FINAL REPORT

SECTION 6

ENDANGERED SPECIES ACT

OKLAHOMA
DEPARTMENT OF
WILDLIFE CONSERVATION

FEDERAL AID PROJECT E-12

HABITAT USE AND REPRODUCTIVE BIOLOGY OF *ARKANSIA WHEELERI* (MOLLUSCA: UNIONIDAE) IN THE KIAMICHI RIVER, OKLAHOMA

JUNE 1, 1990 - MAY 31, 1993

FINAL REPORT

STATE: Oklahoma PROJECT NO: E-12

PROJECT TITLE: Habitat use and reproductive biology of *Arkansia wheeleri* (Mollusca: Unionidae) in the Kiamichi River, Oklahoma.

SEGMENT DATES: 1 JUNE 1990 - 31 MAY 1993

ABSTRACT

The only known remaining viable population of *Arkansia wheeleri* in the world occurs within an 80 mile stretch of the Kiamichi River in Pushmataha county, Oklahoma. Within this river *A. wheeleri* occurs only in the best available mussel habitat: backwaters and pools with fine gravel/coarse sand substrata, significant gravel bar and island development, emergent vegetation, and close proximity to riffles and tributaries. These areas harbor large, diverse mussel communities with which *A. wheeleri* is associated. In its optimal habitat, *A. wheeleri* is always rare: mean relative abundance varies from 0.2 to 0.7% and the average density is 0.27 individuals/m^2.

The reproductive biology and fish host(s) of *A. wheeleri* remain unknown. Two cyprinids, *Notropis umbratilis* and *Notropis* spp (c.f *rubellus*), are the most likely fish hosts. The youngest individual *A. wheeleri* encountered was approximately 12 years of age.

Forty-three percent of the historically known subpopulations of *A. wheeleri* below Jackfork Creek have apparently been extirpated and no new subpopulations have been located. *A. wheeleri* survive at 75% of the historically known locations above Jackfork Creek and five new subpopulations have been located. The relative abundance of *A. wheeleri* per site is slightly higher above Jackfork Creek than below.

In addition, shell length data for live *Amblema plicata*, a dominant mussel species in the Kiamichi River, indicate reduced recruitment below Sardis Reservoir.

Much of the Kiamichi River watershed remains forested and this probably accounts for the high diversity and general health of its mussel community in comparison to other nearby rivers.

Program Narrative Objective

To determine the distribution, abundance and reproductive biology of the freshwater mussel *Arkansia wheeleri* within different habitats in the Kiamichi River of Oklahoma.

Job Procedures

1. Characterize microhabitats and determine the effects of impoundment.
2. Determine movement, growth, and survivorship of individuals.
3. Identify glochidia and fish host.
4. Examine impact of Sardis Reservoir on the populations.
5. Determine historic and current land use within the current range of *Arkansia wheeleri* in the Kiamichi River.

A. Introduction

Arkansia (syn. *Arcidens*) *wheeleri*, the Ouachita rock pocketbook, is a freshwater mussel. Originally named *Arkansia wheeleri* by Ortmann and Walker in 1912, Clarke (1981, 1985) recognized *Arkansia* as a subgenus of *Arcidens*. The species is considered by Clarke to be distinct. However, Turgeon et al (1988) have continued to use the binomial *Arkansia wheeleri.*

The historical distribution of *Arkansia wheeleri* was in the Ouachita and Little rivers in Arkansas and the Kiamichi River in Oklahoma, all south-flowing rivers out of the Ouachita Mountains (Figure 1). A survey by Clarke (1987) indicated that the species is probably extirpated from the Ouachita River and severely depleted in the Little River. In 1992 and 1993, relict shells of *A. wheeleri* were found in the Little River in Oklahoma below Pine Creek Reservoir (Vaughn 1993a). No live *A. wheeleri* have been found in the Little River in Oklahoma as of August, 1993.

A. wheeleri was first reported from the Kiamichi River by Isely (1925). Since the construction of a dam and reservoir in the lower reaches of the Kiamichi in the 1970s, some of the backwater areas where it was known to occur have been destroyed (Valentine and Stansbery 1971), and connection with potential habitats on the Red River and other tributaries to it has been blocked. Clarke (1987) surveyed the Kiamichi River at 11 sites from just above Hugo reservoir upstream to near Albion. He located live specimens at six sites and empty shells at an additional two sites of the 11 sites sampled. A total of 10 live individuals was found along approximately 70 miles of river sampled, indicating a sparse but well distributed population in the river.

