	6	22	28	3.8	86.6
Quadrula quadrula mapleleaf	8	10	18	2.4	89.0
Leptodea fragilis fragile papershell	9	9	18	2.4	91.4
Ellipsaria lineolata **butterfly	6	5	11	1.5	92.9
Lampsilis cardium plain pocketbook	4	5	9	1.2	94.1
Truncilla donaciformis *fawnsfoot	4	5	9	1.2	95.3
Quadrula nodulata *wartyback	2	6	8	1.1	96.4
Megalonaias nervosa *washboard	4	2	6	0.8	97.2

Table 1. continued

	In-refuge	Out-refuge	Total	% Composition	Cumulative %
Potamilus purpuratus	1	5	6	0.8	98.0
bleufer					
Lampsilis rafinesqueana	0	6	6	0.8	98.8
***Neosho mucket					
Lampsilis teres	1	2	3	0.4	99.2
*yellow sandshell					
Strophitus undulatus	0	3	3	0.4	99.6
*squawfoot					
Pleurobema coccineum	2	0	2	0.3	99.9
*round pigtoe					
Quadrula cylindrica	0	1	1	0.1	100.0
***rabbitsfoot					
Total number of individuals	296	448	744		
Total number of species	17	19	20		

State-listed species: endangered***; threatened**; or species in need of conservation*.

(Table 1), although the differences were not significant. Only one *P. purpuratus* was caught in refuge samples,whereas five were captured in non-refuge samples. *Quadrula metanevra*'s mean density per 1-m^2 at refuge sites was 0.9 compared to 1.5 outside the refuge. *Amblema plicata*'s overall mean density was only 0.1 per 1-m^2, with 16 and 17 *A. plicata* caught in refuge and non-refuge sites, respectively. *Quadrula quadrula*'s abundance and density were also low at both refuge and non-refuge sites (n = 8 and 10, density = 0.05 and 0.06 per 1-m^2, respectively).

Shell length of *Q. metanevra* was significantly larger at refuge versus non-refuge sites ($p = < 0.01$) (Table 3). However, there was not a significant difference in the percentage of legal-sized *Q. metanevra* specimens, with 55% and 63%, respectively, of the sampled population protected by the 2.75-inch minimum height limit (Table 4; Fig. 2). Legal size distribution of *A. plicata* (> 3 inches in height) and mean shell length were not significantly different between refuge and non-refuge sites (Table 3 and 4); however, only seven specimens from these sites (21.2%) were under legal size (Table 4; Fig. 3). Although sample size was small, size distribution of *Q. quadrula* was not significantly different between refuge and non-refuge sites (Tables 3 and 4). Sixty-two percent of the refuge population and 90% of the non-refuge population of *Q. quadrula* were smaller than the minimum size required by state harvest size restrictions (Table 4; Fig. 4).

Two species harvestable prior to the 1991 regulation changes, *Obliquaria reflexa* and *Tritogonia verrucosa* yielded significantly larger specimens (mean length) at refuge sites compared to non-refuge sites (Table 3); but *E. dilatata* and *Q. pustulosa* did not reveal a significant difference in mean shell lengths between refuge and nonrefuge sites (Table 3).

Table 2. Summary of unionid collections from 320 sq. m quadrats at eight sites in the Neosho River, Kansas, 1994.

	Refuge				Non-refuge			
Site	A	B	C	D	E	F	G	H
Number of quadrats sampled	40	40	40	40	40	40	40	40
Number of species	13	12	12	9	11	11	12	17
Total number of unionids in quadrats	100	85	62	49	43	126	126	153
Maximum number in one quadrat	8	9	10	5	5	11	12	10
Mean number of unionids per quadrat	2.5	2.1	1.6	1.2	1.1	3.2	3.2	3.8
Standard deviation of unionids per quadrat	2.0	2.3	2.2	1.3	1.5	2.4	2.6	2.9
Shannon's diversity index	2.8	2.5	2.0	2.2	2.8	2.9	1.3	2.7

Sites ABCD = within refuge boundries; EF = upstream from refuge; GH = downstream from refuge.

Table 3. Mean length (mm) and standard deviation (SD) of seven unionid species caught from four refuge and four non-refuge sites in the Neosho River, Kansas, 1994.

	In-refuge	Out-refuge	
	mean (SD)	mean (SD)	*p*-value
Amblema plicata	120.6 (15.79)	111.5 (26.66)	0.25
Elliptio dilatata	104.5 (23.90)	102.4 (23.31)	0.89
Obliquaria reflexa	68.1 (6.87)	57.7 (12.35)	<0.01
Quadrula metanevra	90.1 (20.78)	84.7 (18.70)	<0.01
Quadrula pustulosa	64.1 (13.26)	64.1 (13.61)	0.99
Quadrula quadrula	76.4 (25.51)	69.8 (16.65)	0.52
Tritogonia verrucosa	124.0 (24.61)	98.9 (24.04)	0.02

Table 4. Number and percent distribution of harvest-sized individuals of three unionid species collected from four refuge and four non-refuge sites (320 sq. m) in the Neosho River, Kansas, 1994.

	In-refuge		Out-refuge	
	number	percent	number	percent
Amblema plicata:				
Legal harvest size	14	88	12	71
Under harvest size	2	12	5	29
(G statistic = 0.59, p = 0.44)				
Quadrula metanevra:				
Legal harvest size	69	45	87	37
Under harvest size	83	55	149	63
(G statistic = 2.79, p = 0.10)				
Quadrula quadrula:				
Legal harvest size	3	38	1	10
Under harvest size	5	62	9	90
(G statistic = 1.98, p = 0.16)				

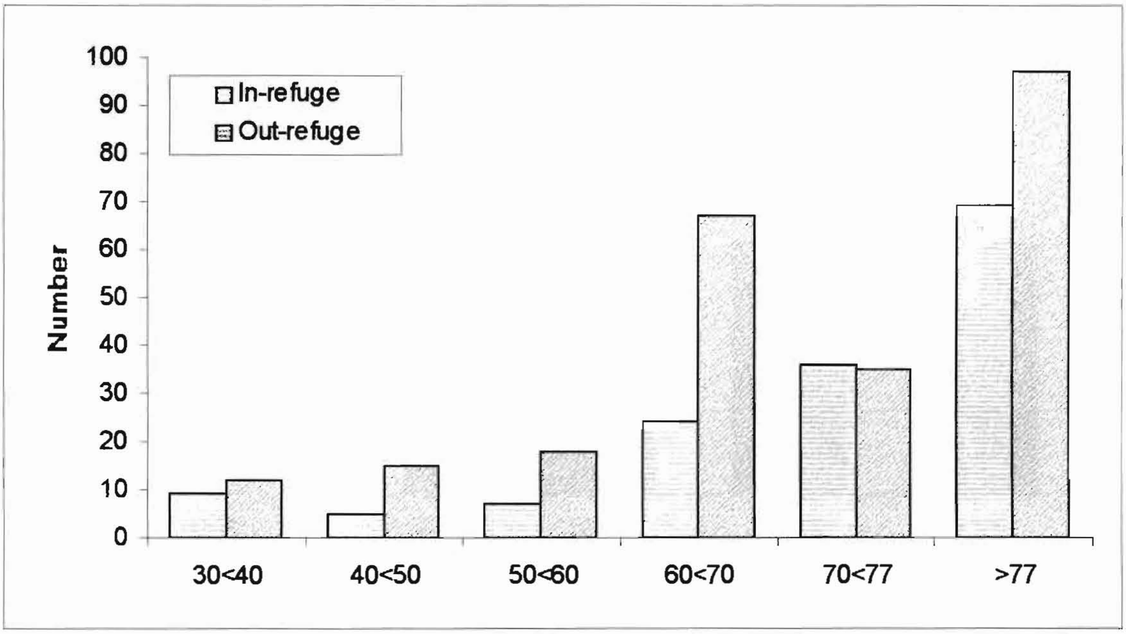

Figure 2. Shell height of *Quadrula metanevra* specimens collected in 1994 from refuge and non-refuge study sites in the Neosho River, Kansas.

