FINAL REPORT

SECTION 6

ENDANGERED SPECIES ACT

FEDERAL AID PROJECT E-34

Determination of the Status and Habitat Preference of the Neosho Mucket in Oklahoma

SEPTEMBER 1, 1994 - AUGUST 31, 1997

FINAL REPORT

STATE: Oklahoma PROJECT NO: E-34

PROJECT TITLE: Determination of the status and habitat preference of the Neosho Mucket in Oklahoma

SEGMENT DATES: September 1, 1994 - August 31, 1997

I. OBJECTIVES

(1) Using SCUBA equipment, survey suitable sites on the Illinois, Neosho, Verdigris, Spring and Caney rivers in northeastern Oklahoma for the presence of the Neosho mucket. Survey sites will include both historic and non-historic sites with potential habitat.

(2) Record abundance data for the Neosho mucket and associated mussel species at each survey site.

(3) Collect data on habitat characteristics at sites with Neosho muckets and at sites without Neosho muckets to determine habitat preferences.

(4) Identify any potential threats at each survey site.

(5) Estimate the availability of suitable habitat and develop a population estimate for the Oklahoma portion of each river.

II. INTRODUCTION

Lampsilis rafinesqueana, the Neosho mucket, is a thin, light brown mussel reaching up to 9.5 cm in length (Oesch, 1984). The species is endemic to the Arkansas River system (Obermeyer et al. 1997) and was first described by Frierson (1927) from specimens collected in Oklahoma from the Illinois River near Moodys, Cherokee Co. (Mather, 1990). The species historical range includes the Illinois system in Arkansas (Harris and Gordon, 1987), the Elk, North Fork Spring, and Spring Rivers in Missouri (Stewart, 1992), the Verdigris, Neosho, Spring, Fall, Big Caney and Cottonwood Rivers in Kansas (Stewart, 1992), and the Verdigris, Neosho (Grand), Spring, Caney and Illinois Rivers in Oklahoma (Mather, 1990).

A 1989 survey by Mather (Mather, 1990) indicated that the range of the Neosho mucket has declined dramatically in Oklahoma, possibly as a result of reservoir construction. Weathered "fossil" valves of *L. rafinesqueana* were found in the Verdigris, Spring, Neosho and Caney Rivers. Living specimens and fresh shells were found only in a 55 mile stretch of the Illinois River between Lake Tenkiller and Lake Francis (Mather, 1990). The 1989 survey was not able to determine how broadly distributed the species is within these rivers or determine its abundance relative to other sympatric mussel species.

L. rafinesqueana was a C2 candidate for listing as a federal endangered species and a listed state of Oklahoma endangered species. Information on the status of this species in Oklahoma, including the extent of its range in each river system, habitat characteristics, evidence of recruitment, population density, and threats, is needed in order to determine whether or not to list this species. Currently the commercial mussel harvest in Oklahoma is small, however most of the take occurs within the historic range of the Neosho mucket. Because the Neosho mucket is listed as state endangered in Oklahoma it is illegal to collect, however incidental take may still occur.

III. METHODS

Site Selection

We surveyed the Illinois, Spring, Neosho, Verdigris and Caney rivers for all mussel species, including Neosho muckets. The entire Oklahoma portions of most of these rivers were traversed by small boat or canoe. We located areas with mussels by looking for dead shells on shore and in shallow water, by back tracking upstream from dead shells until we found live mussels, and by doing "reconnaissance" dives and/or snorkel searches (Vaughn et al., 1997).

We traversed a significant proportion of the Illinois River by canoe and boat during summer 1995. We identified 52 sites (Figure 1) along the Illinois River between Lake Francis and Lake Tenkiller with potential mussel habitat. We traversed the entire upper Verdigris, Neosho and Spring rivers by canoe from the state line to where the rivers enter Oologah and Grand lakes, respectively, during summer 1996 (Figure 2). We identified 47 areas (Figure 2) with potential mussel habitat: 20 sites on the upper Verdigris River, 17 sites on the Neosho River, and 10 sites on the Spring River. We traversed the entire Caney River, from directly below Hulah Lake to where the river joins the Verdigris River near Claremore in the summer of 1997 (Figure 3). We traversed the lower Verdigris River from directly below Oologah Lake to near Claremore, where the river became too large for us to sample (Figure 3). We identified 41 sites with potential mussel habitat, 29 on the Caney River and 12 on the lower Verdigris River (Figure 3).

Mussel Sampling

At each site with live mussels all areas of potential mussel habitat were searched. We used snorkeling and/or SCUBA to determine the edges of the mussel bed. Average width and length of each mussel bed were then measured in meters and used to calculate mussel bed area. We sampled mussels by conducting timed searches (Vaughn et al., 1997). Timed searches were supplemented with quadrat samples at sites where mussels were abundant enough to allow this technique to be used. Sampling was done by hand, with the aid of SCUBA in deeper areas (> .75 m), for both quadrat sampling and timed searches. For both techniques, mussels were placed in a canvas bag underwater and removed to shore. Individual mussels were identified, their total length measured, and returned to the mussel bed after all sampling was completed. Limited voucher specimens of some species were collected and are currently housed in the Oklahoma Biological Survey mussel collection.

In the Verdigris, Caney, Neosho and Spring Rivers we systematically recorded the presence of all species of dead shell observed. In most cases, we make no reference to the age of the shell, except in the case of Neosho muckets. For the Illinois River, which was surveyed during the first year of this project, we did not systematically record species of shells observed for every site. However, we did record the presence and condition of *L. rafinesqueana* shells.

Habitat Characterization

At a subsample of sites where live mussels were sampled we recorded a suite of environmental parameters (Table 1). We measured air and water temperature, pH, conductivity, and dissolved oxygen. We measured stream width. We recorded a minimum of five measures of stream depth, and calculated a mean and coefficient of variation for stream depth. We measured current velocity at a depth of 10 cm above the bottom using a Marsh McBirney flow meter. We took a minimum of five current velocity readings and calculated a mean and coefficient of variation.

Two replicate water samples were taken for mineral determination and sent to a professional water quality laboratory at the University of Georgia for analysi Replicate substrate samples were collected at each site. Substrate samples were dry si i, weighed, and individual proportions of samples assigned to the appropriate trate size classes (in mm) as described in Gordon et al. (1992). Because much of the s rate we collected was categorized as gravel (particles with a least diameter of 2 - 64 mm Table 1), we further characterized the gravel component of the substrate samples by measuring the least diameter of 50 individual gravel particles from each sample. We then calculated mean gravel diameter and coefficients of variation for each sample.

Existing and potential threats to *L. rafinesqueanae* and other mussel species were recorded at each site. We also took notes on the riparian area and composition, bank condition, predominant geological features, and terrestrial animals observed in the vicinity.

IV. RESULTS

Distribution and Abundance of Unionids by River

Illinois River

We identified 52 sites (Figure 1, Table 2) along the Illinois River between Lake Francis and Lake Tenkiller with potential mussel habitat. We examined 42 of these sites for live mussels. However, only 11/42, or 26%, of these sites actually harbored live mussels. The Illinois River is currently the most diverse of the five rivers surveyed. We found 17 species of living mussels in the Illinois River. Mussel abundance for sites with live mussels ranged from 1 to 150 mussels found per hour of searching, with a mean for all sites `8.72 individual mussels found per hour (Table . . Species richness ranged from 0 to 14 species per site, with a mean of 1.62 specie: ›er site (Table 2). The Illinois River fauna included several species that have been ε :irpated in the other four rivers, *Pleurobema coccineum*, *Ptychobranchus occia ıtalis*, *Quadrula cylindrica* and *Truncilla truncata* (Table 3). *Lampsilis rafinesqueana* occurred at 9/11, or 82%, of the sites with live mussels, and was the dominant mussel species in the Illinois River (Table 4).

We graphically examined shell lengths of the most common species from the Illinois River to assess recruitment patterns. Relatively young individuals were found for *Amblema plicata* (Figure 4), *Tritogonia verrucosa* (Figure 5), and *Lampsilis cardium* (Figure 7), but not for *Fusconaia flava* (Figure 6).

Although we did not systematically record the species of dead shell found at all sites along the Illinois River, many areas containing abundant dead shell but no live mussels were observed (Appendix 1). These areas all tended to be in the mid-channel of the river. Areas containing live mussels were almost exclusively in backwaters and side channels of the river. The Illinois River sediments in the mid-channel appear to have been more frequently displaced than those in the side channels and backwaters (Vaughn, pers. obs.). Historically, releases from an upstream reservoir no longer in existence, Lake Francis, may have scoured mid-channel sediments and displaced mussels or smothered them with sediment. Currently, there is very heavy recreational use of this river by canoes. During our surveys we often observed canoers trampling and pulling canoes through areas of mussel habitat in the main channel of the river. We never saw canoers using the side channels or backwaters.

Spring River

Mussel populations in the Oklahoma portion of the Spring River are very sparse and species-poor. In the Spring River 4/10 (40%) of the identified sites had live mussels, however mean abundance was only one mussel/hour and mean species richness was less than one (Table 2). Only three species of living mussels occurred in the Spring River, *Lampsilis cardium*, *Leptodea fragilis* and *Potamilus purpuratus* (Table 3). Dead shell was found for 22 mussel species, indicating that 19 mussel species have probably been extirpated from this stretch of river (Table 3). Because mussels were so sparse in the Spring River, we could not examine recruitment patterns.

Neosho River

In the Neosho River 11/17 (65%) of the sites had live mussels. Abundance ranged from one to 129 mussels for sites with live mussels, with a mean abundance of 12.78 mussels/hour searching (Table 2). We found 12 species of living mussels, and 21 species of dead shell, indicating that 9 species may have been extirpated from the river (Table 3). Mean species richness was 2.71 (Table 2). All of the nine living species are broad-ranging, common species (Williams et al. 1993).

We examined the shell length distributions of the three most common species in the Neosho River. We did not find many young individuals for either *Tritogonia verrucosa* (Figure 8), *Potamilus purpuratus* (Figure 9) or *Quadrula metanevra* (Figure 10).

Verdigris River

In the Verdigris River 26/32 (81%) of the sites examined had live mussels. Abundance at sites with live mussels ranged from one to 82 individuals found per hour, with a mean abundance of 14.43 individuals/found per hour (Table 2) Species richness at sites with live mussels ranged from one to 11 species, with a mean species richness for all sites of 3.29 (Table 2). We found a total of 16 living species in the Verdigris River and 28 species of dead shell, indicating that 12 species of mussels may be extirpated from this river (Table 3).

We examined shell length distributions for the four most common mussel species in the Verdigris River, *Amblema plicata* (Figure 11), *Tritogonia verrucosa* (Figure 12), *Quadrula metanevra* (Figure 13), and *Potamilus purpuratus* (Figure 14). Few young individuals were found for any of these species.

Caney River

In the Caney River 22/29 (75%) of the sites examined had live mussels. Abundance at sites with live mussels ranged from one to 84 individual mussels found/hour, with mean abundance of 12.6 mussels/hour for all sites (Table 2). Species richness at sites with live mussels ranged from one to 7 species, with a mean species richness for all sites of 2.38. We found a total of 12 living species of mussels in the Caney River and 24 species of dead shell, indicating that 12 mussel species may be extirpated from the Caney River (Table 3).

We examined shell length distributions of *Tritogonia verrucosa* (Figure 15), *Fusconaia flava* (Figure 16) and *Quadrula pustulosa* (Figure 17) from the Caney River. Only *Tritogonia verrucosa* appeared to be recruiting young individuals.

Distribution and abundance of Neosho muckets

Lampsilis rafinesqueana occurred at 82% of the sites with live mussels in the Illinois River. No live *L. rafinesqueana* were found in the other four rivers despite very intensive survey efforts (Table 2). Relic *L. rafinesqueana* shells were found at 29% of the sites in the Neosho River, 60% of the sites in the Spring River, 40% of the sites in the Verdigris River, and 20% of the sites in the Caney River. Fresh, dead *L. rafinesqueana* shells were found at two sites on the Spring River. The fresh Spring River shells may have come down river from known, healthy Neosho mucket populations in the Spring River in Missouri (Obermeyer et al. 1997; Chris Barnhart, pers. com.).

Of the sites in the Illinois River where Neosho muckets occurred, 4 of these were historical sites and 5 were newly discovered sites. The number of individual *L. rafinesqueana* located per site (at the nine sites where they occurred) varied from 1 to 61. Relative abundance of *L. rafinesqueana* varied from 6.46% to 63.16%. *L. rafinesqueana* were either the first or second most dominant species at 8/9 sites at which they were found (Table 5).

Table 5. Number of individuals, relative abundance, and dominance rank in the mussel community of *Lampsilis rafinesqueana* at the nine sites in the Illinois River. The last column gives the number of mussel species found at that site.

Site	Number of individuals	Relative Abundance	Dominance Rank	Number of Mussel species
*F95EBE01	36	63.16%	1	5
*F95EBE03	8	6.46%	2	13
F95EBE06	7	9.72%	2 (tie)	14
F95EBE09A	2	33.34%	2	3
F95EBE09B	1	14.29%	1 (tie)	7
F95EBE12	61	39.11%	1	13
*F95EBE14	6	26.09%	2	6
F95EBE27	3	22.77%	3	4
*F95EBE28	5	35.72	1	6

*historical site

We examined the shell size distribution of all sampled Neosho muckets in the Illinois River. We found very few small individuals of either female (Figure 18) or male (Figure 19) muckets. However, we did observe females with swollen marsupia and displaying their mantle flaps.

Habitat Associations for Neosho muckets

We examined the relationship between the presence and absence of Neosho muckets and environmental variables using the data given in Tables 1 and 4. A multiple regression model using all of the habitat parameters to predict the presence or absence of Neosho muckets was significant ($R = 0.97$, $p = 0.01$). We then used discriminant analysis to determine which variables could most accurately predict the presence or absence of Neosho muckets at a site. A highly significant discriminant model was produced using four habitat variables: stream depth, calcium concentration, mean gravel diameter, and the coefficient of variation of gravel diameter (Table 6). This model successfully predicted the presence or absence of Neosho muckets 95% of the time.

Table 6. Discriminant model predicting the presence or absence of Neosho muckets for the data in Tables 1 and 4. The overall model is significant ($F = 20.43$, $p < 0.001$).

Variable	$F_{(4,15)}$	P
Calcium	2.484	0.025
Depth	1.596	0.131
Gravel diameter	0.677	0.509
Variation in gravel diameter	-3.807	0.002

Calcium concentration was higher in the Illinois River (Figure 20), where Neosho muckets occurred, than the other rivers, probably due to the karst topography of the watershed which is on the edge of the Ozark Plateau. However, calcium concentrations were not at limiting levels in the other rivers (Table 1), and the importance of this factor in governing the distribution of the species within these five rivers is doubtful.

Areas where Neosho muckets were found were deeper than sites with significant numbers of live mussels in the other four rivers (Figure 21). The Illinois River is fed by many springs and maintains a higher summer base flow than the other streams studied. Because all Neosho mucket sites were in the Illinois River, stream depth may, like calcium, be an artifact of the analysis rather than a true limiting factor.