In 1988 and 1989 Mehlhop and Miller (1989) conducted a survey for *A. wheeleri* in the Kiamichi River from above Pine Creek to Whitesboro. Prior to this study, the habitat of *A. wheeleri* was reported to be backwater reaches of rivers where current is slow and where there are relatively non-shifting deposits of silt/mud and sand

(Wheeler 1918, Isely 1925, Clarke 1987, C.M. Mather, pers. comm.). Such areas tend to be in water that is shallow during late summer months when rainfall is minimal. In the Kiamichi River, these backwater areas usually are found adjacent to sand/gravel/cobble bars that either are scoured clean or support emergent aquatic vegetation, mainly *Justicia americana*. In preparation for their survey, Mehlhop and Miller (1989) examined aerial photographs of the river to determine probable backwater sites. In the 1989 survey, *A. wheeleri* were found at 13 sites. Population size was estimated to be just over 1000 individuals. Mehlhop and Miller found that the species was not restricted to backwater habitats with silty substrate as previously thought. They found that it occurs in pools with rock substrate as well, a more common habitat type in the Kiamichi River. This suggests that the species is more widely dispersed throughout the river than formerly thought and probably has greater reproductive potential. The Kiamichi River in Oklahoma supports the only remaining substantial population of this mussel in the world (Mehlhop and Miller 1989).

Based on the above information *A. wheeleri* was proposed for listing as a federal endangered species in July, 1990 (Federal Register 55(141):29865-29868). Following a public comment period, the species was actually listed as endangered in October, 1991 (Federal Register 56(205):54950-54957).

The Kiamichi River is a major tributary of the Red River. It flows for a total of 169 miles through the southeastern Oklahoma counties of Leflore, Pushmataha, and Choctaw (OWRB 1990). The river flows across the Ridge and Valley Belt of the Ouachita Mountain geologic province and the Dissected Coastal Plain province (Curtis and Ham 1979). The total watershed area is 1,830 square miles. Currently only the dam at Hugo, OK impounds the main river channel. However, a dam on Jackfork Creek in Pushmataha Co., a tributary of the Kiamichi, impounds Sardis Reservoir. The vegetation cover in the watershed can be described as a patchwork of forest made up of short-leaf and loblolly pine, mesic oak forests, and diverse bottomland habitats in various stages of maturity. Another large component of the watershed coverage is made up of pasture and other agricultural lands.

B. Methods

1. Characterize microhabitat and determine effects of impoundment

In 1990, 31 sites in the Kiamichi River between Antlers and Albion were examined for the presence of *Arkansia wheeleri*. Twenty two of these sites were judged to be appropriate for intensive surveying and habitat analysis. The results of the 1990 survey allowed us to determine that *A. wheeleri* occurs within select pools and backwaters in the Kiamichi River (Vaughn 1991). In 1991 we selected ten of these twenty two sites for intensive habitat analysis and population monitoring of *A. wheeleri* (Figure 2) (Vaughn and Pyron 1992). The ten sites were chosen to be as evenly distributed as possible along the Kiamichi River between Antlers and Albion but still be reasonably accessible and included all sites where *A. wheeleri* had been located by us in 1990 and some sites where it had been found historically (Mehlhop and Miller 1989, Clarke 1987).

Mussel surveys were conducted during July and August 1990, July and August 1991, and June - October 1992 using timed searches. Quadrat sampling techniques were used in addition to timed searches in 1991 and 1992. Quadrat sampling was necessary in order to calculate mussel densities. However, it is difficult to find rare species such as *A. wheeleri* using quantitative techniques such as quadrat and transect sampling, therefore the more thorough timed searches also were conducted. Timed mussel surveys (timed to standardize sampling effort) were conducted by hand searching with the aid of SCUBA in deeper areas and by hand searches in shallow areas in the following manner: (1) an area was selected for surveying; (2) the entire area was searched by at least two people for one hour; (3) all mussels encountered were removed to shore; (4) all mussels were immediately identified and measured (total shell length); (5) mussels were put back in the water as close to where they were removed as possible. Quadrat sampling was done with quarter meter square PVC pipe quadrats. Quadrat sampling was done prior to timed searches. Fifteen random quadrats were sampled for each pool or backwater area. Quadrats were searched by hand, with the aid of SCUBA in deeper areas, until all mussels had been recovered to a depth of 15 cm. Individual mussels were measured and returned to the mussel bed as in timed searches.