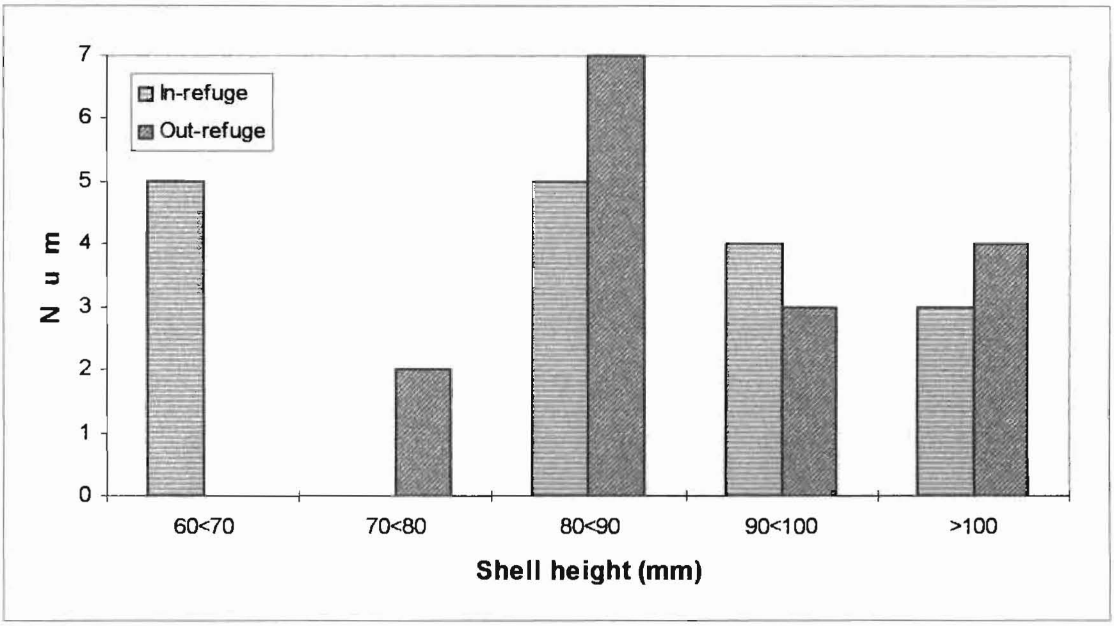

Figure 3. Shell height of *Amblema plicata* specimens collected in 1994 from refuge and non-refuge study sites in the Neosho River, Kansas.

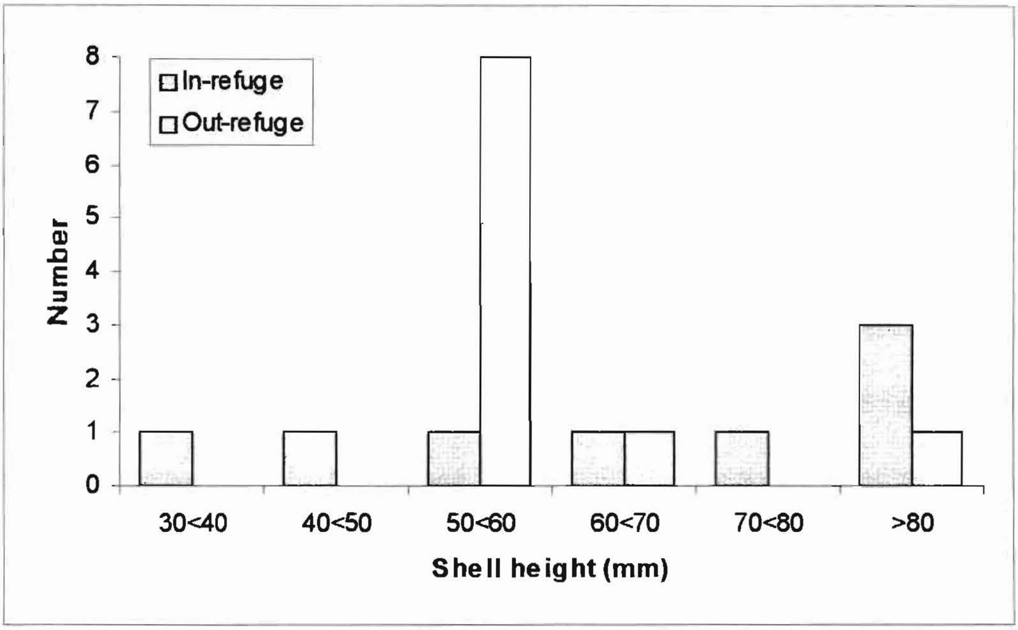

Figure 4. Shell height of *Quadrula quadrula* specimens collected in 1994 from refuge and non-refuge study sites in the Neosho River, Kansas.

DISCUSSION

The abundance of *Quadrula metanevra* at both refuge and non-refuge sites was high compared to that of other species sampled. A variety of size classes of this species was present suggesting consistent recruitment (Fig. 2). Recent harvest pressures appear not to have seriously affected this species; in fact, *Q. metanevra*'s abundance has apparently increased downstream from John Redmond dam during the past two decades when compared to previous surveys (Frazier, 1977; Cope, 1983; Miller and Obermeyer, 1996). Miller (1993) reported a similar trend for this species in the Verdigris River. Current harvest regulations seem appropriate for *Q. metanevra* because a large percentage of the sampled population is protected from legal harvest by size restrictions (63% at non-refuge sites; Table 4) and the density of *Q. metanevra* has apparently increased in both the Neosho and Verdigris rivers despite continued shell-fishing.