Sites with Neosho muckets had larger gravel (Figure 22), with less variation in gravel diameter (Figure 23), than sites in the other four rivers with abundant mussels. Such sites could be more stable and less compacted than sites with overall smaller gravel, and with a large variation in gravel size. Sites with large gravel without small gravel interspersed would provide good water flow through the streambed. Although we did not directly measure sediment stability or compactedness, these have recently been found to be very important to mussels (DiMaio and Corkum 1995). Compacted sediments are difficult for mussels to burrow in and are often low in oxygen. Larger gravel would be more resistant to discharge events (Gordon et al. 1992). Obermeyer et al. (1997) found that *L. rafinesqueana* occurred most often in shallow riffles and runs having predominately gravel substrate and swift currents.

Neosho muckets and other mussel species were generally restricted to side channels and backwaters in the Illinois River. This is in contrast to Obermeyer et al. (1997) who generally found the species in mid-channel riffles and runs in other rivers. The restricted distribution of the species to these relatively protected habitats in the Illinois River is probably not a habitat preference, but a result of past disturbances in the Illinois River that extirpated mussels from the mid-channel areas.

Estimate of Available Habitat and Population Size for the Neosho Mucket in Oklahoma.

It is important to note that Neosho muckets only occurred in one of the 5 rivers surveyed, but that dead shell distributions indicate that Neosho muckets were once widespread in all four of the rivers in which they are now extirpated. Thus, the above habitat analysis necessarily gives undue weight to conditions in the Illinois River. While calcium, depth, gravel size and variation in gravel size may be good descriptors of where mussels occur in the Illinois River. they may be of little importance in the absence of this species from the other four rivers. In addition, at one site in the Illinois River *L. rafinesqueana* were living wedged between rocks on a submerged ledge on the side of the channel.

We surveyed the entire riverine extent of the Neosho and Spring rivers in Oklahoma, and as much of the Caney and Verdigris rivers as our methods and equipment would allow. Areas of the Caney and Verdigris rivers not surveyed were "big river" habitat and would be unlikely to contain Neosho Muckets. We are confident that Neosho muckets are extirpated from these rivers.

We traversed the entire Illinois River from Lake Francis to Lake Tenkiller. We know where the areas of mussel habitat are located and we sampled most of them. However, there are areas in the Illinois River that contained live mussels, but that we were unable to quantitatively survey. There are additional areas that looked like good mussel habitat, and that we were unable to survey. These 10 sites are indicated as "NS" in Table 2 and are described in more detail in the appendix. Since Neosho muckets are the dominant mussel species in the Illinois River it is reasonable to assume that all 10 of these sites may contain the species. Average Neosho mucket abundance at a site is 14 individuals. Thus, these unsurveyed sites could conservatively contain 140 individuals. That combined with the sites we did survey gives a value of approximately 300 individuals for this stretch of the river. However, we should assume that we missed sites and missed sampling at least half of the individuals at each site (due to deeply buried individuals etc...). A more accurate population estimate for the Oklahoma portion of the Illinois River is probably between 500 - 1000 individuals.

Conclusions and Recommendations

The distribution of relic *Lampsilis rafinesqueana* shells indicates that this species was once widespread in all of the rivers (Table 2). Dead shell distribution data indicate that mussels have declined significantly overall, both in terms of abundance of individuals and species richness (Table 3). Size distribution data for all of the rivers surveyed points toward poor recruitment of even the most common species. In addition, even though *L. rafinesqueana* is the dominant mussel species in the Illinois River, dead shell evidence indicate that mussels overall are undergoing a severe decline in this river (Vaughn, pers. obs.).

The apparent extirpation of *L. rafinesqueana* from the Oklahoma portions of the Verdigris, Caney, Neosho and Spring rivers is probably due to the same factor(s) responsible for the decline of freshwater mussels in general in these rivers. The major factors in the Verdigris, Caney and Neosho rivers are impoundments and sedimentation from agricultural runoff (Obermeyer et al. 1997). The Spring River has been impacted by extensive lead and zinc mining in the basin (Obermeyer et al. 1997).

Most mussel species cannot live in impoundments (Watters 1996) and do poorly in the altered hydrologic regimes below impoundments (Mehlhop and Vaughn 1994). Mussels are sedentary filter-feeders that are rooted to approximately the same spot for their entire 40 to 50 year life span. Because of this they are among the most sensitive organisms to siltation (Ellis 1936. Simmons and Reed 1973). A heavy layer of silt can cause suffocation of an entire mussel bed, and siltation has contributed to massive extirpations of mussels in other rivers (Anderson et al. 1991). The erosional processes causing increased silt loads may also lead to shifting, unstable stream bottoms in which mussels cannot survive (Williams et al. 1993).

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VII.

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Table 1. Environmental parameters for sites where live mussels were sampled.

	F95EBE01	F95EBE03	F95EBE06	F95EBE09	F95EBE12
Water temp (C)	31.000	28.500	30.100	27.100	29.400
pH	8.000	8.250	8.200	7.060	8.100
Conductivity (umho)	204.000	189.000	189.000	319.000	371.000
Dissolved oxygen (mg/L)	8.800	7.200	7.300	5.000	8.500
Stream width (m)	35.000	25.000	18.000	7.000	14.000
Mean depth (cm)	76.000	133.200	101.000	101.800	95.800
Depth CV	28.917	22.292	16.163	17.077	17.285
Mean flow (m/s)	0.028	0.070	0.050	0.022	0.176
Flow CV	85.267	76.265	31.623	20.328	54.141
Bed area (m2)	159.900	1500.000	4557.000	161.000	473.000
Percent gravel	96.000	95.471	73.935	92.000	94.053
Percent coarse sand	1.000	2.696	7.776	4.000	2.940
Percent fine sand	3.000	1.833	18.289	2.010	3.007
Mean gravel diameter (mm)	11.500	11.500	11.160	11.000	12.600
Gravel diameter CV	5.245	5.245	5.637	5.730	6.725
Mineral concentrations (mg/L)					
Al	0.005	0.063	0.034	0.048	0.048
B	0.046	0.034	0.040	0.037	0.037
Ba	0.067	0.074	0.070	0.072	0.072
Ca	33.388	40.795	37.092	38.943	38.943
Cd	0.021	0.010	0.015	0.012	0.012
Co	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000
Cu	0.000	0.066	0.033	0.050	0.050
Fe	0.000	0.081	0.041	0.061	0.061
K	3.755	3.032	3.394	3.213	3.213
Mg	1.840	2.316	2.078	2.197	2.197
Mn	0.011	0.029	0.020	0.025	0.025
Mo	0.004	0.000	0.002	0.001	0.001
Na	6.140	7.316	6.728	7.022	7.022
Ni	0.011	0.000	0.006	0.003	0.003
P	0.000	0.000	0.000	0.000	0.000
Pb	0.000	0.000	0.000	0.000	0.000
Si	0.626	0.562	0.594	0.578	0.578
Sr	0.051	0.062	0.057	0.059	0.059
Zn	0.000	0.000	0.000	0.000	0.000

Table 1. Environmental parameters for sites where live mussels were sampled.

F95EBE14	F95EBE27	F95EBE28	F96VAU32	F96VAU41	F96VAU57	F96VAU59
27.000	28.300	27.000	30.000	30.000	29.000	29.000
7.820	7.990	7.800	7.540	8.100	7.530	7.600
372.000	379.000	344.000	335.000	315.000	410.000	420.000
6.600	8.400	7.400	8.700	7.000	9.900	9.000
27.000	30.000	39.000	36.570	58.000	27.000	38.000
13.600	13.000	73.400	34.200	13.000	42.200	21.400
38.769	79.756	23.629	13.463	23.709	15.394	47.494
0.006	0.200	0.338	0.342	0.450	0.274	0.180
149.071	57.000	34.969	19.329	26.434	46.424	38.087
120.000	23.000	247.000	250.802	7424.000	69.412	2730.000
57.632	88.302	58.766	97.351	85.664	99.196	98.402
35.145	10.970	13.604	2.231	10.223	0.447	0.790
7.224	0.728	27.630	0.418	4.113	0.357	0.809
10.580	10.320	13.780	1.102	1.104	3.125	1.730
6.341	4.089	5.918	8.718	7.961	5.627	10.898
0.048	0.048	0.048	0.581	0.865	0.553	0.556
0.037	0.037	0.037	0.000	0.092	0.043	0.021
0.072	0.072	0.072	0.016	0.126	0.576	0.073
38.943	38.943	38.943	22.343	25.789	29.528	27.912
0.012	0.012	0.012	0.000	0.081	0.041	0.021
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.048	0.052	0.063
0.050	0.050	0.050	0.017	0.065	0.045	0.021
0.061	0.061	0.061	0.050	0.240	0.035	0.045
3.213	3.213	3.213	0.000	3.616	5.359	6.178
2.197	2.197	2.197	5.000	5.669	7.051	6.633
0.025	0.025	0.025	0.000	0.061	0.030	0.011
0.001	0.001	0.001	0.000	0.000	0.000	0.000
7.022	7.022	7.022	6.333	6.561	19.392	18.681
0.003	0.003	0.003	0.000	0.057	0.007	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.578	0.578	0.578	4.910	5.970	3.000	2.994
0.059	0.059	0.059	0.181	0.317	0.385	0.354
0.000	0.000	0.000	0.000	0.025	0.023	0.009

Table 1. Environmental parameters for sites where live mussels were sampled.

F96VAU62	F96VAU66	F96VAU71	F97VAU57	F97VAU68	F97VAU71	F97VAU87
29.000	28.000	29.000	34.000	28.000	28.000	26.000
7.600	7.500	7.100	8.100	6.700	7.500	7.600
460.000	560.000	479.000	400.000	412.000	425.000	420.000
12.300	11.100	8.550	9.600	7.000	0.600	8.000
35.000	35.000	46.000	30.000	10.000	9.000	12.800
16.600	19.600	22.600	16.950	7.600	11.600	26.200
39.640	20.599	30.910	40.371	7.207	34.267	45.754
0.144	0.408	0.088	1.034	0.396	0.458	0.641
60.660	34.024	34.468	54.131	57.877	42.236	51.162
8400.000	1008.000	1380.000	30.000	16.000	80.000	140.000
86.830	77.374	96.083	95.961	94.272	90.425	90.191
7.149	13.927	1.497	2.076	3.422	8.515	8.460
6.020	8.700	2.421	1.963	2.306	1.060	1.348
1.634	1.040	2.806	2.016	2.178	1.422	1.886
9.788	13.069	8.424	19.298	15.873	14.035	16.791
0.527	0.541	0.534	0.023	0.515	0.705	0.610
0.014	0.018	0.016	0.000	0.000	0.005	0.002
0.064	0.068	0.066	0.052	0.079	0.092	0.085
22.550	25.231	23.890	36.143	39.562	44.078	41.820
0.025	0.023	0.024	0.011	0.033	0.025	0.029
0.000	0.000	0.000	0.012	0.000	0.000	0.000
0.032	0.047	0.040	0.079	0.000	0.046	0.023
0.035	0.028	0.031	0.000	0.009	0.025	0.017
0.006	0.026	0.016	0.021	0.281	0.383	0.332
7.774	6.976	7.375	4.825	1.676	2.362	2.019
4.929	5.781	5.355	9.384	7.630	8.441	8.035
0.012	0.011	0.011	0.025	0.000	0.021	0.010
0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.794	17.737	17.265	13.447	14.272	14.169	14.221
0.003	0.001	0.002	0.000	0.014	0.000	0.007
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.528	2.761	2.644	3.929	5.964	6.502	6.233
0.255	0.305	0.280	0.326	0.292	0.307	0.299
0.010	0.010	0.010	0.000	0.000	0.000	0.000

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
ILLINOIS	1	1	F95EBE01	56	90	37	5	
ILLINOIS	1	2	F95EBE02	1	60	1	1	
ILLINOIS	1	3	F95EBE03	125	120	63	11	
ILLINOIS	1	4	F95EBE04	0	30	0	0	
ILLINOIS	1	5	F95EBE05	0	120	0	0	
ILLINOIS	1	6	F95EBE06	74	90	49	14	
ILLINOIS	1	7	F95EBE07	0	30	0	0	
ILLINOIS	1	8	F95EBE08	0	30	0	0	
ILLINOIS	1	9a	F95ENE9A	6	45	8	3	
ILLINOIS	1	9b	F95EBE9B	7	45	9	6	
ILLINOIS	1	10	F95EBE10	NS				
ILLINOIS	1	11	F95EBE11	0	30	0	0	
ILLINOIS	1	12	F95EBE12	150	60	150	14	
ILLINOIS	1	13	F95EBE13	0	30	0	0	
ILLINOIS	1	14	F95EBE14	23	60	23	4	
ILLINOIS	1	15	F95EBE15	0	30	0	0	
ILLINOIS	1	16	F95EBE16	0	30	0	0	
ILLINOIS	1	17	F95EBE17	0	30	0	0	
ILLINOIS	1	18	F95EBE18	0	30	0	0	
ILLINOIS	1	19	F95EBE19	0	30	0	0	
ILLINOIS	1	20	F95EBE20	0	60	0	0	*relic*
ILLINOIS	1	21	F95EBE21	0	90	0	0	
ILLINOIS	1	22	F95EBE22	1	90	1	1	
ILLINOIS	1	23	F95EBE23	NS				
ILLINOIS	1	24	F95EBE24	0	30	0	0	
ILLINOIS	1	25	F95EBE25	0	30	0	0	
ILLINOIS	1	26	F95EBE26	0	30	0	0	
ILLINOIS	1	27	F95EBE27	11	60	11	3	
ILLINOIS	1	28	F95EBE28	14	60	14	6	
ILLINOIS	1	29	F95EBE29	0	30	0	0	*relic*
ILLINOIS	1	30	F95EBE30	0	30	0	0	
ILLINOIS	1	31	F95EBE31	NS				
ILLINOIS	1	32	F95EBE32	0	30	0	0	

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
ILLINOIS	1	33	F95EBE33	0	30	0	0	
ILLINOIS	1	34	F95EBE34	0	30	0	0	
ILLINOIS	1	35	F95EBE35	NS				
ILLINOIS	1	36	F95EBE36	NS				
ILLINOIS	1	37	F95EBE37	NS				
ILLINOIS	1	38	F95EBE38	0	30	0	0	
ILLINOIS	1	39	F95EBE39	NS				
ILLINOIS	1	40	F95EBE40	NS				
ILLINOIS	1	41	F95EBE41	NS				
ILLINOIS	1	42	F95EBE42	0	30	0	0	
ILLINOIS	1	43	F95EBE43	0	30	0	0	
ILLINOIS	1	44	F95EBE44	0	30	0	0	
ILLINOIS	1	45	F95EBE45	0	30	0	0	
ILLINOIS	1	46	F95EBE46	0	30	0	0	
ILLINOIS	1	47	F95EBE47	0	30	0	0	
ILLINOIS	1	49	F95EBE49	NS				
ILLINOIS	1	50	F95EBE50	0	30	0	0	
ILLINOIS	1	51	F95EBE51	0	30	0	0	
ILLINOIS	1	52	F95EBE52	0	30	0	0	
					Mean	**8.72**	**1.62**	
				Standard deviation		**26.15**	**3.62**	