At each site we characterized the substratum on the stream bottom and measured water depth, water temperature, current velocity, conductivity, dissolved oxygen, and pH. Current velocity was measured 10 cm above the stream bottom with a Marsh-McBirney model 201 portable flow meter. Conductivity and dissolved oxygen were measured with YSI meters. pH was measured with a Fisher Accumet portable pH meter. In 1990, water samples were taken for phosphate and nitrate.

Phosphate and nitrate analyses were performed by the Oklahoma State Department of Health. Three replicate substratum samples were collected at each site. These were brought back to the laboratory and allowed to dry. Samples were dry sieved, weighed, and individual proportions of samples assigned to the appropriate substrate size class (in mm) following Hynes (1970, p. 24). Standard sieving techniques do not segregate particles greater than about 2 mm in diameter (i.e. gravel from pebble from cobble). To determine the proportion of fine gravel, coarse gravel, pebble, and cobble in samples we took the proportion of the sample greater than 2 mm in diameter and randomly measured the diameter of 100 particles in that subsample (Dunne and Leopold 1978).

We used a variety of statistical techniques to explore any relationship between *A. wheeleri* distribution and abundance and measured habitat parameters. Associations between *A. wheeleri* and other species of mussels as well as fish species were calculated using UGPMA Clustering (on relative abundance data), Spearman Rank correlations (on relative abundance data) and the Jaccard Index (on presence/absence data) (Ludwig and Reynolds 1988). Habitat affinities were examined using three ordination techniques, Principal Components Analysis, Reciprocal Averaging, and Canonical Correspondence Analysis.

2. Determine movement, growth, and survivorship of individuals.

All *A. wheeleri* found were measured using digital calipers (height, width, and length), and individually marked using numbered, laminated plastic fish tags. *A. wheeleri* were returned to the precise location from which they were captured.

To obtain additional information on *A. wheeleri* size and age distribution we measured shells of *A. wheeleri* that we found on the Kiamichi River between 1990 - 1992, that had been deposited in the Oklahoma Museum of Natural History, and that are in the collection of Dr. Charles M. Mather at the University of Science and Arts of Oklahoma. We then counted external annuli on the shells we had collected and those in the OMNH (McMahon 1991). We used the above data to calculate shell length, width and height vs. number of annuli regression lines. Shell height vs. number of annuli produced the best fit, and the resulting equation was used to predict the number of annuli for live mussels that had been measured in the field.

In early fall 1992 we brought four live *A. wheeleri* back to our laboratory for observation. The maximum number of *A. wheeleri* we were allowed to sacrifice or bring back to the laboratory under Vaughn's endangered species subpermit was five. These individuals were housed in a 626 liter Frigid Units artificial stream along with other mussel species that normally co-occur with *A. wheeleri*. The artificial stream was housed in an unheated room and stream temperatures approximated outdoor air temperatures. Mussels were fed Argent artificial plankton, a mixture of whole egg powder, egg yolk, shrimp meal, and fish meal which has been used to successfully raise freshwater prawn and larval finfish. *A. wheeleri* were checked daily for any material extruding from the siphon or shell. This material was examined under a dissecting microscope.

3. Identify glochidia and fish host.

We collected fish by seining (2 X 1.2 m high with 0.5 cm mesh, 6 X 1.2 m high with 0.5 cm mesh) for 45 minutes per site, including all available habitats. We used experimental gill-nets on several dates to capture larger fish that are missed by seining. Fish collection dates were: 10 and 23 July 1990; 13 August 1991; 12 and 13 October 1991; 7 December 1991; 23 June 1992; 7, 8, 9, and 26 July 1992; 18 and 19 September 1992; and 12 October 1992. Fish were killed and preserved in 10% formalin and later transferred to 50% propanol before identification in the laboratory. Gills of individual fish were examined for glochidia under a dissecting microscope. We recorded the number of glochidia per individual fish. We removed all glochidia (except when glochidia were extremely numerous) and placed them in 50% propanol for future identification. Fish will be deposited in the Oklahoma Museum of Natural History.