The status of *A. plicata* at refuge and non-refuge sites in the Neosho River differed greatly from that of *Q. metanevra*. *Amblema plicata*'s abundance ranked less in my study than surveys of Isely (1925) and Frazier (1977). Observations of worn and relic shells also suggest abundance reductions for this species. Miller (1993) indicated that *A. plicata* had also declined in the Verdigris River. The negative effect of commercial harvesting on this species is not known; however, because *A. plicata* is considered more tolerant of silt and pollution than many other unionid species (Starrett, 1971; Oesch, 1984), harvesting probably contributed to its decline. Another indication that harvesting is impacting *A. plicata* in the Neosho River is the disparity of catch rates between secluded, harvestable sites in deeper habitats and more accessible habitats with depths less than one meter. Qualitative searches from 19 sites in the Neosho River in 1994 revealed that catch per unit effort (CPUE) for *A. plicata* was greatest at a shallow water site off-limits to shell-fishing (upstream from John Redmond Reservoir); whereas in the stretch open to musseling, the highest CPUE for *A. plicata* was 33.0 (Obermeyer, unpublished data). One site open to shell-fishing yielded 81.1 *A. plicata* per h of effort from a SCUBA search at depths greater than one meter, compared to the above mentioned high of 33.0 in shallower habitats.

The scarcity of this species at most Neosho River sites (Obermeyer, unpublished data), may indicate a need for revisions of harvest regulations for *A. plicata*. For example, the 3-inch minimum height limit protects few individuals for future reproduction; only 9.0% (66 vs. 665) of *A. plicata* specimens caught from qualitative searches during summer 1994 at 11 Neosho River sites were protected by the 3-inch height limit (Obermeyer, unpublished data).

Quadrula quadrula has also apparently declined in relative abundance compared to Isely's (1925) and Frazier's (1977) surveys. However, the ratio of legal versus under harvestable-sized individuals seems adequate, although the number of observations in this study was small.

Despite *Q. metanevra*'s higher relative abundance in the Neosho River compared to that of *A. plicata* (n = 388 versus n = 33), similar harvest yields for each species were reported from the Neosho River in 1994. Approximately 16,850 to 24,050 *Q. metanevra* and 16,250 to 22,950 *A. plicata* were sold to shell dealers, excluding processed mussels (i.e., cooked mussels with softparts removed). These estimations are based on the 1994 reported live weights of harvested mussels from the Neosho River (Mosher, 1995), whereas mean weight values were taken from Miller's (1993) Verdigris River study. The disparity between my collections and the reported harvest yields of these two species is likely the result of musselers harvesting *A. plicata* in deeper, more secluded beds. My observations of more *A. plicata* at greater depths versus shallower habitats supports this explanation.

Although *O. reflexa* and *T. verrucosa* revealed significantly larger specimens at refuge site compared to non-refuge sites, the Neosho River refuge failed to show significant size differences for several other species. Furthermore, refuge sites revealed generally lower densities than non-refuge sites.

Many factors are likely influencing the standing crop of mussels at these sites. Because refuge versus non-refuge sites are separated by as much as 48 km, drainage area, discharge, physicochemical, and geologic differences may have skewed these data. I believe that habitat variability among sites was greater at my Neosho River sites than for sites in Miller's (1993) Verdigris refuge study. Events prior to refuge establishment may also have influenced these data, including past pollution and mussel harvesting; past harvesting would especially mask the effectiveness of the refuge if harvest pressure was low at my non-refuge sites and if illegal harvest has occurred in the refuge. Site vulnerability to drought (e.g., water depth of beds), and recruitment rates that failed to match or exceed mortality would also effect these data.

Differences in the densities of mussels between refuge and non-refuge sites may have existed before the Neosho River refuge was established. Cope (1983) reported that the average density of mussels at one of my refuge sites was approximately half that of a site outside the refuge (2.9 versus 5.7). Although I found a similar difference in average densities at these same sites, my data suggest that populations have decreased about 40%

compared to his data. Densities since Cope's survey (1983) appear to have decreased at both of these sites at about the same rate--about a two-fold decrease.

A further complication of comparing mussel densities, relative abundance, and species diversity between refuge and non-refuge sites is the possible illegal harvest of protected species, which is possible since several Kansas unionid species are marketable in other states. These include *Lampsilis rafinesqueana* (which could be marketed as *Actinonaias ligamentina*), *Pleurobema coccineum, Fusconaia flava, Megalonaias nervosa, Ellipsaria lineolata*, and *Obliquaria reflexa.*

Miller's (1993) study indicated that the Verdigris River refuge was protecting *A. plicata* and *Q. metanevra* from commercial harvest within refuge boundaries. However, because of site dissimilarity, the lack of quantitative baseline data from most of my sites prior to refuge establishment, and because actual past harvest pressure from each site is unknown, I can not accurately assess the effectiveness of the Neosho River refuge in protecting unionids from harvest. Although these results are inconclusive regarding the impact of commercial harvesting, they do provide valuable baseline data that will enable future studies to assess more accurately the effectiveness of the refuge, as well as changes in Neosho River mussel assemblages.

MANAGEMENT RECOMMENDATIONS

Although *Q. metanevra* is apparently capable of tolerating current harvest pressures, other mussel species may not. Stable mussel beds in shallow riffle and run habitats in the Neosho River are limited in number (Obermeyer et al., 1995). Because these habitats are critical links for unionid population stability and continued recruitment

(Vannote and Minshall, 1982; Neves, 1993), regulations that ensure their protection are needed. Clarke (1986) stated that dense mussel beds may provide the only suitable substrate for juvenile mussels in unfavorable habitats (e.g., muddy habitats), and speculated that intense harvesting of mussel beds may adversely affect the mussel bed's function as a juvenile nursery area. Moreover, disturbances from shell-fishing can dislodge protected species (personal observations) and juvenile mussels, leaving them vulnerable to predation and to floods that could sweep them downstream into less favorable habitats. Imlay (1972) provided evidence that mussels are sometimes unable to reposition themselves into the substrate following artificial disturbances, and questioned the benefit of regulations that restrict the harvest of rare species and under-sized mussels if disturbed mussels are unable adapt to shell-fishing disturbances. Another consideration is that handling and sorting of under-sized and protected mussels can stress gravid females, causing them to abort glochidia prematurely (Lefevre and Curtis, 1910; Coker, 1919; Yokely, 1972; Yeager and Neves, 1986). Determining and maintaining viable population densities for unionid reproductive success (Downing et al., 1993) is also needed to properly regulate mussel harvest rates.

Coker (1919) recommended rivers be closed to mussel harvest periodically to lessen the impact of harvest disturbances and to ensure replenishment of mussel beds. The current system of three refugia for mussels in southeast Kansas is a good beginning, although one refuge per stream probably provides minimal benefits for the overall mussel assemblage. Resting streams from harvest as recommended by Coker (1919) would likely be more beneficial to mussels in the Neosho River than maintaining one small refuge. Permanently closing stretches of streams from harvesting that contain rare species not found in other areas, such as *Quadrula cylindrica* in the stretch of the Neosho River from Iola to Humboldt (Obermeyer et al., 1995), may also warrant consideration.

Currently, the criterion used to limit the number of legal-sized mussels harvested in Kansas is the law of diminishing returns. Because returns vary depending on shell prices, the recent high demand for shells and, thus, increased harvest pressures warrants re-evaluating current management strategies. Potential management practices that might help the state better manage riverine mussel populations follow:

1. determine minimum viable population densities;
2. periodically rest streams to allow replenishment of beds;
3. re-evaluate beds to assess mussel densities and recruitment (e.g., identify replenished beds);
4. establish appropriate size limits by assessing the percentage of under-sized mussels protected from harvest, and determine the age and size at sexual maturity for commercial species, or even better, though difficult to regulate, harvest only senescent individuals of long-lived species;
5. extend the current 6.1 km refuge to include the speciose stretch between Iola and Humboldt.