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
VERDIGRIS	2	1	F96VAU64	1	10	6	1	*relic*
VERDIGRIS	2	2	F96VAU66	51	98	31	9	
VERDIGRIS	2	3	F96VAU65	2	45	3	1	
VERDIGRIS	2	4	F96VAU67	28	45	37	9	
VERDIGRIS	2	5	F96VAU61	11	45	15	6	
VERDIGRIS	2	6	F96VAU62	72	105	41	5	
VERDIGRIS	2	7	F96VAU63	8	15	32	4	
VERDIGRIS	2	8	F96VAU68	2	30	4	2	*relic*
VERDIGRIS	2	9	F96VAU69	1	30	2	1	*relic*
VERDIGRIS	2	10	F96VAU70	7	15	28	3	*relic*
VERDIGRIS	2	11	F96VAU71	82	135	36	11	*relic*
VERDIGRIS	2	12	F96VAU72	8	30	16	3	
VERDIGRIS	2	13	F96VAU53	9	20	27	4	*relic*
VERDIGRIS	2	14	F96VAU54	5	30	10	1	*relic*
VERDIGRIS	2	15	F96VAU56	3	25	7	2	
VERDIGRIS	2	16	F96VAU57	28	60	28	5	*relic*
VERDIGRIS	2	17	F96VAU55	3	30	6	2	
VERDIGRIS	2	18	F96VAU58	5	30	10	1	
VERDIGRIS	2	19	F95VAU59	21	90	14	9	
VERDIGRIS	2	20	F96VAU60	0	45	0	0	
VERDIGRIS	3	30	F97VAU50	0	90	0	0	
VERDIGRIS	3	31	F97VAU51	0	25	0	0	
VERDIGRIS	3	32	F97VAU52	0	40	0	0	
VERDIGRIS	3	33	F97VAU53	5	40	8	3	*relic*
VERDIGRIS	3	34	F97VAU54	0	90	0	0	*relic*
VERDIGRIS	3	35	F97VAU55	2	40	3	2	
VERDIGRIS	3	36	F97VAU56	3	45	4	3	*relic*
VERDIGRIS	3	37	F97VAU57	29	45	39	4	*relic*
VERDIGRIS	3	38	F97VAU58	8	45	11	2	
VERDIGRIS	3	39	F97VAU88	16	90	11	6	
VERDIGRIS	3	40	F97VAU89	19	60	19	3	*relic*
VERDIGRIS	3	41	F97VAU90	0	NS		0	
					Mean	**14.43**	**3.29**	
				Standard deviation		**13.47**	**2.99**	

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
NEOSHO	2	21	F96VAU33	0	15	0	0	
NEOSHO	2	22	F96VAU34	1	40	2	1	
NEOSHO	2	23	F96VAU35	0	60	0	0	*relic*
NEOSHO	2	24	F96VAU36	3	60	3	3	*relic*
NEOSHO	2	25	F96VAU41	129	60	129	7	
NEOSHO	2	26	F96VAU42	13	45	17	7	
NEOSHO	2	27	F96VAU40	3	40	5	2	
NEOSHO	2	28	F96VAU26	0	30	0	0	
NEOSHO	2	29	F96VAU27	17	60	17	4	
NEOSHO	2	30	F96VAU28	0	60	0	0	*relic*
NEOSHO	2	31	F96VAU29	4	60	4	3	*relic*
NEOSHO	2	32	F96VAU30	22	60	22	9	
NEOSHO	2	33	F96VAU31	0	60	0	0	*relic*
NEOSHO	2	34	F96VAU32	20	120	10	5	
NEOSHO	2	35	F96VAU37	0	30	0	0	
NEOSHO	2	36	F96VAU38	7	60	7	3	
NEOSHO	2	37	F96VAU39	2	60	2	2	
					Mean	**12.78**	**2.71**	
				Standard deviation		**30.76**	**2.87**	

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
SPRING	2	38	F96VAU46	0	45	0	0	*relic*
SPRING	2	39	F96VAU47	2	40	3	2	
SPRING	2	40	F96VAU48	3	45	4	2	*relic*
SPRING	2	41	F96VAU49	2	45	3	2	***fresh***
SPRING	2	42	F96VAU50	0	30	0	0	
SPRING	2	43	F96VAU51	0	30	0	0	***fresh***
SPRING	2	44	F96VAU52	1	20	3	1	
SPRING	2	45	F96VAU43	0	45	0	0	
SPRING	2	46	F96VAU44	0	45	0	0	*relic*
SPRING	2	47	F96VAU45	0	45	0	0	*relic*
					Mean	**1.27**	**0.70**	
				Standard deviation		**1.67**	**0.95**	

Table 2. Mussel abundance and species richness for all sites.

River	Figure	Number on Figure	Site Code	Total live Mussels	Minutes Searched	Mussels/ hour	Number of Species	Neosho mucket shells
CANEY	3	1	F97VAU62	0	45	0	0	
CANEY	3	2	F97VAU63	0	90	0	0	*relic*
CANEY	3	3	F97VAU64	3	65	3	1	
CANEY	3	4	F97VAU65	0	90	0	0	
CANEY	3	5	F97VAU66	19	45	25	4	
CANEY	3	6	F97VAU67	10	45	13	4	
CANEY	3	7	F97VAU68	65	45	87	5	
CANEY	3	8	F97VAU59	13	40	20	4	
CANEY	3	9	F97VAU60	2	45	3	1	
CANEY	3	10	F97VAU61	4	45	5	3	*relic*
CANEY	3	11	F97VAU71	61	90	41	6	*relic*
CANEY	3	12	F97VAU82	1	20	3	1	
CANEY	3	13	F97VAU83	0	90	0	0	
CANEY	3	14	F97VAU84	1	30	2	1	*relic*
CANEY	3	15	F97VAU69	0	45	0	0	
CANEY	3	16	F97VAU70	3	45	4	2	*relic*
CANEY	3	17	F97VAU72	5	30	10	2	
CANEY	3	18	F97VAU73	2	45	3	2	
CANEY	3	19	F97VAU74	21	45	28	2	
CANEY	3	20	F97VAU75	0	45	0	9	
CANEY	3	21	F97VAU76	0	90	0	0	
CANEY	3	22	F97VAU77	15	25	36	4	
CANEY	3	23	F97VAU78	7	45	9	4	*relic*
CANEY	3	24	F97VAU79	2	45	3	2	
CANEY	3	25	F97VAU80	0	90	0	0	
CANEY	3	26	F97VAU81	7	45	9	2	
CANEY	3	27	F97VAU85	4	120	2	2	
CANEY	3	28	F97VAU86	3	45	4	1	
CANEY	3	29	F97VAU87	84	90	56	7	
					Mean	**12.60**	**2.38**	
					Standard deviation	**20.14**	**2.31**	

Table 3. Live mussel species and dead shell found by river.

	Illinois	Spring		Neosho		Verdigris		Caney	
Mussel species	Live	Live	Shell	Live	Shell	Live	Shell	Live	Shell
Amblema plicata plicata	X		X	X	X	X	X	X	X
Cyprogenia aberti							X		
Ellipsaria lineolata			X		X		X		
Elliptio dilatata	X		X		X		X		X
Fusconaia flava	X		X		X	X	X	X	X
Lampsilis cardium	X	X	X	X	X	X	X		X
Lampsilis rafinesqueana	X		X		X		X		X
Lampsilis teres			X	X	X	X	X	X	X
Lasmigona complanata	X				X	X	X	X	X
Lasmigona costata	X								
Leptodea fragilis	X	X	X	X	X	X	X	X	X
Ligumia recta			X				X		
Ligumia subrostrata			X						X
Megalonaias nervosa			X	X	X	X	X		X
Obliquaria reflexa	X		X	X	X	X	X	X	X
Pleuorbema coccineum	X		X		X	X	X		X
Potamilus ohiensis					X	X	X		X
Potamilus purpuratus	X	X	X	X	X	X	X	X	X
Ptychobranhcus occidentalis	X		X		X		X		X
Pyganodon grandis	X		X				X		X
Quadrula cylindrica	X		X		X		X		X
Quadrula metanevra			X	X	X	X	X	X	X
Quadrula nodulata							X	X	X
Quadrula pustulosa	X		X	X	X	X	X	X	X
Quadrula quadrula			X	X	X	X	X	X	X
Strophitus undulatus							X		
Tritogona verrucosa	X		X	X	X	X	X	X	X
Truncilla donaciformis			X	X	X	X	X		
Truncilla truncata	X						X		X
Uniomerus tetralasmus							X		X
Number of Species	*17*	*3*	*22*	*12*	*21*	*16*	*28*	*12*	*24*

Table 4. Mussel species abundance by site for sites used in the habitat analyses. Mussel abundance is standardized as mussels found per hour of sampling effort.

River	Illinois	Illinois	Illinois	Illinois	Illinois	Illinois	Illinois	Illinois	Illinois
Site	F95EBE01	F95EBE03	F95EBE06	F95EBE09A	F95EBE09B	F95EBE12	F95EBE14	F95EBE27	F95EBE28
Amblema plicata	0.00	**44.00**	**3.96**	0.00	**1.30**	**6.00**	0.00	0.00	**1.00**
Elliptio dilata	0.00	0.00	**1.32**	0.00	0.00	0.00	0.00	0.00	0.00
Fusconaia flava	3.00	**1.00**	**3.30**	0.00	0.00	**20.00**	**1.00**	0.00	0.00
Lampsilis cardium	0.00	**2.00**	**9.90**	0.00	0.00	**8.00**	**11.00**	**4.00**	**4.00**
Lampsilis rafinesqueana	**36.00**	**4.00**	**4.62**	**2.60**	**1.30**	**65.00**	**6.00**	**3.00**	**5.00**
Lampsilis teres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lasmigona complanata	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00
Lasmigona costata	**1.00**	**0.50**	**3.30**	0.00	0.00	**5.00**	0.00	0.00	**1.00**
Leptodea fragilis	0.00	0.00	0.00	**1.30**	**2.60**	0.00	0.00	0.00	0.00
Megalonaias nervosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Obliquaria reflexa	0.00	**0.50**	**1.98**	0.00	0.00	**4.00**	0.00	0.00	0.00
Pleurobema coccineum	0.00	0.00	**0.66**	0.00	0.00	**2.00**	0.00	0.00	0.00
Potamilus ohiensis	**0.00**	0.00	0.00	0.00	**0.66**	0.00	0.00	0.00	0.00
Potamilus purpuratus	**13.00**	**1.00**	**3.96**	**3.90**	**1.30**	**5.00**	0.00	**4.00**	**2.00**
Ptychobranchus occidentalis	0.00	**1.00**	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00
Pyganodon grandis	0.00	0.00	**1.98**	0.00	**1.30**	0.00	0.00	0.00	0.00
Quadrula cylindrica	0.00	0.00	**1.32**	0.00	0.00	**3.00**	0.00	0.00	0.00
Quadrula metanevra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quadrula pustulosa	0.00	**2.00**	**5.94**	0.00	0.00	**14.00**	**5.00**	0.00	0.00
Quadrula nodulata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quadrula quadrula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tritogonia verrucosa	**3.00**	**3.00**	**4.62**	0.00	0.00	**12.00**	0.00	0.00	**1.00**
Truncilla truncata	0.00	1.00	**0.66**	0.00	0.00	**4.00**	0.00	0.00	0.00
Total mussels/hour	***56.00***	***60.00***	*47.52*	*7.80*	***8.46***	***150.00***	*23.00*	*11.00*	*14.00*
Number of species	***5.00***	***11.00***	***14.00***	***3.00***	***6.00***	***14.00***	***4.00***	***3.00***	***6.00***

Table 4. Mussel species abundance by site for sites used in the habitat analyses. Mussel abundance is standardized as mussels found per hour of sampling effort.

Neosho F96VAU32	Neosho f96vau41	Verdigris f96vau57	Verdigris f96vau59	Verdigris f96vau62	Verdigris f96vau66	Verdigris f96vau71	Verdigris f97vau57	Verdigris f97vau87	Caney f97vau68	Caney f97vau71
0.00	2.00	11.00	6.60	36.00	3.66	21.56	11.97	0.66	3.99	1.98
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.98	0.00	0.00	0.44	1.33	0.00	22.61	17.82
1.00	4.00	0.00	1.32	2.85	0.61	0.88	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	3.00	1.00	0.00	0.57	1.22	0.44	0.00	0.00	0.00	0.66
0.00	0.00	0.00	0.66	0.00	0.00	0.44	0.00	0.00	0.00	0.00
5.00	0.00	0.00	0.66	0.00	6.71	0.00	0.00	66.00	0.00	1.32
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	4.00	4.00	1.32	1.14	2.44	5.28	0.00	0.66	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	108.00	7.00	0.66	0.00	12.20	3.96	21.28	0.00	0.00	0.00
0.00	2.00	0.00	0.00	0.57	1.22	0.00	3.99	6.60	14.63	12.54
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.36	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.61	0.88	0.00	1.32	2.66	0.00
2.00	6.00	5.00	0.66	0.00	2.44	1.32	0.00	15.18	2.66	5.94
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.00	*129.00*	*28.00*	*13.86*	*41.13*	*31.11*	*36.52*	*38.57*	*120.78*	*46.55*	*40.26*
5.00	*7.00*	*5.00*	*8.00*	*5.00*	*9.00*	*11.00*	*4.00*	*7.00*	*5.00*	*6.00*

Figure 1. Sites examined for mussels in the Illinois River, 1995.