Drift samples for planktonic glochidia were collected during the summer and fall of 1991 and 1992. Drift nets were run for two hours and four replicate samples were collected from each site. Samples were preserved in buffered formalin and later transferred to 70% ethanol. Glochidia were counted under a dissecting microscope using standard plankton counting techniques (Lind 1979). Glochidia samples are currently being stored in Dr. Vaughn's laboratory and are available for identification by appropriate experts.

We sacrificed some common, female mussels in the field and examined them for glochidia. These samples are also currently being stored in Dr. Vaughn's laboratory.

At the suggestion of Dr. Mark Gorden, Tennessee Technological University, and as permitted under Vaughn's endangered species subpermit, we placed live *A.*

wheeleri in the field inside plastic bags filled with river water. *A. wheeleri* were then held in these bags in the shade at stream side for several hours. This technique causes a build up of carbon dioxide which causes some mussels to release any glochidia they are harboring, but does not unduly stress the mussels (M.E. Gordon, pers. comm.).

4. Examine impact of Sardis Reservoir on the populations.

The impact of Sardis reservoir was examined by statistical comparison of the data obtained in procedures 1, 2 and 3 above and below the inflow from Sardis Reservoir via Jackfork Creek (see results section).

5. Determine historic and current land use within the current range of Arkansia wheeleri in the Kiamichi River.

We used spectral data collected from a satellite and completed an unsupervised classification of a portion of the data distinguishing several different landuse categories within the Kiamichi River watershed. Landuse information about the Kiamichi River watershed was extracted using a single, full-scene Landsat Thematic Mapper (TM) image. The image data were recorded on a series of tapes in 7 separate spectral bands. Each band represents the brightness value for each pixel in the image within specific wavelength intervals of the electromagnetic spectrum. The potential range of spectral values for each band can be found in Table 1. The acquisition date for this image was 13 July, 1992. This particular date was chosen because it provided a clear and almost cloud-free image occurring during the summer of 1992. These image data have a spatial resolution of 30 x 30 meters per pixel and cover a total area approximately 180 km on a side. All image processing and classification was done using the ERDAS 7.5 software package on a personal computer.

Preclassification

We used bands 1, 4, and 5 without any additional enhancement in carrying out the classification. This band combination has been shown to provide the best differentiation of general landuse types for TM imagery (Chavez et al. 1982, 1984; Jensen 1986). Our final landuse classification was based on one developed by Anderson et al. (1976) for use with natural resource applications.

The portion of the image that includes the Kiamichi River watershed and the headwaters of the Little River watershed[1] was selected and subsetted into a separate file for processing using a state watershed map as a guide for determining watershed boundaries. This image file was then divided into east and west portions of the watershed in order to reduce the size of the image files and to allow for easier manipulation within the computer environment. The final image and classification is a combination of these two files.

Classification

An unsupervised classification was completed for each of the two image files (see Jensen, 1986 for a detailed discussion of supervised and unsupervised classifications along with the different clustering algorithms). Unsupervised classifications are generally used when there is little *a priori* knowledge of the study

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[1] Current watershed maps were at too large a scale to allow us to separate out this small portion of the Little River watershed. However, including it did not affect our results.

area. We chose a clustering routine that uses a minimum spectral distance classification algorithm to assign each pixel a class value (1-27) that corresponds to an individual spectral class. We consistently used the default values calculated by ERDAS for the following clustering parameters: 1) N=27 - maximum number of clusters, 2) R=3.75 - minimum spectral distance between clusters, 3) C=5.25 - maximum cluster radius, 4) M=256 - number of points to process before merging clusters, and 4) T=1% - cluster elimination threshold. The initial classification identified 27 spectral classes. We manually compared each class to the original, unenhanced, 3-band image in order to group like-classes together and produce a classified image with three general categories: forest, cut forest, and water/cloud shadow. A fourth spectral class included all the clouds that were visible in the image. Clouds covered less than 1 % of the total image area.

The clustering routine did not do well at distinguishing urban areas due to their generally small size and the fact that the high resolution of the image allowed for multiple landuse types to be detected within an urban area (e.g. road, lawn, woodlot, etc). Because of this, we digitized the larger urban areas (population of 3,000 or more) and created a file that was later incorporated into the final classification. Roads also did not cluster independently. They consistently clustered with other surface features such as clearcuts, pasture, and clouds. This was due to their spectral similarity to these classes and the fact that pixels that included roads were often dominated by other landuse types (e.g. forest). For this reason, a second digitized file was created to include the primary roads that were visible on the image. This digitized file was later incorporated into the final classification.