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Chapter 4

COMPARISON OF SAMPLING METHODS FOR ASSESSING FRESHWATER MUSSELS

Abstract. I surveyed 9 sites for unionid mussels in the Neosho River, Kansas, during summer 1994 to compare the effectiveness of quadrat sampling versus timed snorkel searches for evaluating relative abundance, species richness, species diversity, size distribution, assemblage structure, and evidence of recruitment. At each site, I first conducted snorkel searches in a 10 x 100 m stretch; mussels were returned to their original location following identification and sizing. I next sampled 40 1-m^2 quadrats from the same stretch. A total of 786 mussels was caught during 12 h 11 min of snorkel searches compared to 896 mussels from 360 1-m^2 quadrats. *Quadrula metanevra* was the most abundant species collected by both methods. Differences in assessments of species diversity and relative abundance between methods was not significant; however, snorkel searches revealed significantly fewer species, and were less effective in detecting small, cryptic species. Little evidence of recent recruitment was detected by either method. The selection of a sampling protocol should be based on the specific objectives of a project. Quantitative methods are recommended for assessments of density, biomass, size demographics, and local scale phenomena, whereas qualitative searches are more efficient when targeting large species or examining broad distributional patterns. However, some form of substrate sieving is necessary to detect small, cryptic species and to evaluate mussel recruitment.

Keywords: freshwater mussels, Unionidae, sampling methods, quadrats, snorkel searches, sieve samples.

Introduction

Freshwater mussels have experienced dramatic range and population reductions during the past century (Stansbery 1970, Neves 1993, Williams et al. 1993), and have been ranked as the most imperiled group of animals in North America (Allen and Flecker 1993). Of the 297 species of freshwater mussels known to occur in North America, 22 are believed to be extinct, 56 have been included on the U.S. list of threatened and endangered species, and an additional 67 species are considered species of concern (Neves 1993). Consequently, monitoring remaining mussel populations has become a top priority with many resource agencies.

Historically, most mussel surveyors relied on qualitative methods (e.g., forking, brailing, dredging, and groping searches) to sample unionid populations; however, as early as 1912 Isely (1925) quantitatively sampled unionids by collecting from 10 by 10 ft (9.3-m^2) grids in the Verdigris River, Oklahoma. Recently, quantifiable sampling methods (e.g., randomly placed quadrats) have become more commonly used, especially for assessments of population density, size demography, and recruitment. However, quantitative sampling is time-consuming and expensive (Cummins 1962, Kovalak et al. 1986, Miller and Payne 1993, Strayer et al. 1996). Qualitative methods (e.g., timed groping, snorkel, and SCUBA searches) may be more appropriate for surveys of rare species (Miller and Payne 1993, Vaughn et al. 1996, Strayer et al. 1996), especially because aggregated distributions may require a prohibitive number of quantitative samples to catch uncommon species (Kovalak et al. 1986). Green and Young (1993) recommended increasing the number of quadrats while decreasing quadrat size (e.g., 1-m^2 to 0.25-m^2) to increase the probability of detecting rare species, but they considered species with a density of less than 0.1/m^2 as rare and difficult to detect with any sampling method.

Although researchers have evaluated quantitative and qualitative sampling methods in assessing unionid community structure (Miller and Payne 1988, 1993), few (Strayer et al. 1996, Vaughn et al. 1996) have compared methods by repeated sampling from the same population. To evaluate each method's characterization of unionid assemblage structure and to detect method biases and possible shortcomings, I sampled the same stretch of habitat twice at each of 9 Neosho River (Kansas) sites, first qualitatively with a snorkel search, then quantitatively with 40 1-m^2 quadrats. Snorkel searches were supplemented by 15 sieve substrate samples in an effort to detect juvenile mussels.

Methods

Sampling

Nine stations were sampled for unionids during summer 1994 along an approximately 80-km stretch of the Neosho River in Coffey, Woodson, and Allen counties, Kansas (Fig. 1). Each site consisted of at least a 100 m stretch of riffle habitat (< 1 m deep; $\bar{x}$ = 31.8 cm, SD = 12.88) with cobble-gravel-sand substratum. At each site, I conducted a timed snorkel search in the chosen 10 x 100 m area of habitat, beginning at the downstream end of the reach and working upstream (Fig. 2). I monitored the time expended sampling at each sampling station ($\bar{x}$ = 81.2 min, SD = 17.58), and I searched each habitat in a zig-zag pattern to generate comparable data among sites. Mussels were located both by visual and tactile cues, and were handed to an assistant for immediate