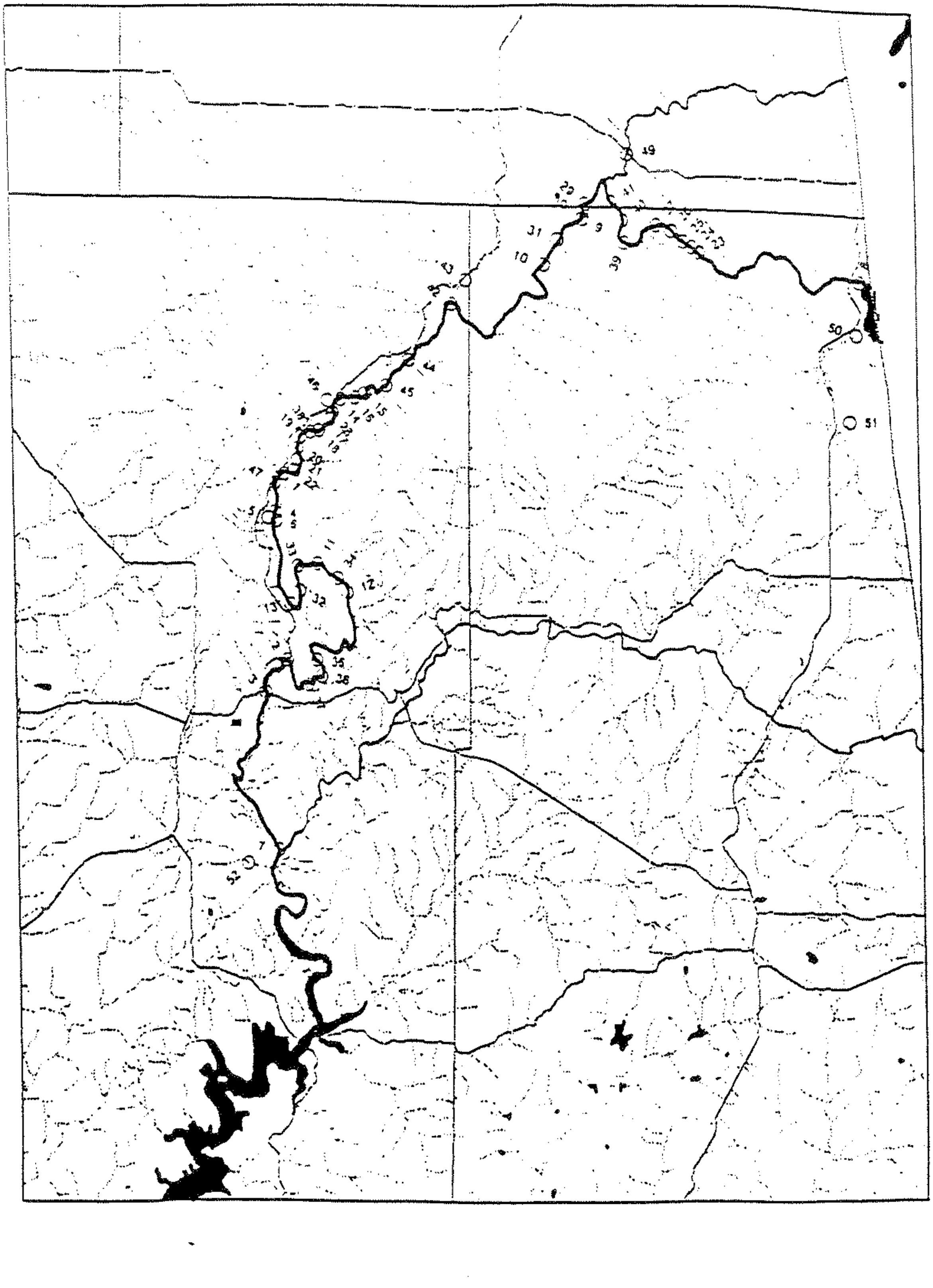
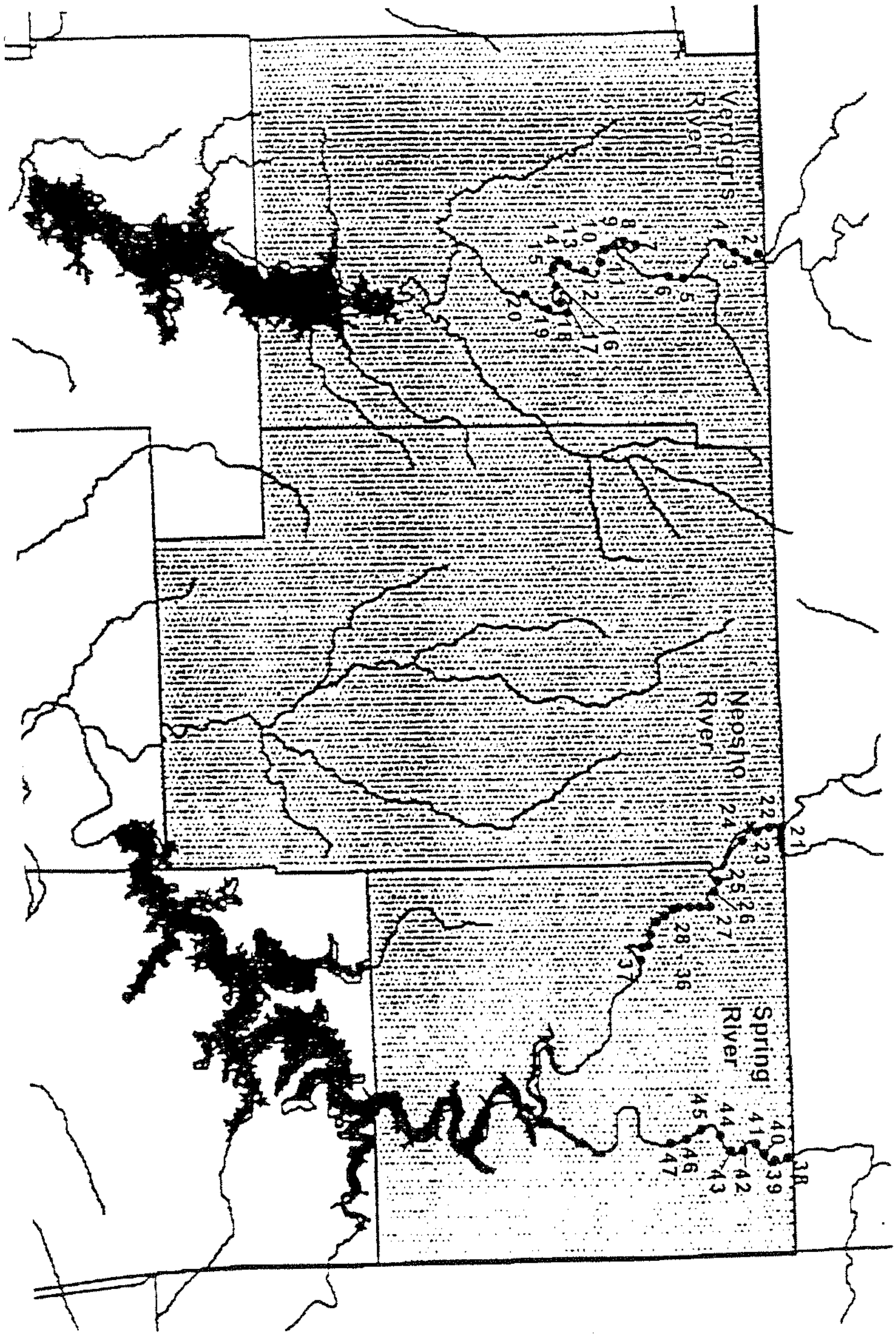


Figure 2. Location of sample sites on the Spring, Neosho and upper Verdigris rivers, 1996.



the Caney and lower Verdigris rivers, 1997.

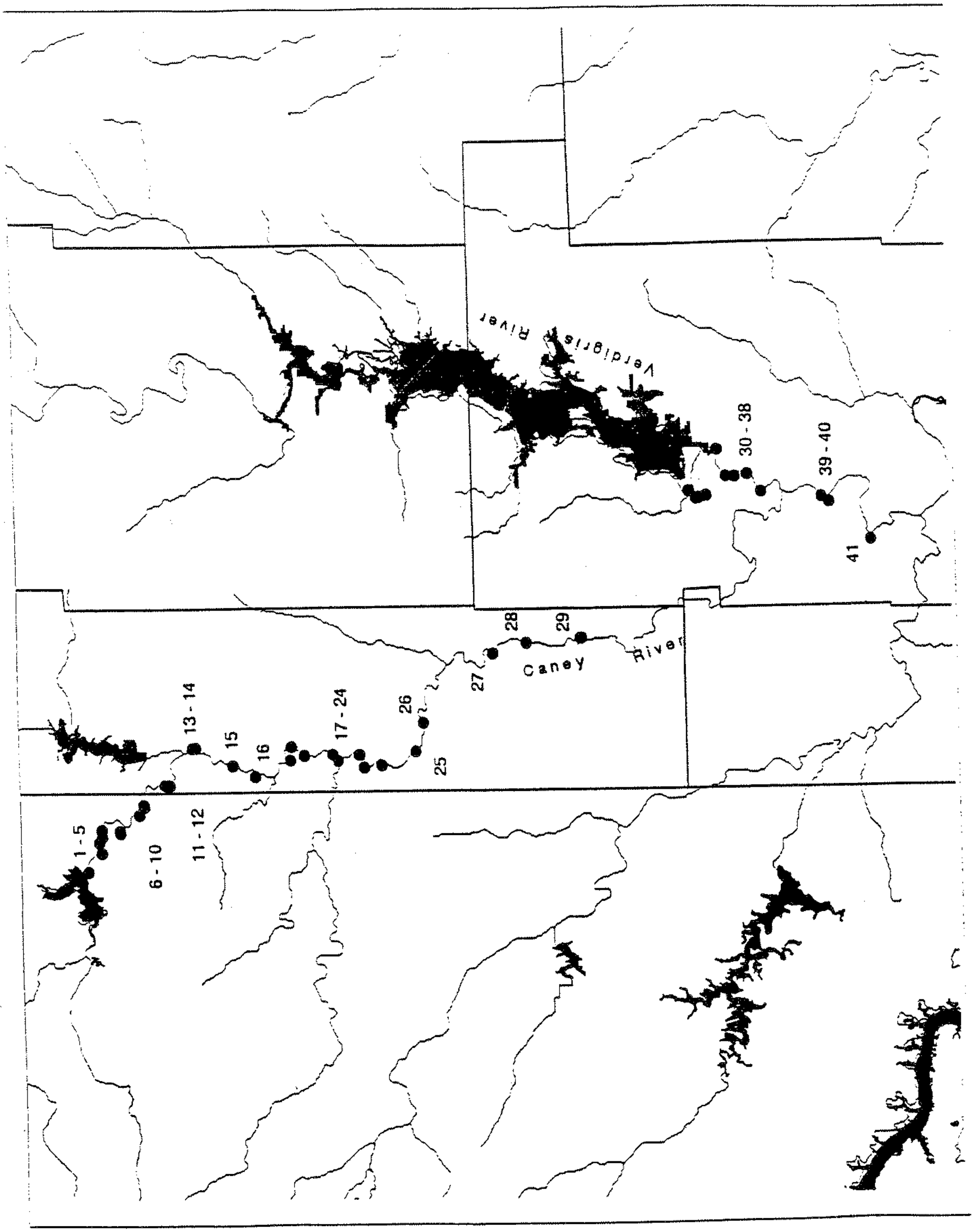
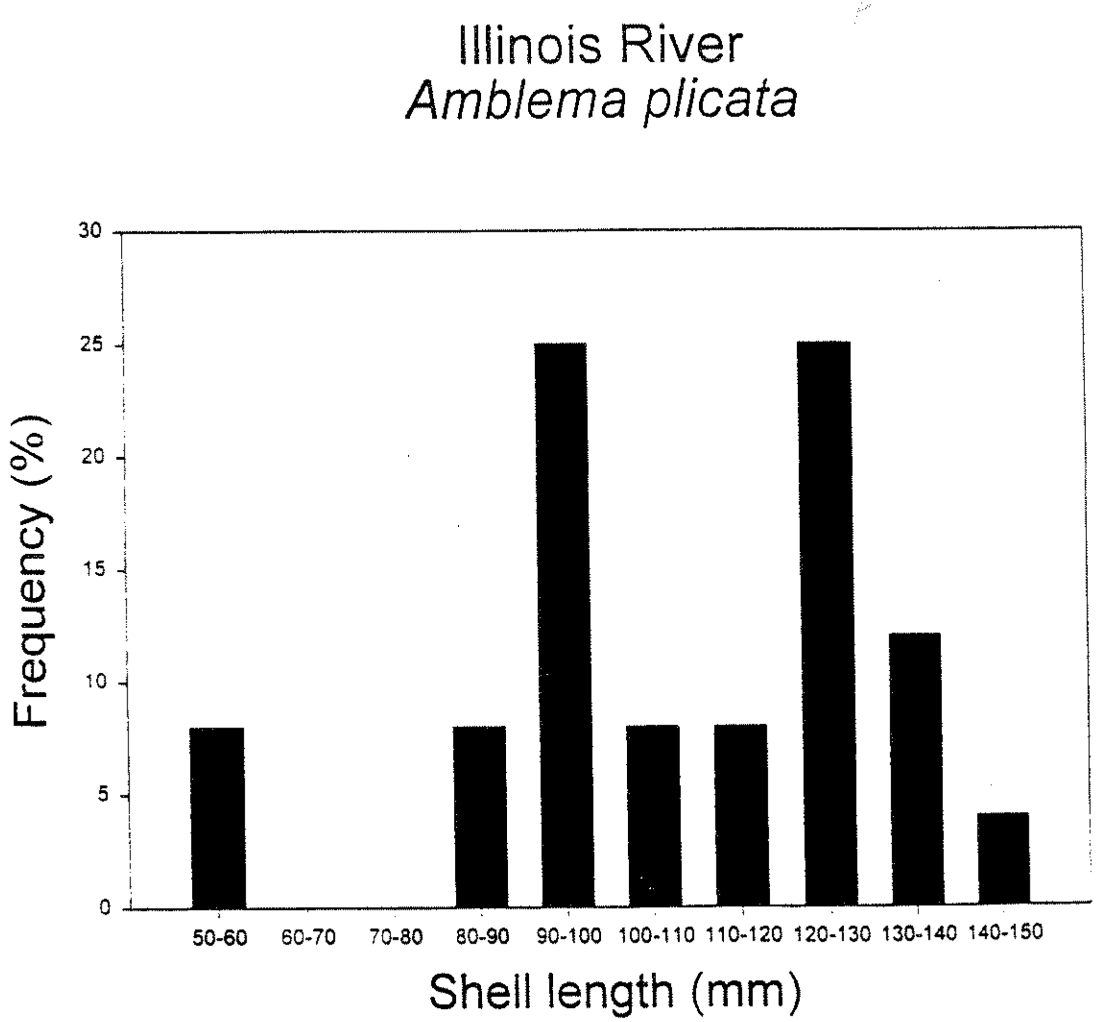
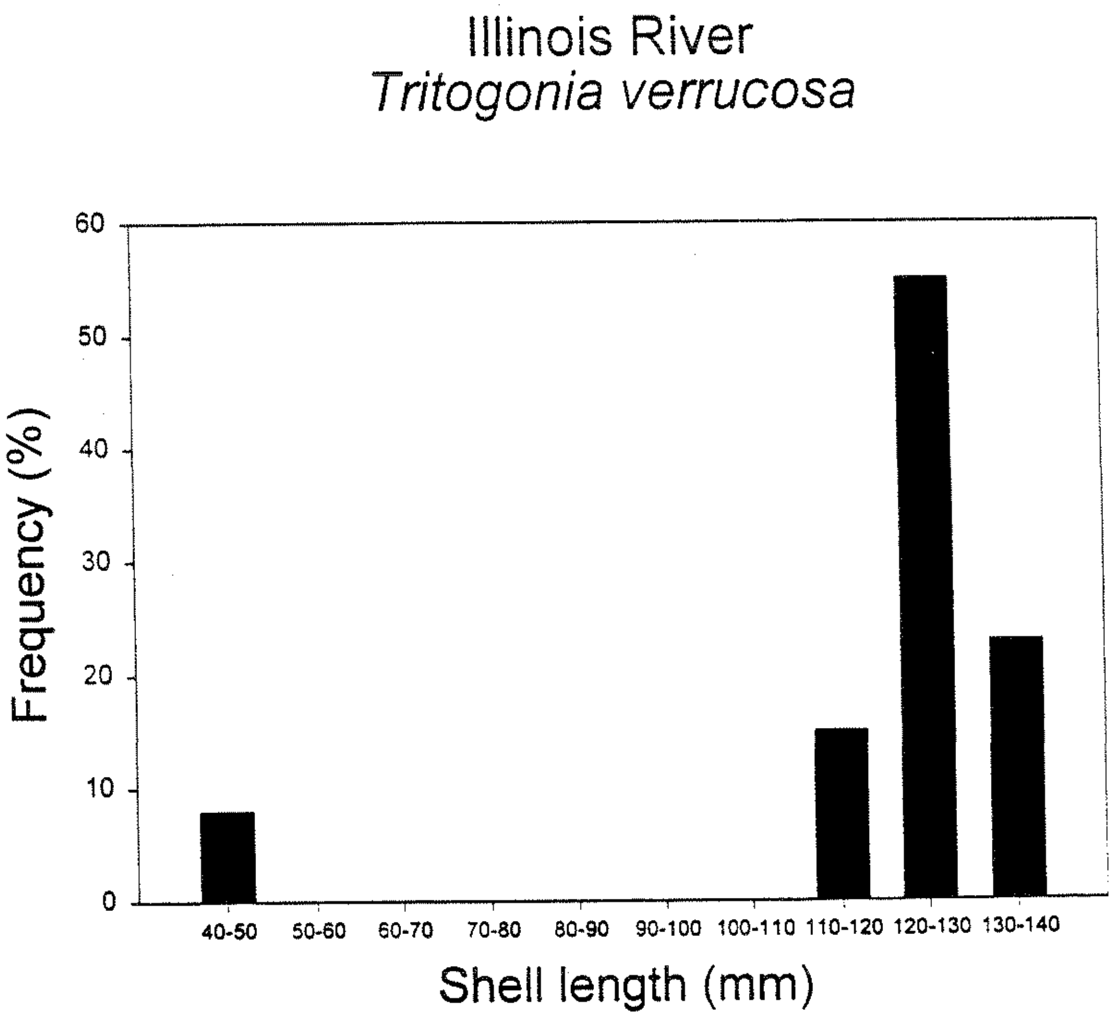