From the original classification we separated each of the first three general categories (forest, cut forest, water/cloud shadows) into their own data file so that each could be further clustered to provide greater detail in landuse recognition. Each of these classes was clustered with the same clustering algorithm used in the initial classification. This gave us at least six additional spectral classes for each general category that could then be compared to ancillary data in order to make decisions about which spectral classes should be combined and into which of the final landuse categories they belonged. Ancillary data consisted of black and white aerial photography (scale of 1" = 660') of Pushmataha and LeFlore counties provided by the Agricultural Stabilization and Conservation Service, and a general knowledge of the landscape. The acquisition date for photography from Pushmataha County was 1991 while Leflore County photography dated from 1978. The cloud class was already sufficiently identified so that no additional clustering was required.

An exception to the use of the 3-band combination for clustering occurred when we used only band 4 to carry out the second classification of the forest landuse class. Band 4 alone can better distinguish conifers from deciduous trees (Jensen 1986) and was used to help distinguish three forest types: coniferous, deciduous, and mixed.

Historical Land Use

Significant land use changes in the Kiamichi watershed occurred in the first few decades of this century when the area was extensively logged. Unfortunately, we were unable to obtain aerial photographs from this era.

C. Results

1. Characterize microhabitats and determine the effects of impoundment.

The Kiamichi River contains an abundant and diverse mussel fauna with a high proportion of rare species. The fauna has changed little since originally described in the 1920's (Isely 1925). Mean total densities of mussels by site are shown in Figure 3. Mean densities of mussel species by site are shown in Table 2. Mean relative abundances of individual mussel species are shown in Figure 4.

Water quality data and substrate data are shown in Table 3. Phosphate, nitrate, and water quality data collected by the USGS are given in Appendix 1. Most measured water quality parameters did not vary significantly between sites. Current velocity, water depth, and substratum composition did vary between sites.

Arkansia wheeleri are extremely rare in the Kiamichi River. Figure 5 shows the number of *A. wheeleri* found at ten study sites on the Kiamichi River from 1989 - 1992 (sites 1 - 5) and 1990 - 1992 (sites 6 - 10). In this figure individual mussels found in any one year may represent recaptures from an earlier year and, therefore, numbers of mussels found should not be totalled over years for a site (see paragraph on recaptures below).

In 1990 two individual mussels were found, one at site 4 and one at site 10, which we were unsure of whether they were immature *A. wheeleri* or a pustule-less morph of *Quadrula pustulosa*. Juvenile *A. wheeleri* and some unusual morphs of *Q. pustulosa* can be very difficult to tell apart. The only way to be absolutely sure of the identification of these two individuals would have been to sacrifice them and examine characteristics inside the shell, which we did not have permission to do in 1990. To be on the safe side, we assumed that these individuals were *A. wheeleri* and marked them. In 1992 we received permission to sacrifice up to five *A. wheeleri*. In 1992 we opened some mussels that were identical to the ones that we had been unsure about in 1990. The opened mussels were *Q. pustulosa*. We have therefore corrected the data to show that during our study no live *A. wheeleri* were found at either site 4 or 10.

In most cases *A. wheeleri* were located only through timed searches and did not occur in quadrat samples. Mean relative abundance of *A. wheeleri* at individual sites in 1990-92 is shown in Figure 6 and varied from 0.2% to 0.7%. In 1991 *A. wheeleri* occurred in quadrat samples at two sites, 6 and 7. This allowed us to calculate the density of *A. wheeleri* at these two sites. The density of *A. wheeleri* was 0.27 individuals per square meter at both of these sites.

Arkansia wheeleri only occurs in large mussel beds in association with other mussel species. Mussel sites or "beds" where *A. wheeleri* occur are more species-rich than other mussel beds that we sampled in the Kiamichi River (Figure 7, t=3.18, df=15, P=0.006 (data for 22 sites from 1990).