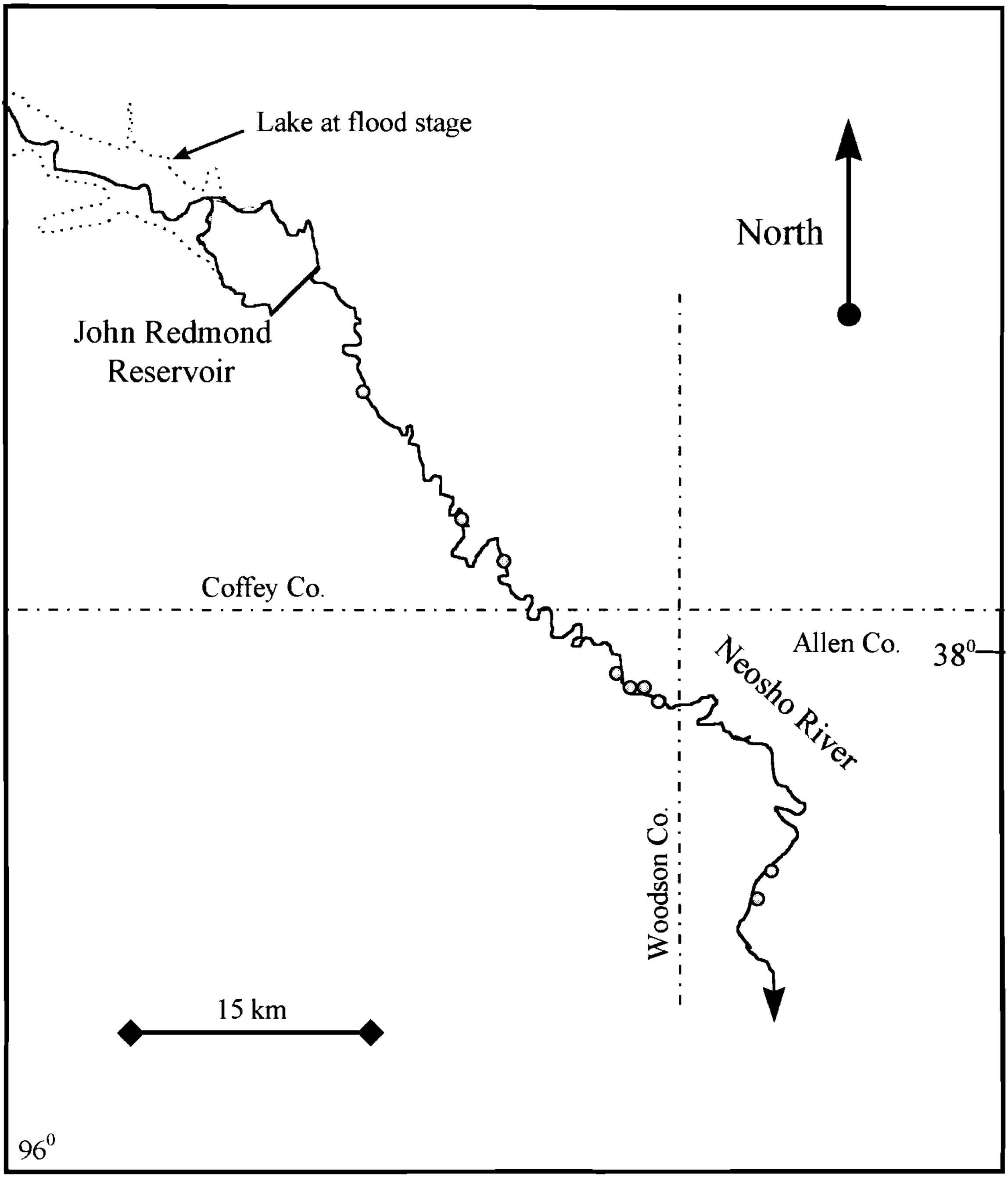

Fig. 1. Map of the study area on the Neosho River, Kansas.

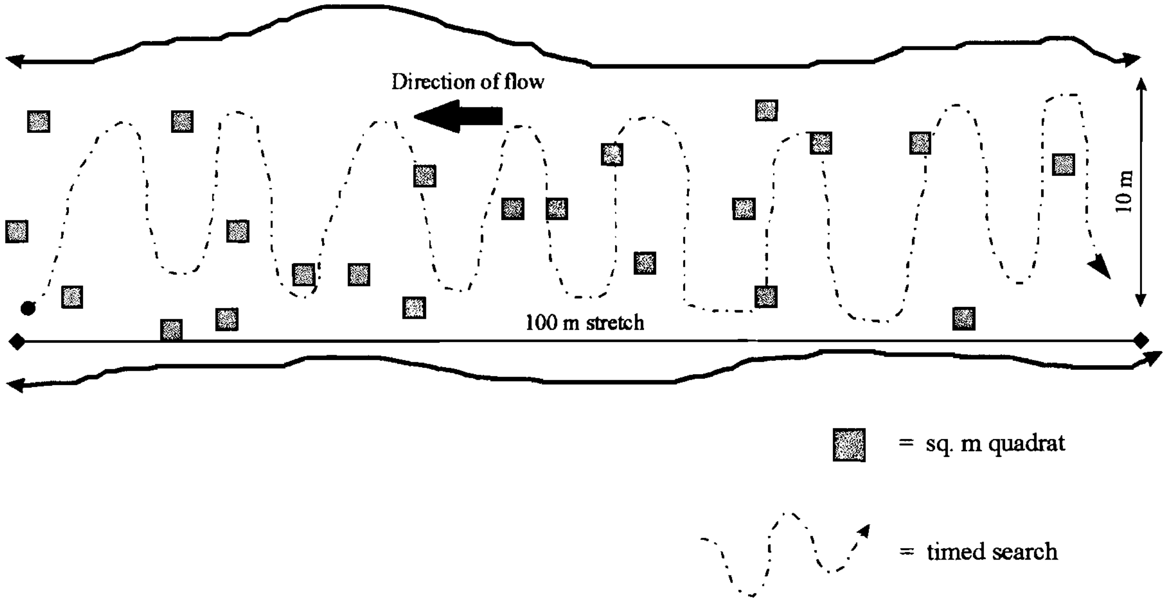

Fig. 2. Example of sampling layout.

identification and measurement. Approximate shell height of each mussel was estimated by passing its smallest dimension through an aluminum shell-sizer with openings of 2, 3, 4, 6, 8, 10, and 12 cm (Fig. 3). Mussels were then returned to their original location; measuring, identifying, and replacing of unionids during the timed searches required only about 5-10 seconds per mussel.

After the snorkel search was completed, I resampled the same stretch of river using a 1-m^2 steel rod quadrat placed at 40 randomly selected locations (Fig. 2). Quadrats that fell on bedrock were rejected and other random coordinates were selected. Substrate within each quadrat was removed by hand to a depth of 10-15 cm and carefully examined for live mussels. Each unionid collected was identified, and its shell width, height, and length were measured to the nearest mm using a dial caliper. Mussels were then returned to their approximate original location.

To supplement snorkel searches in locating endobenthic and small mussels, I dredged the substrate with a shovel and transferred it to a floating sieve, which was constructed of 6-mm galvanized mesh screen supported by a 1 x 1 m frame of 15 cm diameter PVC pipe. Dredging ceased when the weight of the substrate caused the frame to sink. The collected substrate was then sieved and inspected for unionids; shell height measurements were taken with the shell-sizer. Fifteen of these sieve samples were taken at each site. Selection of dredging locales was haphazard within the chosen habitat, though care was taken to avoid areas previously disturbed by quadrat sampling.

Nomenclature herein follows Turgeon et al. (1988), however, subspecies are not recognized. A representative collection of voucher shells collected from these study sites is housed at The Ohio State University Museum of Zoology in Columbus, Ohio.

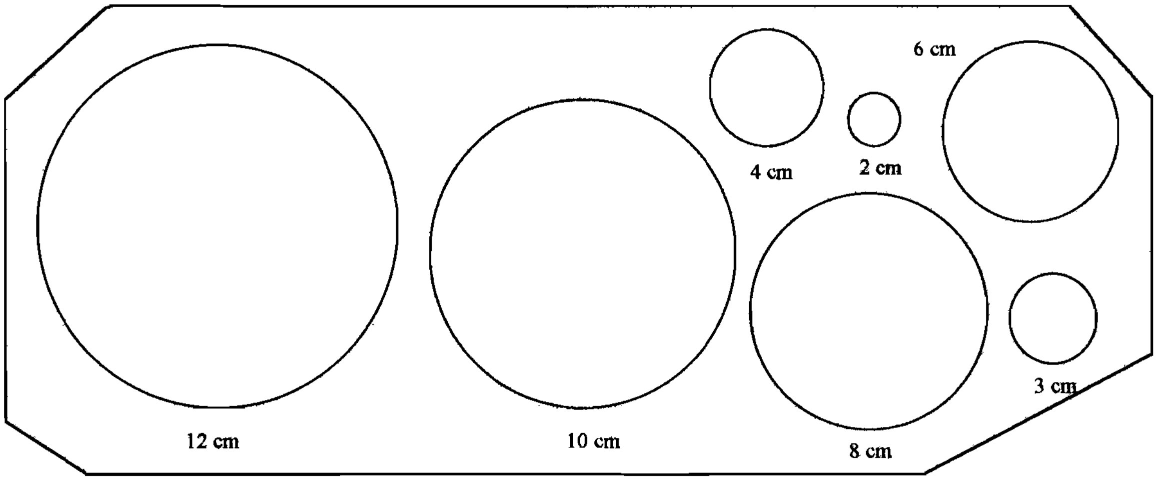

Fig. 3. Aluminum plate shell-sizer used to measure approximate mussel shell height.