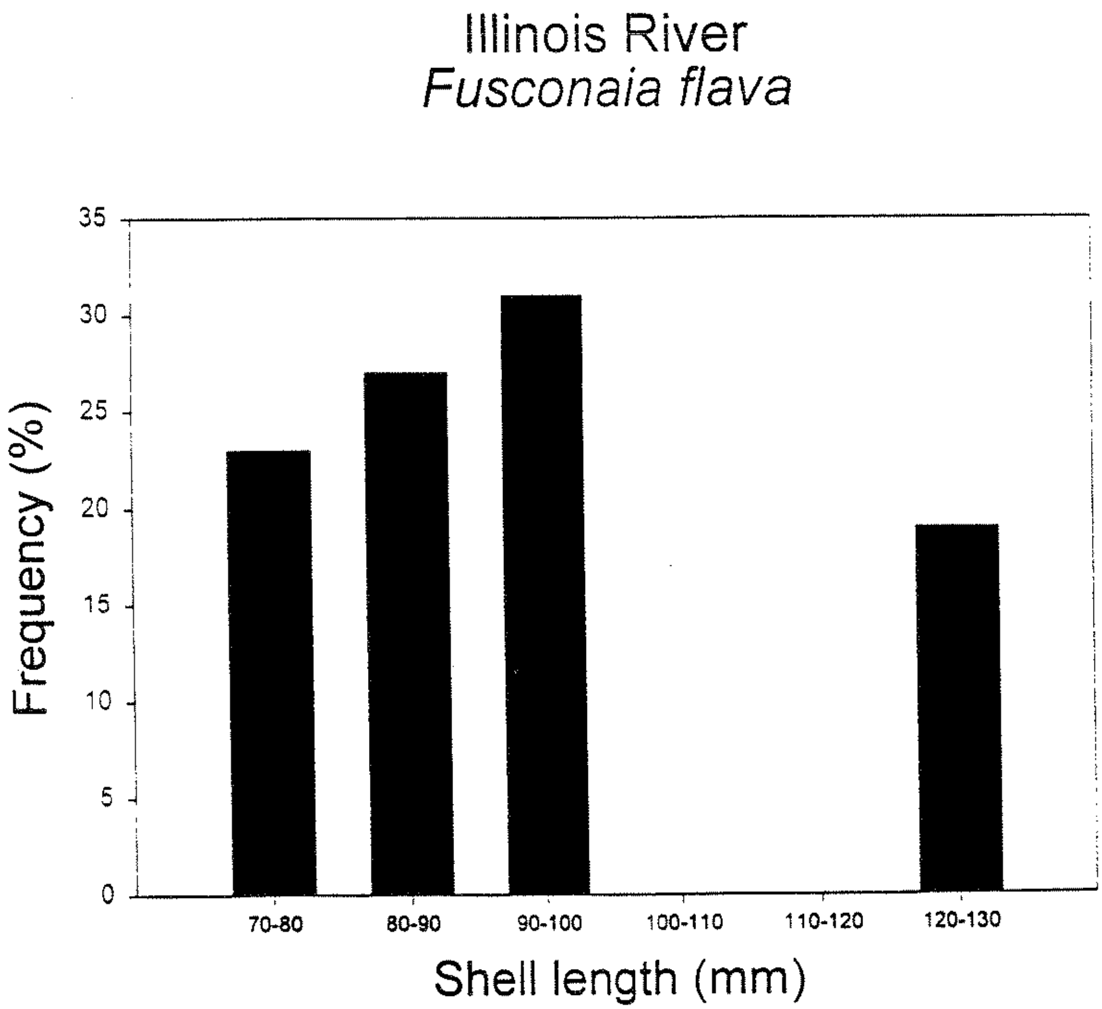
Figure 4. Size distribution of Amblema plicata in the Illinois River. N = 23.



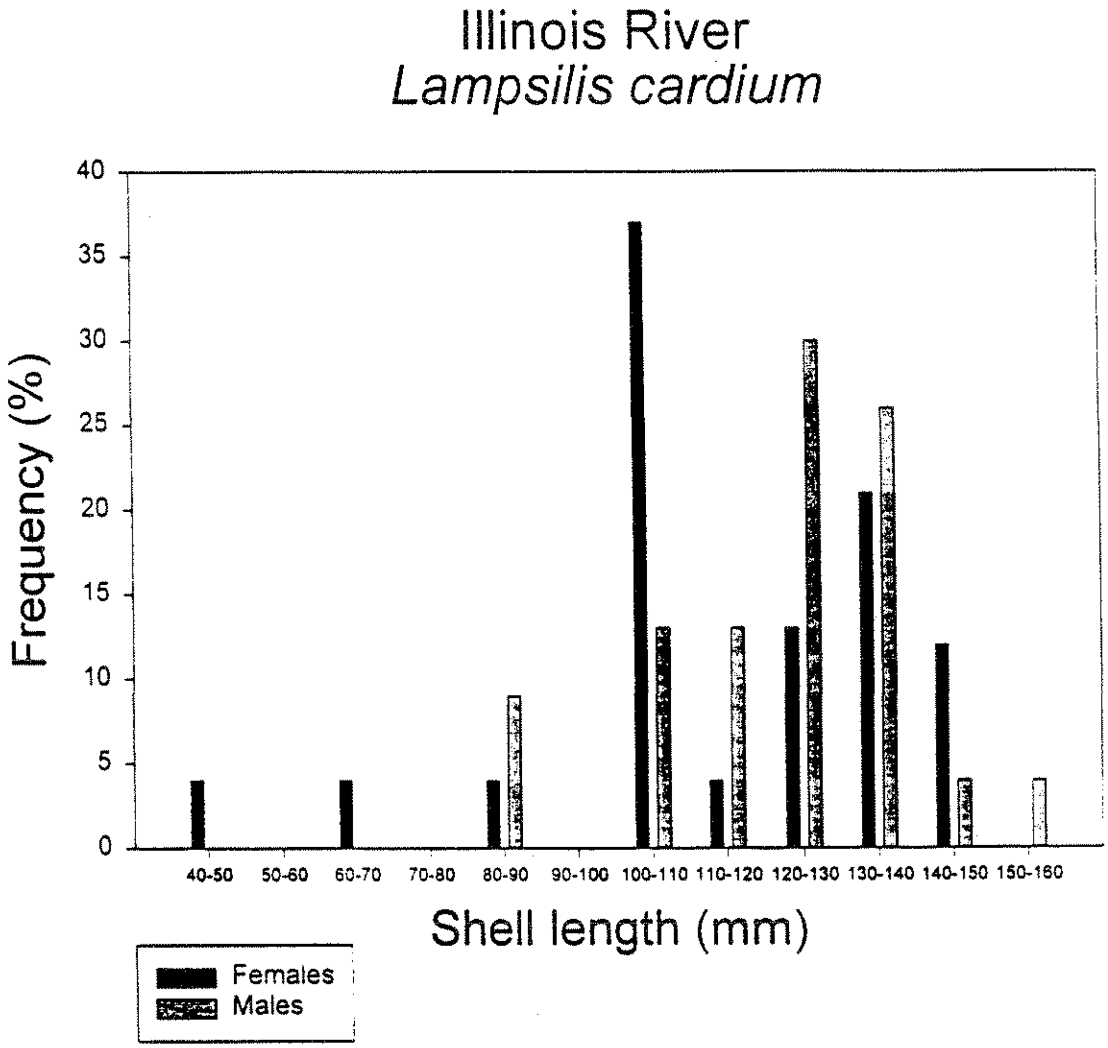
Tritogonia verrucosa in the Illinois River. N = 24.



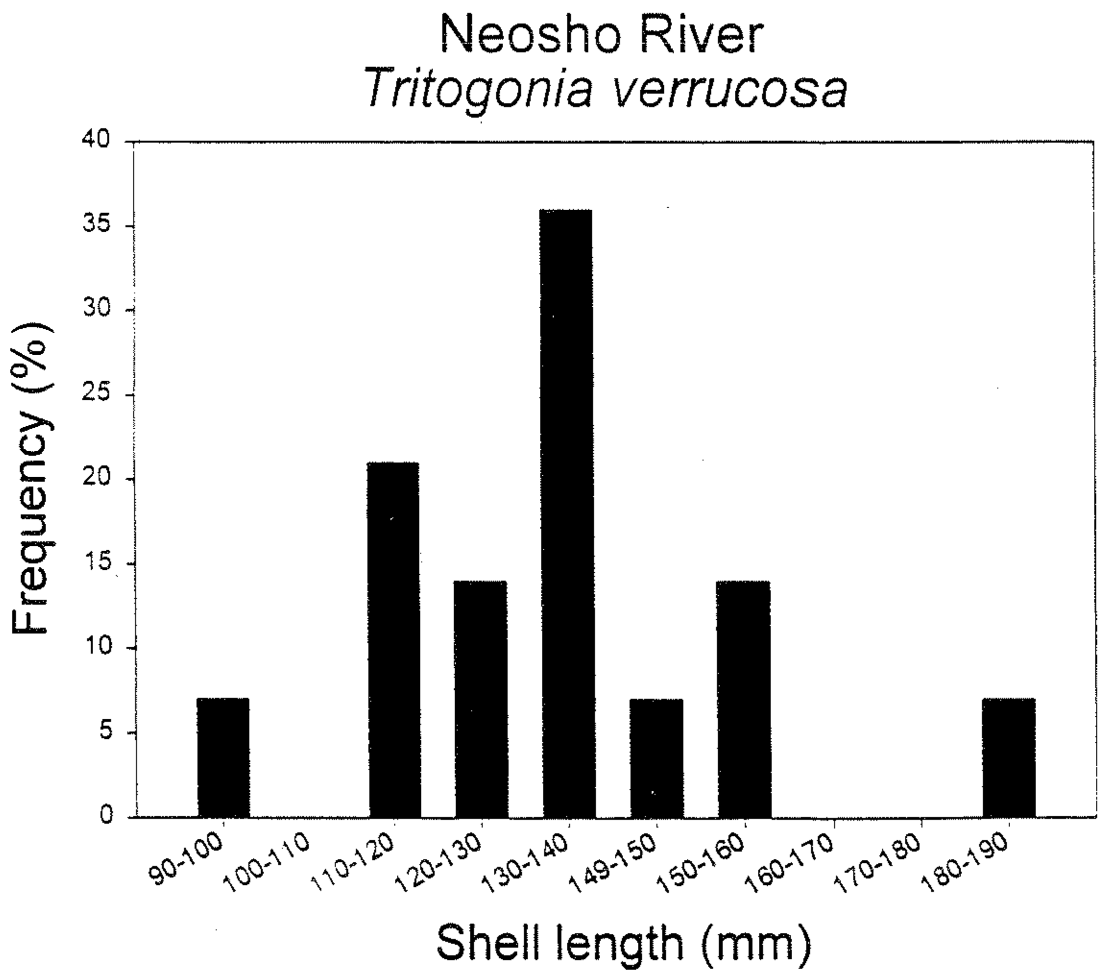
Fusconaia flava in the Illinois River. N = 24.



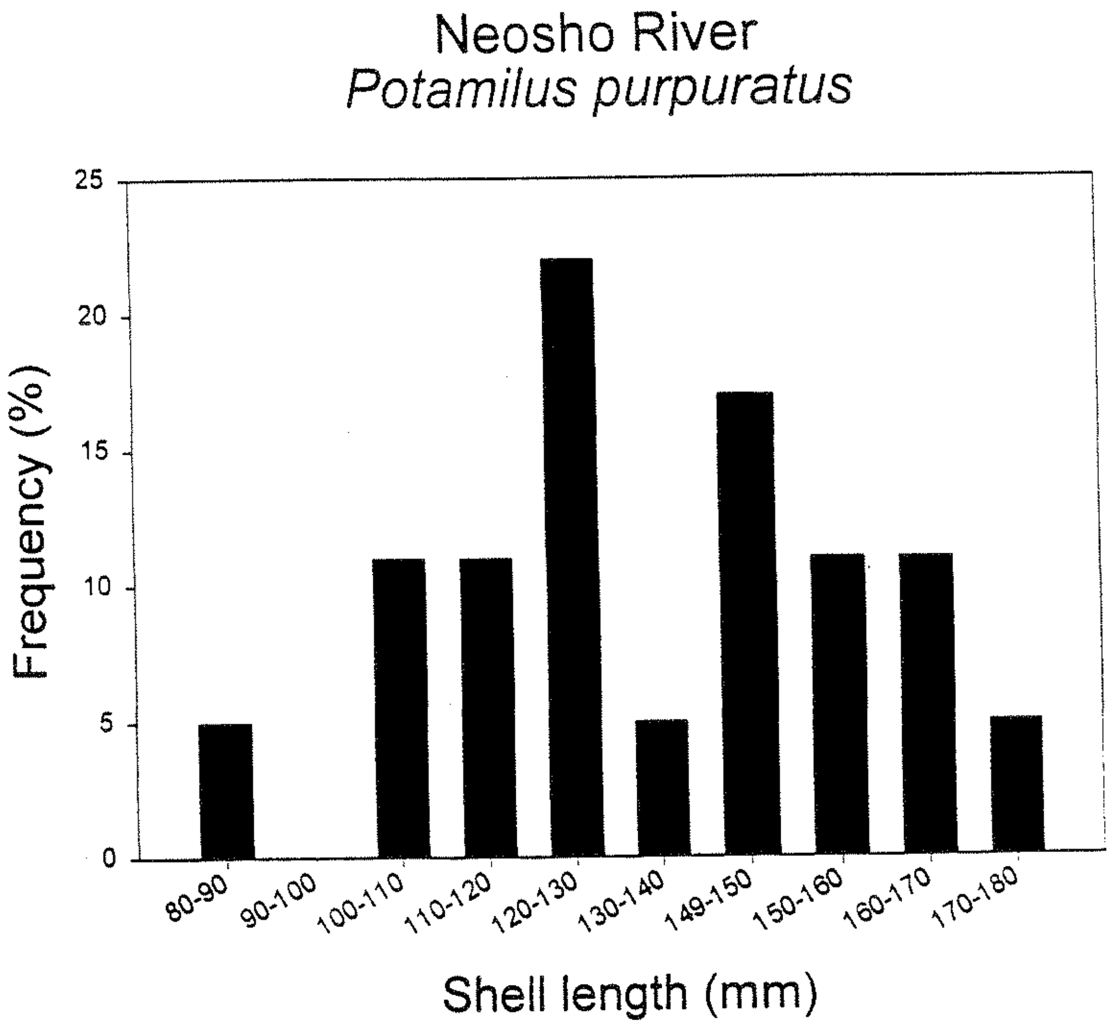
Lampsilis cardium in the Illinois River. N = 41.