Using data from the twenty-two sites sampled in 1990, we used cluster analysis, Spearman Rank Correlation and the Jaccard Index to look for associations between *A. wheeleri* and other mussel species. The strongest association was between *A. wheeleri* and *Quadrula quadrula*. This positive association was found with Spearman Rank correlations (Table 4) and the Jaccard Index (Table 5). The next strongest association was between *A. wheeleri* and *Ellipsaria lineolata*, found using both Spearman Rank correlations and the Jaccard Index.

We used several different ordination techniques to explore the habitat affinities of *A. wheeleri*. Data used in these ordinations included mussel relative abundances, fish abundances, quantitative habitat data, and coded habitat data. Sites were scored or coded as to whether they were a backwater or a pool (Htype), contained emergent vegetation, were within one fourth mile of a tributary entering the Kiamichi, contained gravel bar development, longitudinal position along the river and whether they were above or below Sardis Reservoir. Substrata data were coded as to the dominant substratum type for the 1990 data. Quantitative substratum data were used for 1991-1992.

Data for eight sites for which we had both fish and mussel abundance data were analyzed using Principal Components Analysis (PCA). Data used were means for 1991-1992. *Arkansia wheeleri* loaded positively on PCA axis 1 and was highly negatively correlated with PCA axis 2 (Figure 9, Table 6). In this analysis the amount of sand and fine gravel also loaded negatively on PCA axis 2. Therefore, from this analysis *A. wheeleri* would be predicted to be found in areas with more fine gravel and sand.

Reciprocal averaging produces simultaneous ordinations of sites and species allowing one to examine relationships between sites and species in one analysis (Ludwig and Reynolds 1988). RA was performed on the same data used for the PCA. Our ordination using RA separated species better than sites (Figure 10). Pearson correlations with the resulting first and second RA axes produced only two biologically meaningful relationships (Table 7). Flow correlated with the first RA axis and Htype (habitat) correlated with second axis. Depth, conductivity, and substratum type were not strongly correlated with either RA axis. *A. wheeleri* came out along the middle of both axes and showed no distinct habitat preferences in this analysis.

Canonical correspondence analysis (CCA) is a direct gradient ordination technique that relates species abundances to measured variation in the environment (Ter Braak 1986; Taylor et al. 1992; Pyron and Taylor 1993). We used CCA to determine if any association exists between measured habitat variables and mussel relative abundances, including the relative abundance of *A. wheeleri*. CCA was performed on data for the 22 sites sampled in 1990 and on data from the ten sites sampled intensively in 1991.

The results of the CCA ordination for the 22 1990 sites are shown in Figure 11. In this analysis the first CCA axis accounted for 42.9% of the variance and the second CCA axis accounted for 23.6% of the variation. In Figure 11 the top graph shows the approximate centers of species distributions along the first two CCA axes, the middle graph shows the habitat vectors along those axes, and the bottom graph shows the positions of the 22 study sites along the CCA axes. Numbering of these sites does not correspond to numbering of the ten sites from 1991-1992. For example site three in this ordination is not the same as site three in Figure 12 (see below). In this ordination all of the habitat variables were clumped and intercorrelated and mussel species were also clumped. Sites, however, were well spread out. This ordination mainly separated "good" from "poor" mussel habitat. The majority of mussel species were most abundant at those sites falling in the middle of the ordination. These sites had in common the following habitat characteristics: pools or backwaters, substratum composed predominately of coarse sand and fine gravel, proximity to a tributary, emergent vegetation, gravel bars, islands, and low flow.

The results of the CCA ordination for the ten 1991 sites are shown in Figure 12. *A. wheeleri* was not associated with any distinct habitat vector in this analysis, but neither were most mussel species sampled. It is important to point out that the ten study sites were chosen because they were pools or backwaters that contained large mussel beds that at least historically harbored *A. wheeleri*. By definition these habitats should be very similar to one another, and mussel species with the ability to survive in a variety of microhabitats within these pools and backwaters would not be expected to show a distinct habitat preference in this analysis. Mussel species that do occupy specific microhabitats within pools and backwaters did show a distinct habitat preference in the ordination. For example, *Lampsilis teres* prefers sandy substrate, *Megalonaias nervosa* only occurs in large downstream pools, and *Villosa arkansasensis* only occurs in cobble substrate (Oesch 1984). All of these associations were identified by the CCA ordination (Figure 12). A variable ("habitat") was used in the ordination to distinguish pools from backwaters. *A. wheeleri* showed no preference for pools versus backwaters.