Statistical analyses

Species diversity (Shannon's index, $\log_2$), species richness, and relative abundance were determined for snorkel and quadrat searches, and differences between these methods were tested using Wilcoxon's signed ranks test (WRS); these calculations did not include mussels caught in the sieve samples. Size selection bias between snorkel searches and quadrats was examined for *Quadrula metanevra* (the most abundant species collected in this study) by comparing mean shell height using WRS test; I compared measurements taken with the aluminum plate shell-sizer versus the dial caliper by using caliper-measured *Q. metanevra* data and assigning an additional size value, that is, the corresponding shell-sizer value to test for correlation.

To examine difference in the portrayal of assemblage structure of the two sampling techniques, I used Jaccard's similarity index (Pielou 1984) to construct symmetric similarity matrices with presence/absence data for each method. Two additional matrices were constructed with abundance data using Kendall's rank correlation coefficient (τ), which can be used as a nonparametric comparison of assemblage structure (Baev and Penev 1995). Similarity matrices were constructed using BIODIV 5.1 statistical software (Baev and Penev 1995). These values were converted to distance matrices by subtracting each value from 1 and then subjecting them to the Mantel test (Mantel 1967), which tests the null hypothesis of no association between the two matrices (Smouse et al. 1986, Sokal and Rohlf 1995); rejection of the null hypothesis indicates a significant similarity or correlation between the two matrices. Mantel tests were run on the BIOM-pc statistical package (Rohlf and Slice 1995), each with 1000 random permutations. All statistical tests were conducted at the 0.05 level of significance.

Results

Twenty-one species of freshwater mussels were caught at the 9 sites from the combined efforts of 360 1-m^2 quadrat samples and 12 h 11 min of snorkel searches. Quadrat samples yielded 896 live mussels of 20 species (Table 1) with a mean density of 2.5/m^2 (SD = 2.59); the overall distribution of unionids caught in quadrats was significantly aggregated (CD = 2.68, $X^2 = 2403.9$, $p < 0.001$; Brower et al. 1989). Snorkel searches yielded similar catch results with 786 mussels of 18 species (Table 1). The most abundant species caught by both methods was *Q. metanevra*, which constituted 45.9% of the mussels found in quadrat samples and 48.2% collected in snorkel searches.

Snorkel searches favored the capture of larger mussels. For example, *Amblema plicata* and *Megalonaias nervosa* were favored almost two-to-one in snorkel samples, although the difference was not significant (Table 1). In contrast, collections of *Leptodea fragilis*, *Elliptio dilatata, Quadrula nodulata, and Quadrula pustulosa* were significantly greater in quadrat samples; *Truncilla donaciformis* was significant at the 0.10 level (Table 1). Size differences of *Q. metanevra* (based on shell height) between methods revealed larger specimens at 7 of the 9 sites; however, the difference was not significant following a sequential Bonferroni adjustment ($p = 0.021$ vs. corrected $\alpha = 0.005$; Rice, 1989). Although the shell-sizer and caliper measurements were correlated ($r = 0.926$, df = 409, $p = <0.001$), means of shell height for these same mussels differed considerably ($\bar{x} = 70.3 \pm 1.63$ vs. 80.3 ± 1.79, caliper vs. shell-sizer, respectively).

Conflicting associations between methods were found for estimates of assemblage structure. For example, relative abundance and species diversity were not significantly

Table 1. Number of each unionid species collected (% composition) and corresponding *p*-value (WRS) from 9 sites using 360 quadrat samples and 12 h 11 min of snorkel searches within the same habitats in the Neosho River, Kansas.

	Quadrat captures	Snorkel captures	
Species	# caught (% contribution)	# caught (% contribution)	*p*-values
Quadrula metanevra	411 (52.0)	379 (48.0)	0.515
Amblema plicata	51 (34.9)	95 (65.1)	0.128
Quadrula pustulosa	91 (68.4)	42 (31.6)	0.012*
Tritogonia verrucosa	42 (37.8)	69 (62.2)	0.057
Elliptio dilatata	70 (64.2)	39 (35.8)	0.011*
Obliquaria reflexa	56 (63.6)	32 (36.4)	0.181
Quadrula quadrula	42 (59.2)	29 (40.8)	0.916
Fusconaia flava	32 (55.2)	26 (44.8)	0.611
Megalonaias nervosa	14 (37.8)	23 (62.2)	0.180
Potamilus purpuratus	8 (30.8)	18 (69.2)	0.498
Leptodea fragilis	24 (96.0)	1 (4.0)	0.007**
Lampsilis cardium	9 (39.1)	14 (60.9)	0.157
Ellipsaria lineolata	12 (63.2)	7 (36.8)	0.339
Lampsilis rafinesqueana	6 (50.0)	6 (50.0)	1.000
Quadrula nodulata	10 (90.9)	1 (9.1)	0.041*
Truncilla donaciformis	9 (100)	-	0.066
Strophitus undulatus	3 (75.0)	1 (25.0)	0.655
Lampsilis teres	3 (100)	-	0.083
Lasmigona complanata	-	3 (100)	0.180
Pleurobema coccineum	2 (66.6)	1 (33.3)	0.655
Quadrula cylindrica	1 (100)	-	0.317
Total number of individuals	896	786	
Species richness	20	18	

* < 0.05; ** < 0.01

different ($p = 0.208$ and $p = 0.285$, respectively; Fig. 4), whereas a disparity in species richness was significant ($p = 0.048$, Fig. 4), with more species found by quadrats. Furthermore, pairwise Mantel comparisons of assemblage structure revealed a significant positive correlation between methods for abundance data ($r = 0.57$, $n = 36$, $p = 0.002$); however, the null hypothesis of no association between presence/absence data matrices was not rejected ($r = 0.24$, $n = 36$, $p = 0.11$).

Neither sampling method yielded much evidence of recent reproductive success for any species. Quadrat samples yielded more individuals less than 40 mm in height than did the combined efforts of snorkel searches and sieve samples, especially in the 20-40 mm size-class. However, the qualitative sieve samples of dredged substrate yielded a greater proportion of juveniles less than 20 mm in height (Fig. 5).