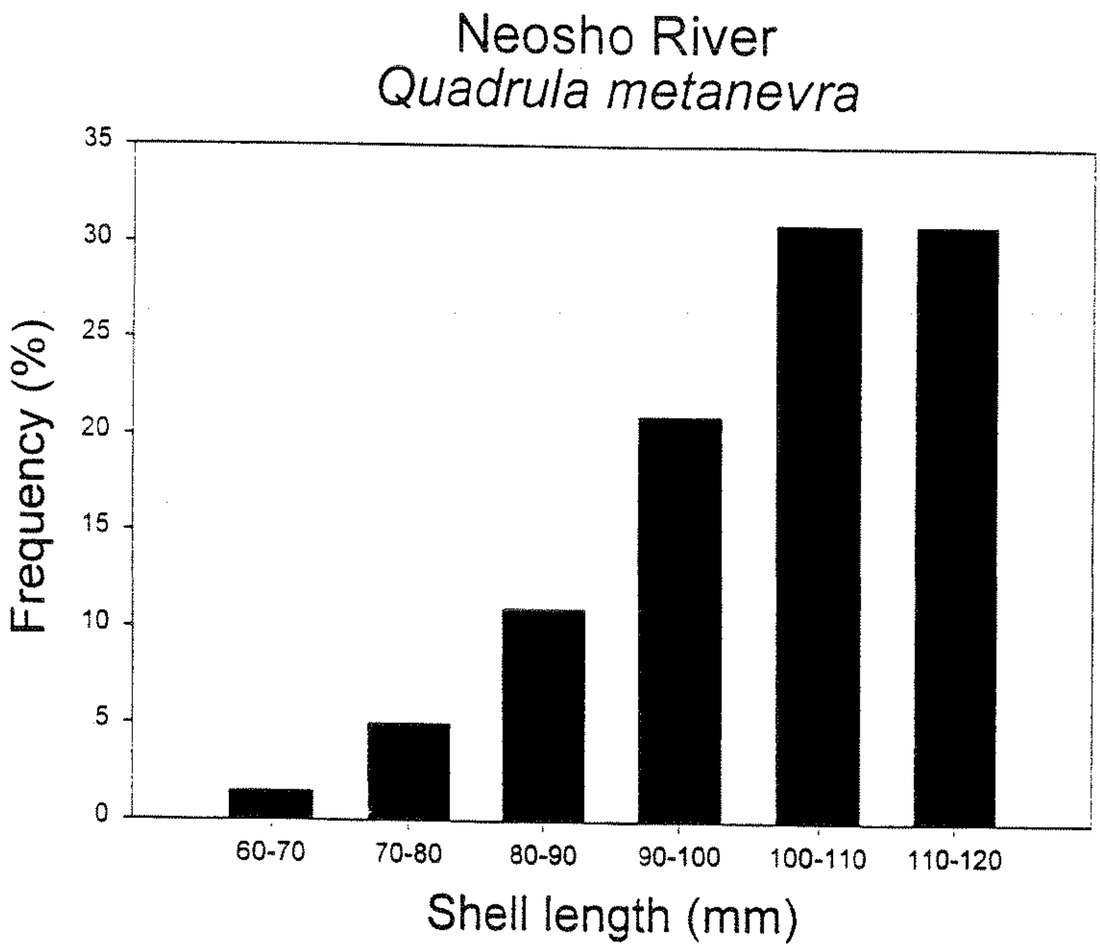
Tritogonia verrucosa in the Neosho River. N = 14.



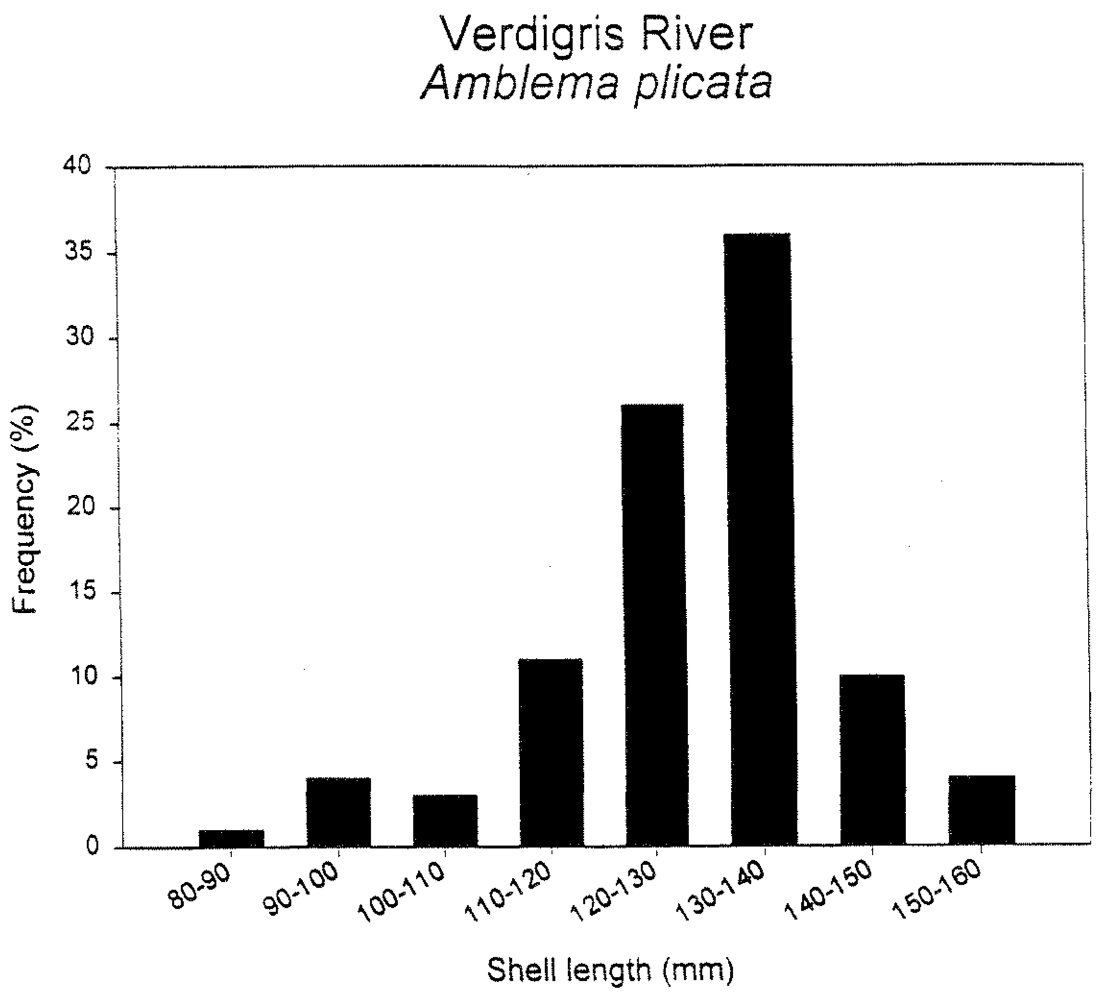
Potamilus purpuratus in the Neosho River. N = 18.



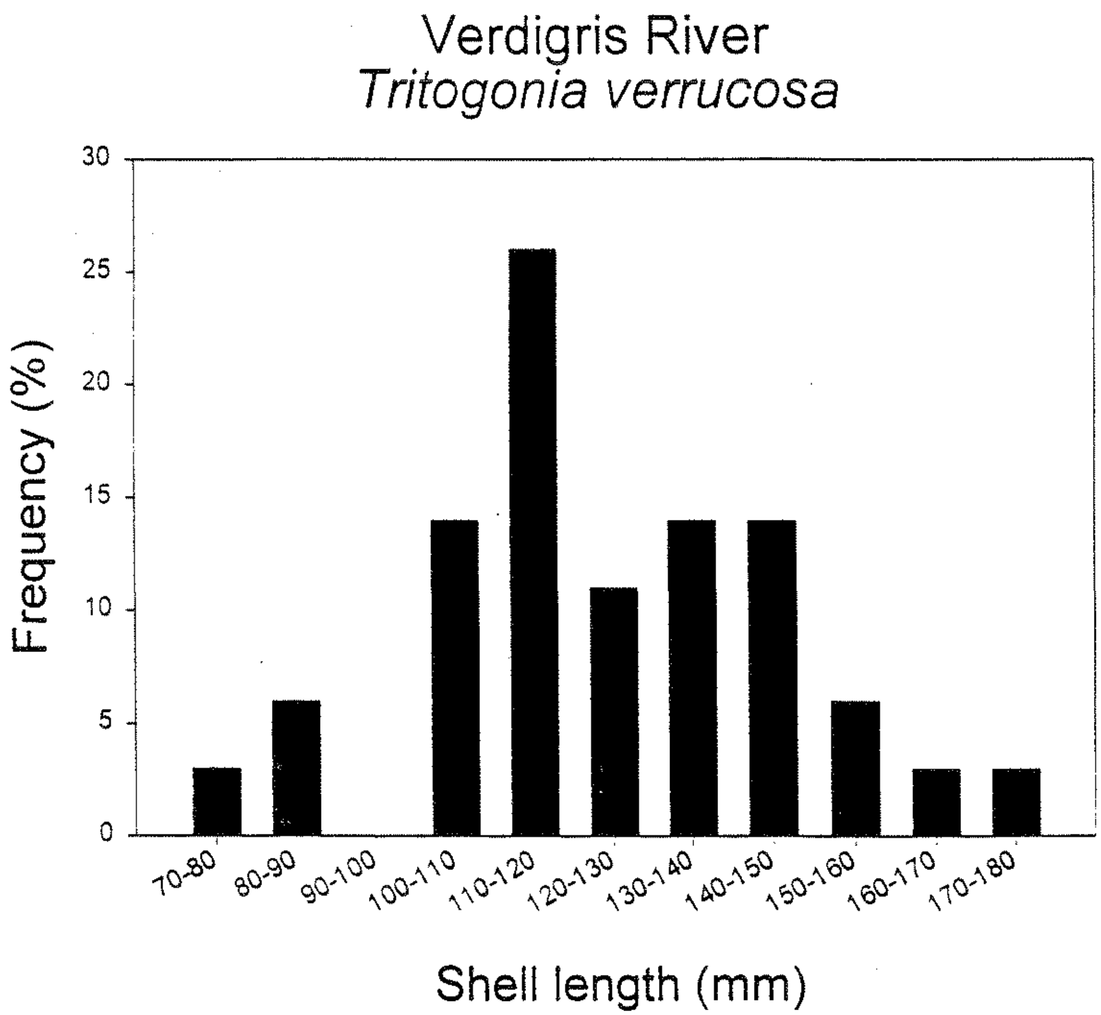
Quadrula metanevra in the Neosho River. N = 136.



Amblema plicata in the Verdigris River. N = 16.



Tritogonia verrucosa in the Verdigris River. N = 11.



Quadrula metanevra in the
Verdigris River. N = 42.

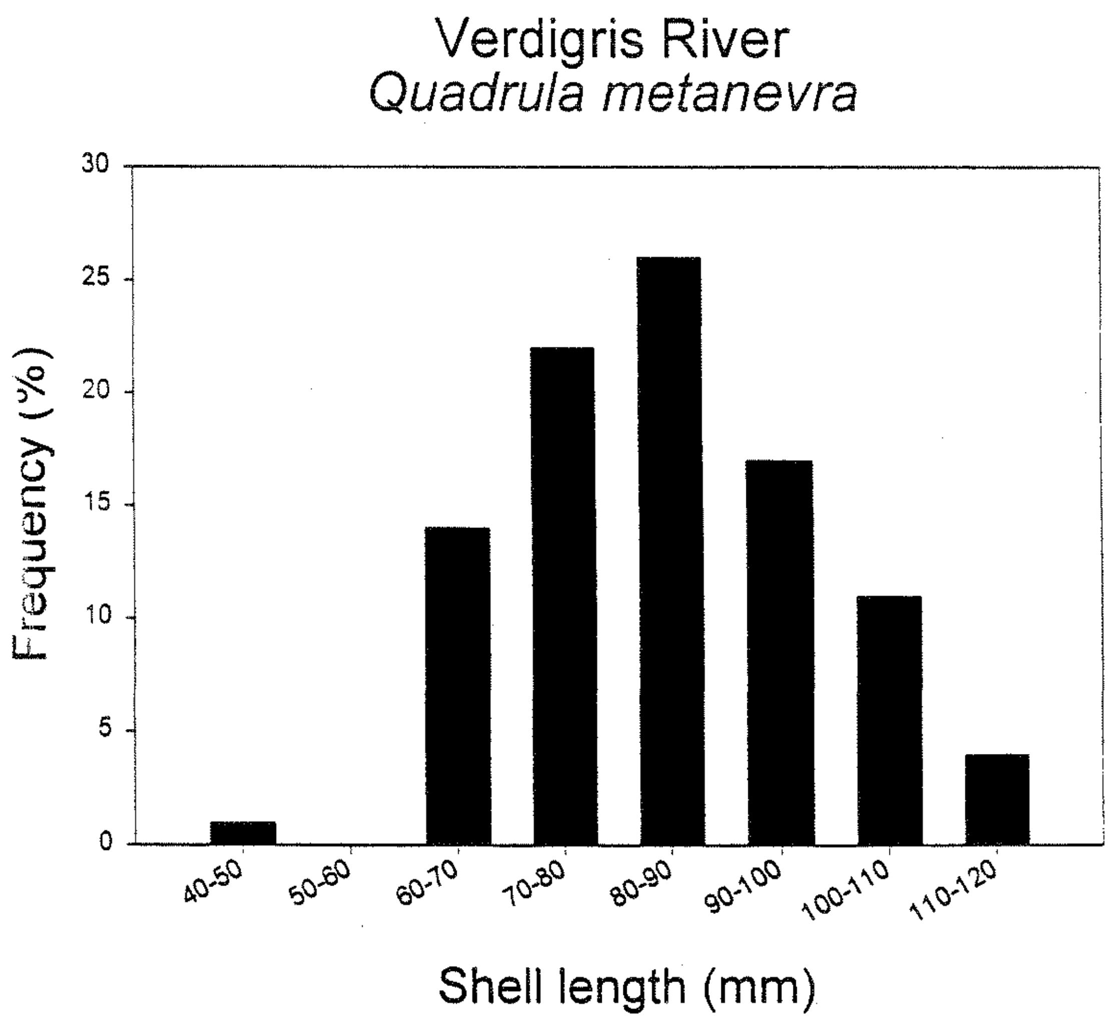


Figure 11. Size distribution of Potamilus purpuratus in the Verdigris River. N = 26.