2. Determine movement, growth, and survivorship of individuals.

In 1990 we marked and released at the point of capture nine *A. wheeleri*. In 1991 we marked and released at the point of capture nine *A. wheeleri*. In 1991 we recaptured only two marked individuals, although we found nine live individuals (Figure 5). Both recaptured *A. wheeleri* were found at site 3. Both of these individuals were found within one meter of where they were released in 1990. No other live *A. wheeleri* were found at site 3. In 1992 we recaptured the same two *A. wheeleri* at site 3 that we had recaptured in 1991. The individuals were within a few meters of where they had been released in 1991. The recaptured individuals had not grown discernably and changes (<1mm) are within the margin of error of our calipers (.1mm). No other marked *A. wheeleri* were recaptured in 1992.

Four individual *A. wheeleri* were brought back to the laboratory on September 20, 1992. *A. wheeleri* survived as well in the laboratory as any other mussel species we brought back, which included most non-rare species in the Kiamichi River, and survived better than some very abundant species such as *Lampsilis ovata* and *Amblema plicata*. *A. wheeleri* appeared to be doing very well for the first few months. They appeared well, were actively siphoning, and produced pseudofeces on a regular basis. The first *A. wheeleri* died in early December and the second followed in late December. At this time a large number of other species of mussels held in the laboratory also died. The third *A. wheeleri* died on January 11 and the last individual survived until March 8, 1993, or almost six months.

The size distribution (means for 1990 - 92) for *A. wheeleri* in the Kiamichi River is shown in Figure 13. Lengths of individual *A. wheeleri* captured in 1990 - 1992 at each site are shown in Figure 14. In Figure 14 each bar represents an individual mussel.

Lengths of spent shells in the OMNH and USAO collections were significantly different than lengths of live *A. wheeleri* in the Kiamichi River (Figure 15, $t=1.9$, $df=78$, $P=0.03$).

The resulting regression equation for number of annuli on shell height was $Y = (-.483)X + 49.62$ ($n=24$, $R^2=0.467$, $P < 0.05$). Predicted ages based on number of annuli for live *A. wheeleri* from the Kiamichi River are shown in Figure 16. Predicted ages of spent shells vs. live *A. wheeleri* were not significantly different ($t=-0.84$, $df=54$, $P=0.19$).

The youngest predicted age for a live *A. wheeleri* was 12 years. Using this method none of the *A. wheeleri* we encountered on the Kiamichi River during our study were produced after Sardis reservoir was filled in 1983.

3. Identify glochidia and fish host.

We were not able to identify the glochidia or fish host of *A. wheeleri*. *A. wheeleri* examined in the field and held in the laboratory were not gravid and thus we were unable to obtain any glochidia either for identification or fish-host studies.

We were, however, able to obtain indirect information narrowing the field of potential fish hosts for *A. wheeleri*. Fish abundances and the numbers of glochidia found on fish are shown in Tables 8 and 9, respectively. Table 10 gives Spearman

Rank correlation coefficients of the association between fish and mussel abundance. Significant correlations are shown in bold type. *A. wheeleri* was positively associated with several cyprinid species, notably *Notropis* spp. (formerly *Notropis rubellus*), *N. umbratilis*, *N. volucellus*, and a darter, *Percina copelandi*. No glochidia were found on *P. copelandi* or *N. volucellus*, but glochidia were found on *N. rubellus* and *N. umbratilis* from several sites (Table 9).

As discussed above, we performed a Principal Components Analysis (PCA) ordination of fish and mussel relative abundances. The relative abundance of *A. wheeleri* and *N. umbratilis* both had a strong negative loading on PCA axis 2 (Figure 9, Table 10).

Densities of drifting glochidia are shown in Figure 17 and discussed in more detail in the next section.

4. Examine impact of Sardis Reservoir on the populations.

A. wheeleri occurs both above and below the inflow to the Kiamichi River from Sardis Reservoir via Jackfork Creek. Of our ten study sites selected for detailed study, three were located above Sardis Reservoir and seven below (Figure 2). All of these sites historically harbored *A. wheeleri*. *A. wheeleri* was found during this study at all three sites (100%) above Sardis Reservoir. *A. wheeleri* was found at three of seven (43%) of the sites below the reservoir inflow. The relative abundance of *A. wheeleri* at sites above Sardis reservoir was on average greater than the relative abundance of *A. wheeleri* at sites below the reservoir (Figure 6), although these differences are not statistically significant.