Discussion

Despite similar overall catch numbers in the present study, over twice as many species were found in greater proportion (14 vs. 6) in quadrat samples than in snorkel searches (Table 1). Detection of cryptic mussel species (e.g., small, smoothed-shelled, and deep burrowing species) was greater in quadrat samples, whereas qualitative methods biased the capture of more conspicuous mussels; this trend was also noted by Vaughn et al. (1996). The tendency to miss small or burrowed mussels is probably responsible, in part, for the significantly fewer species caught during snorkel searches. Uneven sampling effort could also have contributed to the disparity. The disparity between methods for rarer species, however, may be more of a function of chance rather than sampling efficiency (Miller and Payne 1993). Vaughn et al. (1996) more evenly matched sampling

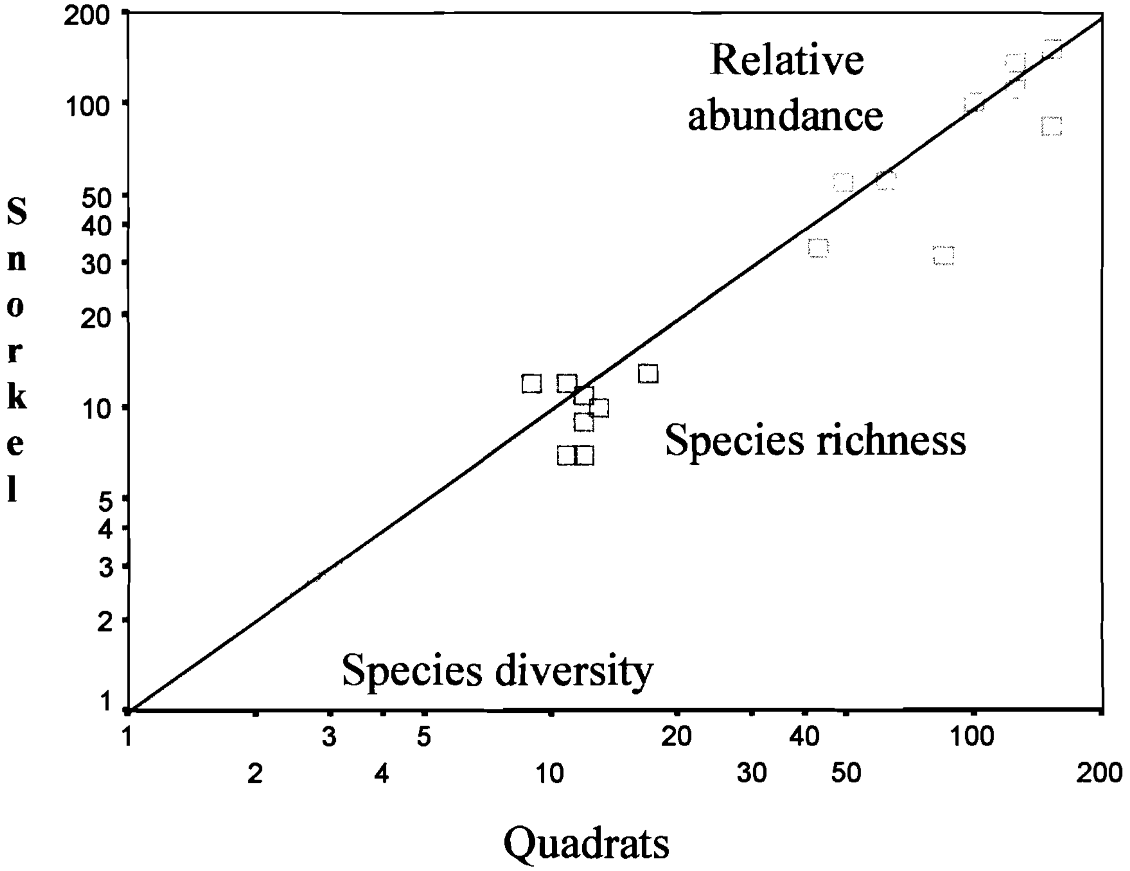

Fig. 4. Comparison of species diversity, species richness, and relative abundance between sampling methods.

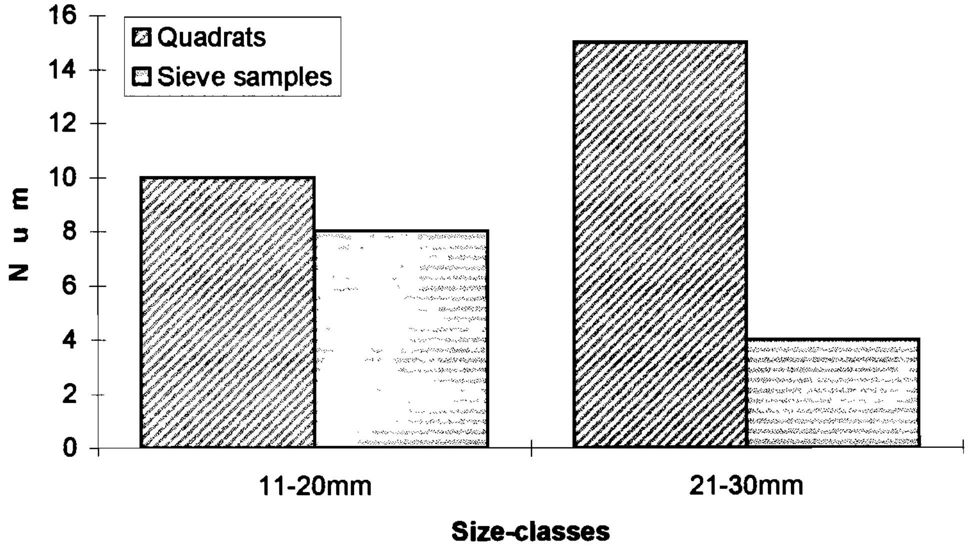

Fig. 5. Juvenile mussels collected from 1994 quadrat and sieve sampling from 9 Neosho River sites, Kansas, 1994.

effort (time-wise) by comparing results from 15 0.25-m^2 quadrats with 2 person-h of timed searches within the same habitat, and reported that, although species richness was significantly correlated between methods, more species were found during timed searches. Timed snorkel searches during my study may have yielded comparable species richness data with quadrat samples had I used fewer quadrats per site. The mean number of quadrats needed to reach the maximum number of species collected per site was 27 (SD = 9.12), and a species:area curve, constructed a posteriori and based on the mean proportional increase in the number of species collected for each additional quadrat sample, indicated that less than 30 quadrats would have been an adequate sample size, using a 1:0.5 cut-off criterion (Fig. 6).