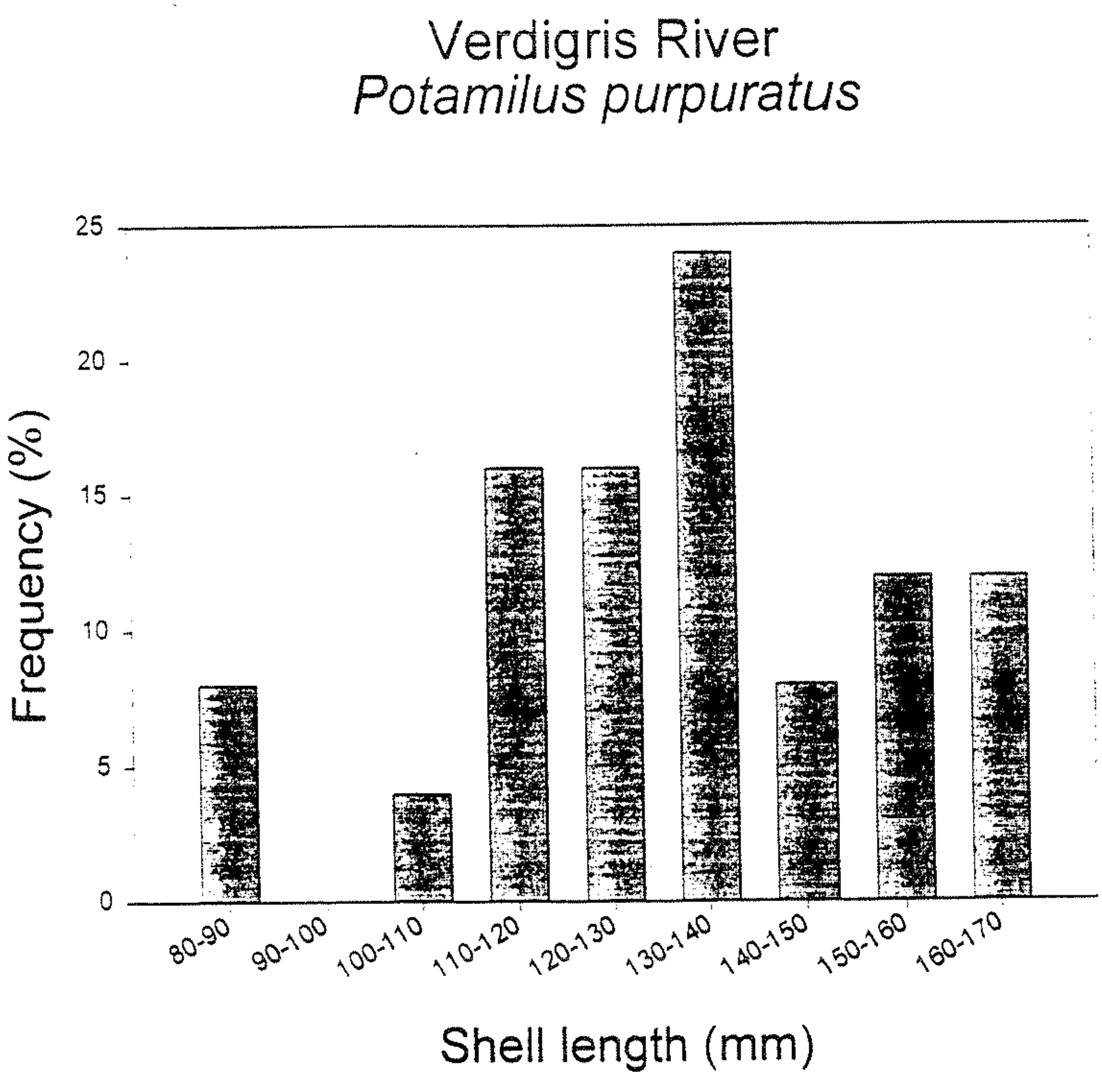


Figure 15. Size distribution of Tritogonia verrucosa in the Caney River. N = 82.

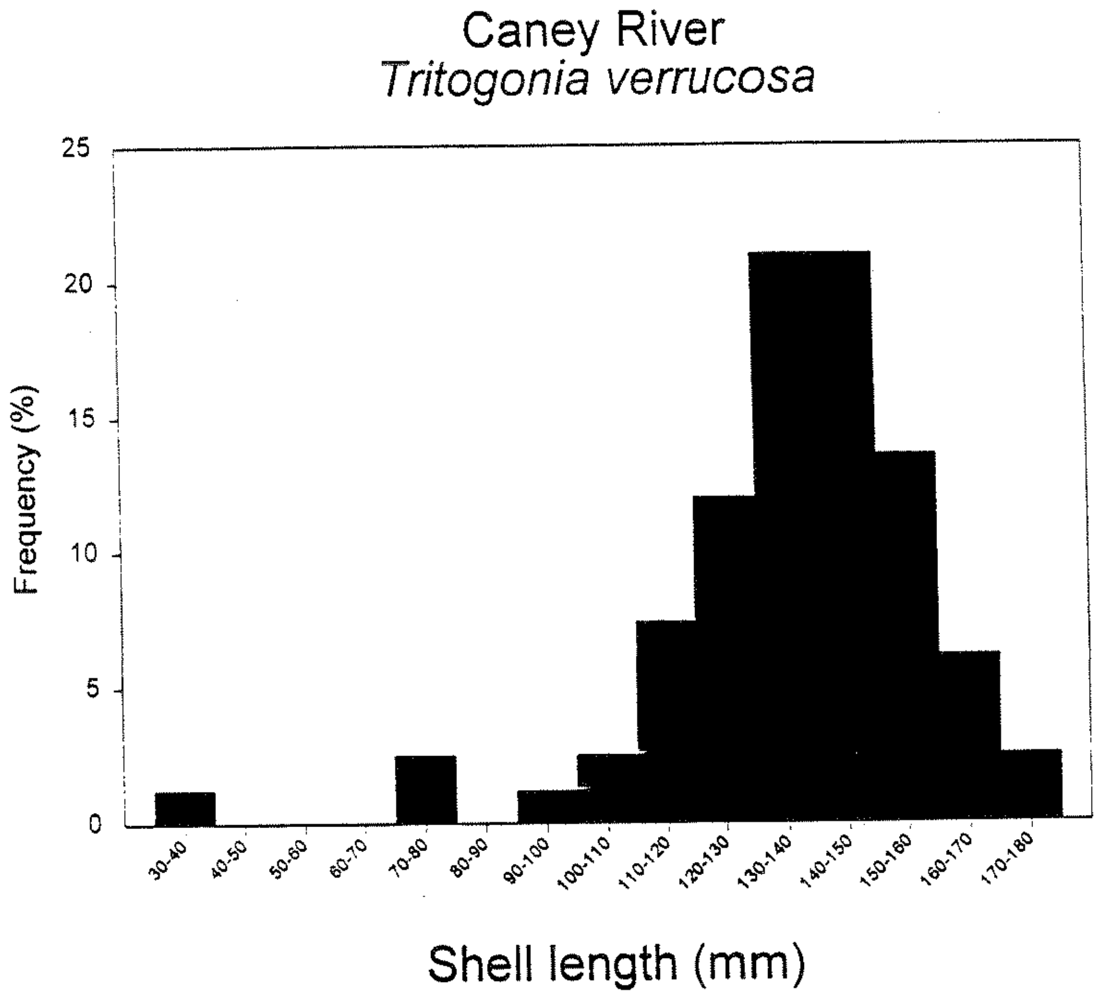
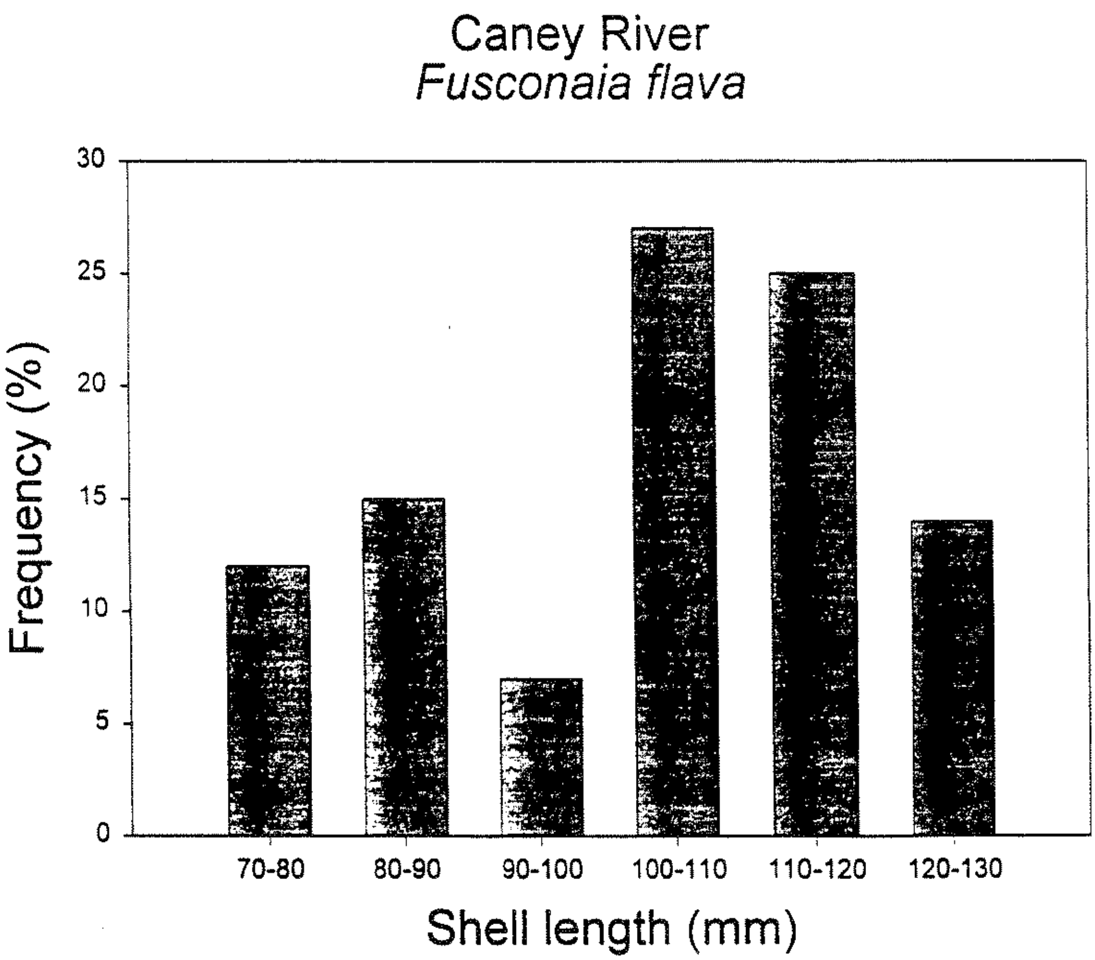


Figure 1[illegible]. Size distribution of Fusconaia flava in the Caney River. N = 60.



Quadrula pustulosa in the Caney River. N = 62.

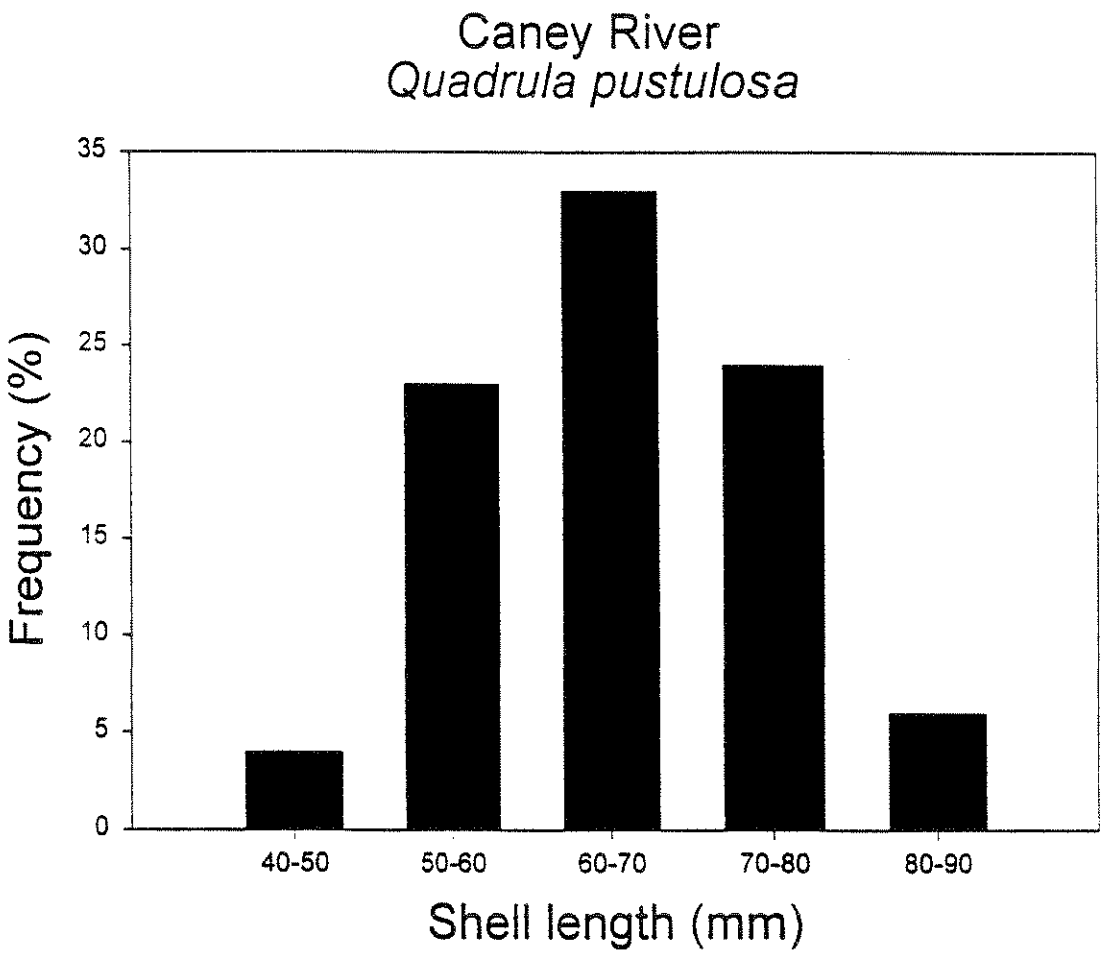
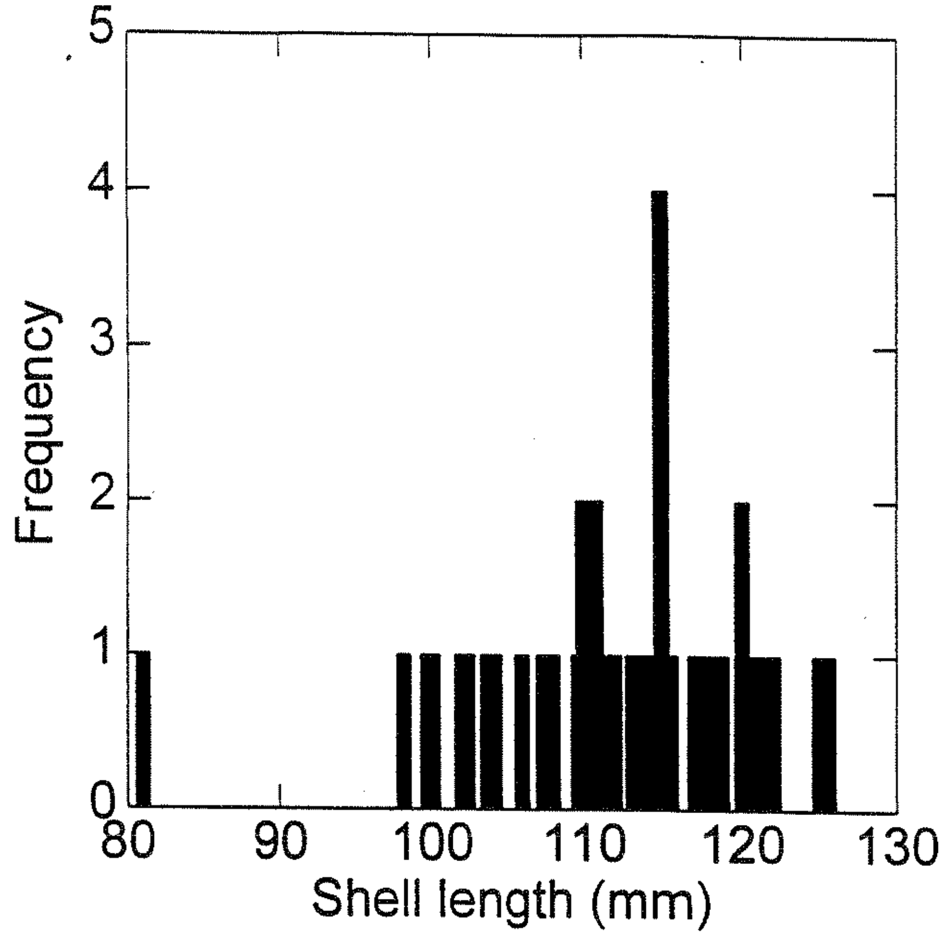