Although my snorkel searches revealed fewer species and a bias for larger mussels, similar assemblage and relative abundance information was provided with considerably less effort expended than required for quadrat samples. Strayer et al. (1996) and Vaughn et al. (1996) also found that timed searches yielded more species for each h of effort. I estimated that about 24 person-h of effort per site was required to sample 40 1-m^2 quadrats, whereas snorkel searches and sieve sampling required less than 4 person-h at each site. The use of the shell-sizer helped to reduce the overall expenditure of time since there was no additional measuring or identifying following timed searches. Although shell height confidence limits for *Q. metanevra* revealed about a 10 cm difference between shell-sizer and caliper measurements, similar size distributions were obtained from each method. Moreover, Obermeyer (1995) found the shell-sizer to be an efficient and effective tool in assessing legal-size distribution of mussels in shallow habitats. Immediate repositioning of mussels likely reduced predation and the chance of disturbed mussels

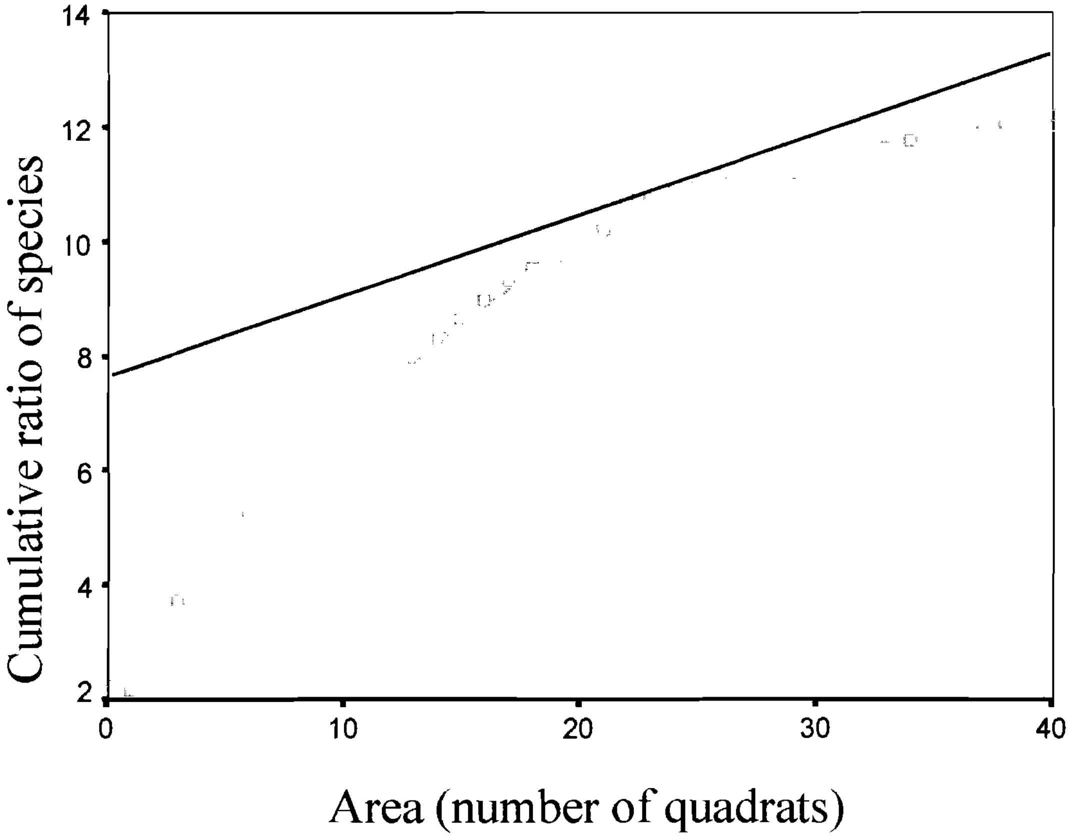

Fig. 6. Species:area curve based on the mean proportional increase in the number of species collected for each additional quadrat sample. The curved line represents a quadratic model, whereas the straight line represents a 1:0.5 cut-off criterion.

being swept downstream into less favorable habitats (see Imlay 1972). Furthermore, the minimization of handling mussels by using the ring-sizer probably reduced abortions of glochidia by gravid females (Lefevre and Curtis 1910; Yokely 1972, Yeager and Neves 1986).

Miller and Payne (1988) stated that the greatest liability of qualitative sampling (e.g., timed snorkel and SCUBA searches) is the inability to accurately assess recruitment. However, my supplemental sieve samples required only about 1 h of effort per site and qualitatively estimated recruitment. In fact, these sieve samples detected a greater proportion of juveniles less than 20 mm in height than did quadrat sampling (Fig. 5). Because mesh screen was not used to sieve quadrat samples, the low proportion of mussels less than 20 mm that were found compared to screened dredge samples indicates that substrate in quadrat samples should be screened to detect small mussels.

Another criticism of qualitative sampling is its failure to provide population density data (Miller and Payne 1993), which are needed to accurately assess population size and trends. Nonetheless, Strayer et al. (1996) found that timed qualitative searches were correlated with population densities based on quadrat sampling from New Hampshire and North Carolina streams, and they stated that qualitative searches may provide an economical estimate of population density (although large errors were associated with these estimates).

Matthews (1990) stated that the accuracy of riverine fish surveys might be improved by increasing the number of sites rather than expending more effort (replications) per site. Because mussel assemblages often exhibit considerable variation among sites, qualitative examination of many sites for spatial abundance patterns is probably more important for assessing a stream's overall mussel assemblage than quantitative studies restricted to a few sites, provided that qualitative methods incorporate some type of substrate screening. The greater sampling effort used for quadrat sampling could have been re-allocated towards snorkel searches at additional sites. Thus, for studies of large-scale interpretation, qualitatively derived estimates of abundance such as a density index (Strayer et al. 1996) would probably be more accurate than would density values obtained quantitatively from a few sites, which might be misleading when extrapolated to a wider geographic coverage (Levin 1992, Brown 1995). Extrapolation of density data can be especially misleading because mussel surveys often sample aggregated beds (Cawley 1993).

Despite the adequacy of qualitative sampling in the above mentioned situation, other research objectives require methods that can be quantified and duplicated. For instance, accurate assessments of density and dispersion can only be determined with quantitative methods (Miller and Payne 1988, 1993). The finer resolution that quantitative sampling provides is especially important for sites targeted for long-term monitoring. Determining population change through time at a particular site or to assess the impact of local anthropogenic effects would also benefit from more precise sampling measurements.

Although both methods have advantages, each can complement the other. For example, preliminary qualitative surveys are valuable in identifying sub-habitats prior to quantifiable sampling (Kovalak et al. 1986). Qualitative searches can not only identify boundaries of a mussel bed, but can also estimate species richness and rank abundances (Kovalak et al. 1986, Miller and Payne 1988), as well as provide preliminary information useful for calculating sampling adequacy (Elliott 1971, Green 1979). Information gained from these preliminary searches would also help in designing stratified random samples to prevent, for example, biased sampling of one sub-habitat (Cummins 1962, Elliott 1971). Snorkel searches conducted during this study helped identify unionid aggregations, located areas with promising habitat, and accurately predicted quadrat coordinates that yielded the most mussels (personal observations). Thus, qualitative sampling could be used to delineate suitable habitat, and quantitative sampling used to examine dispersion and density, and perhaps, more accurately assess species abundance ratios.

Resource agencies should understand the biases of different sampling methods when selecting mussel sampling strategies to meet specific project objectives. If an objective is to assess density and biomass, obtain accurate size demographics at a particular site, or to appraise suspected deleterious factors on a local scale, then quantitative methods are necessary. If the objective is to detect small, cryptic species or to evaluate mussel recruitment, then substrate sieving, qualitative or quantitative, is needed. However, qualitative searches may be more efficient in studies targeting large species or examining broad distributional patterns.

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