Figure 18. Shell lengths of Neosho mucket females in the Illinois River. N = 44.



mucket males in the Illinois River.
N = 67.

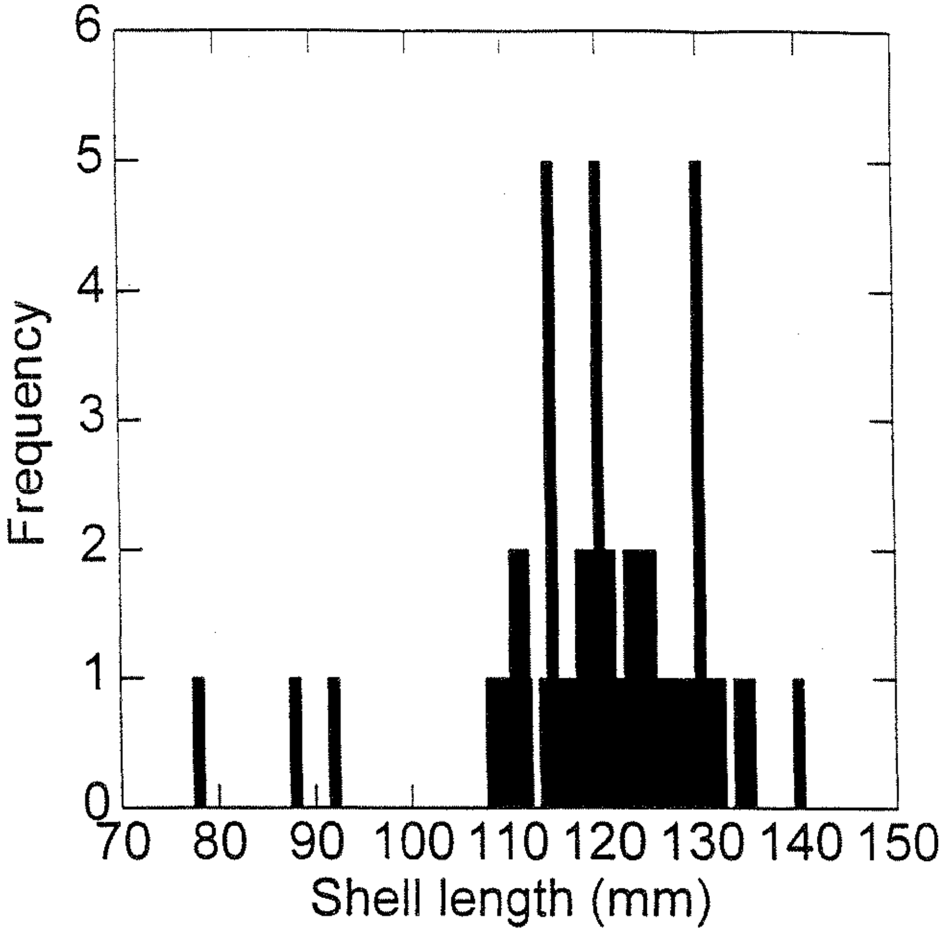


Figure 20. Calcium concentration at sites with and without Neosho muckets.

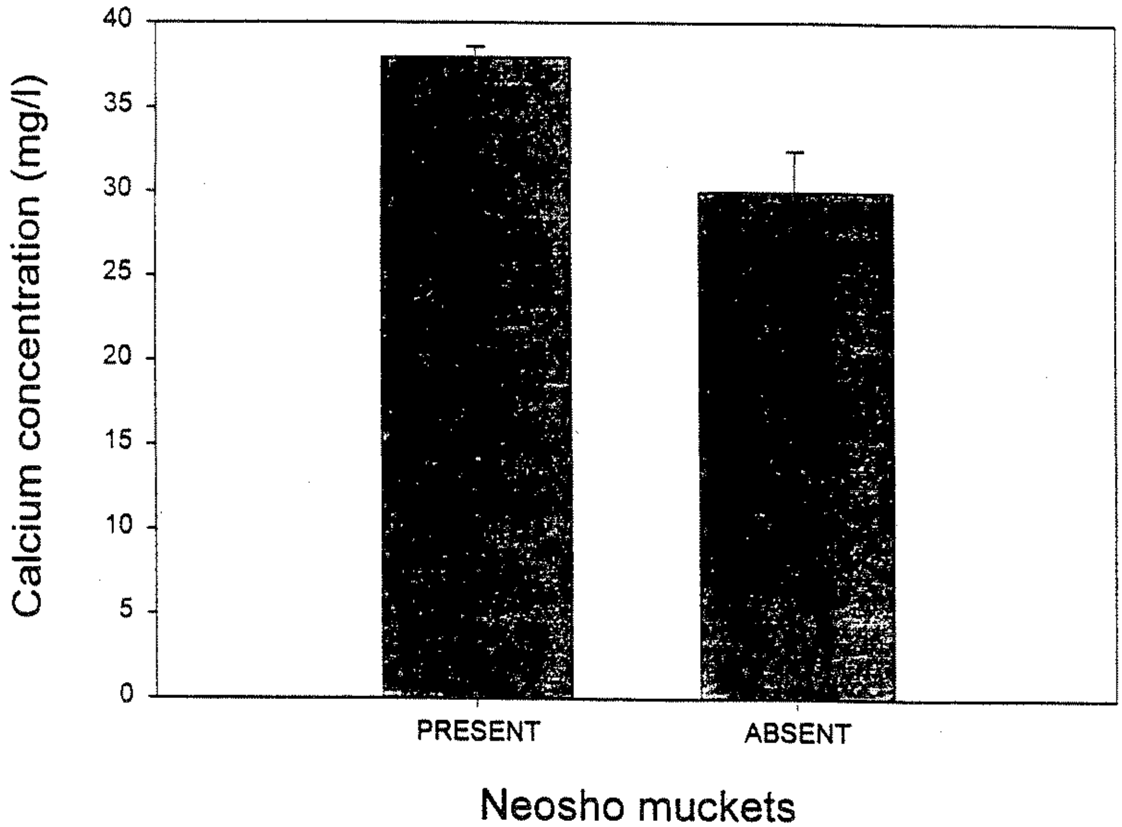


Figure 21. Mean stream depth at sites with and without Neosho muckets.

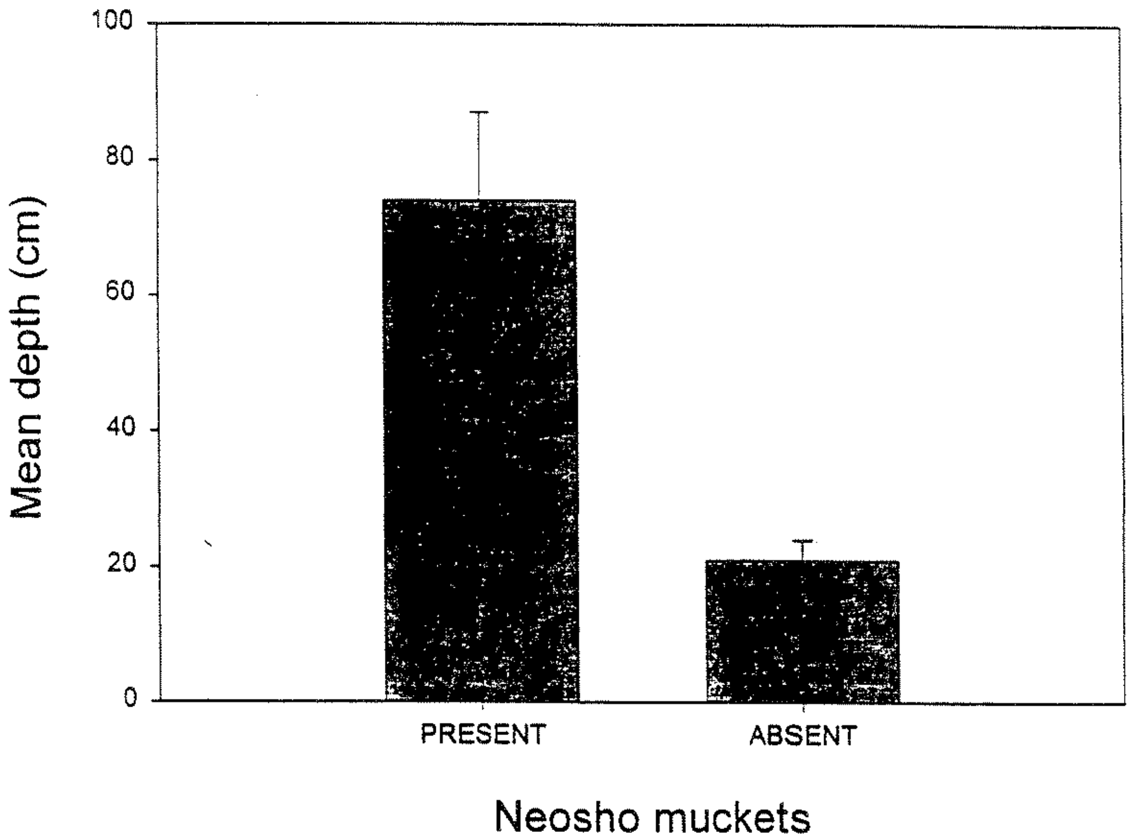
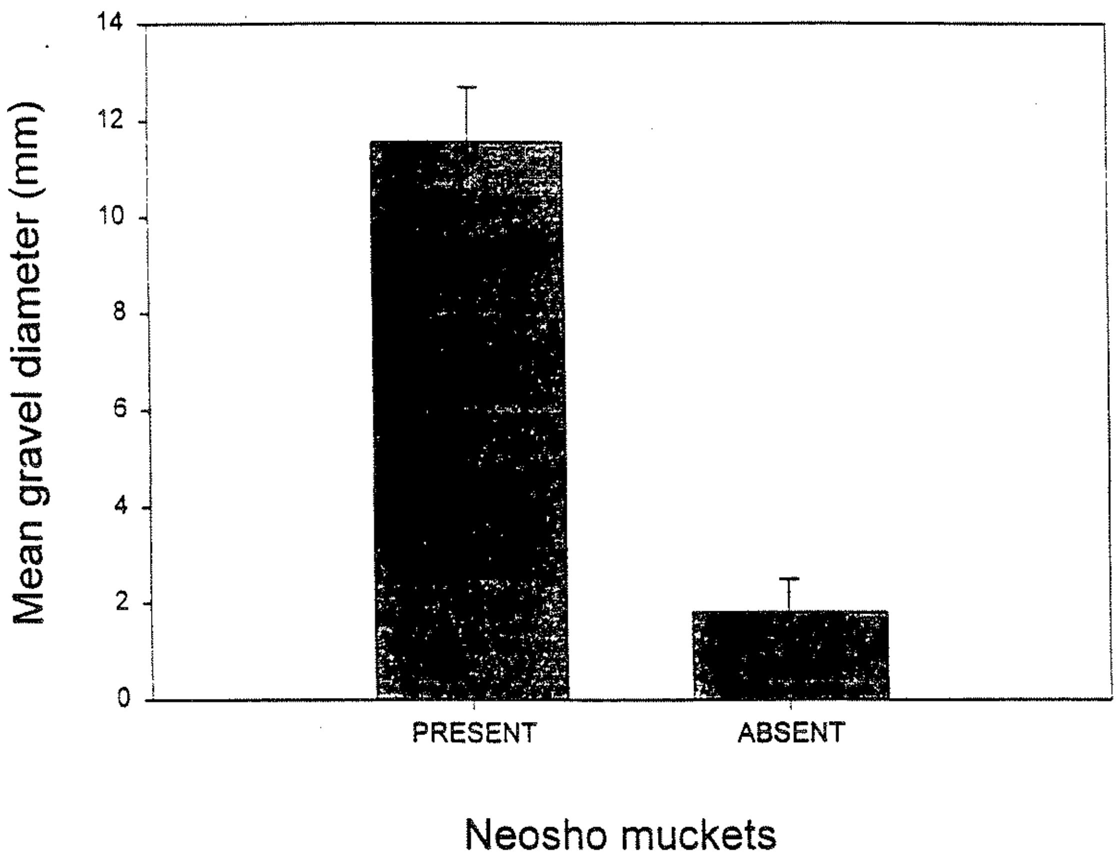


Figure 22. Mean gravel diameter at sites with and without Neosho muckets.



gravel size at sites with and without Neosho muckets.