The smallest live *A. wheeleri* was found at site 2 (above the reservoir) and the next smallest at site 7 (below the reservoir). However, if our predicted age distributions are correct, both of these individuals are older than Sardis reservoir which was filled in 1983.

Overall, mussel densities vary both above and below Sardis Reservoir (Figure 3). Relative abundances of most mussel species are not significantly different above and below the reservoir (Figures 18 and 19).

To determine the effects of Sardis Reservoir on the recruitment of mussels in the Kiamichi River we examined the size distribution of *Amblema plicata*. *A. plicata* is a generalist mussel species that is extremely abundant in the Kiamichi River and occurred at all of our sites. Many juvenile mussels are extremely difficult to identify to species, but juvenile *A. plicata* are readily identifiable and we knew we had seen and measured them in the Kiamichi River. We measured the shell lengths of 1435 live *A. plicata* in the Kiamichi River in 1991. Shell lengths of *A. plicata* from above Sardis reservoir were significantly different than shell lengths of *A. plicata* from below the reservoir (F=9.55, P=.01). Smaller *A. plicata* were much more common above Sardis Reservoir than below (Figure 20).

We examined mean densities of glochidia drifting in the water column and compared these to mean mussel densities for each sites. Mean densities of glochidia in the drift are lowest at sites 4 and 5, the sites directly below and closest to the inflow from Jackfork Creek. Mussel densities, however, are not low at these sites (Figure 21).

5. Determine historic and current land use within the current range of Arkansia wheeleri in the Kiamichi River.

Every attempt was made to compare 1992 satellite imagery and recent aerial photography with older aerial photography in order to determine land use changes in the Kiamichi watershed. We could not locate pre-logging or 1930's aerial photography for the Kiamichi watershed. It is possible that some older photographs may exist in the National Archives, but we did not have the time or financial resources to pursue this source. 1954 photography for the Kiamichi watershed was available from ASCS in Salt Lake City. We did not use these photographs for two reasons. (1) We did not think they were old enough to be very useful since most logging (the significant land use change) occurred long before 1954. (2) They did not appear to be useful enough to be worth the expense and the long wait. ASCS has a minimum 12 week turn around time, but on other projects we have found it to be much longer. Our impression from the satellite image, photography we have examined, talking to locals, and the considerable amount of time we have spent driving around Pushmataha County, is that there has been very little recent development in the watershed, other than the construction of the two reservoirs.

The final classification categories were developed using the Anderson et al. (1976) classification scheme only as a guide. Final classification categories include: 1) urban, 2) primary roads, 3) pasture/regrowth/cropland, 4) deciduous forest, 5) coniferous forest, 6) mixed forest, 7) rivers/streams/woodlands, 8) reservoirs and, 9) clouds/cloud shadows (Figs. 25,26) Cropland is a separate land class category in the

Anderson et al. classification scheme but because this cover type comprises such a small part of our study area (C. Vaughn and D. Certain, personal observation) and is spectrally similar to pasture we chose to combine the two. The regrowth category was the only category included in our classification but not used in the Anderson et al. classification. This category was included due to the occurrence of many forest clearcuts in early stages of regeneration. The obvious areas of regrowth after forest clearcutting were combined with pasture and cropland because of spectral similarities. Areas of regrowth were distinguished from mature forest based on spectral and geometric features that are obvious when the image is viewed. These regrowth areas have high brightness values and are of a regular geometric shape. They often stand out in landscape since they are often surrounded by mature forest (Figure 27). Some of Anderson et al.'s categories were not included since they do not occur within the Kiamichi watershed (e.g. tundra, perennial snow or ice).

The percent coverage of each landuse category in terms of the number of pixels included in that class is detailed in Table 12. The mixed forest category includes the largest number of pixels overall; however, the number of pixels included in each category is not a direct measure of the areal coverage of that category due to the two-dimensionality of the image data. Accurate aerial coverage estimates require including topographic relief parameters such as slope and elevation. The clouds/cloud shadows category is not a landuse class and was not included in these calculations.

Error Analysis

Classification accuracy for each landuse category (omitting clouds/cloud shadows category since it is not a landuse and because it covers less than 1 percent of the total area) was estimated by choosing at least 20 reference data sites for each category from aerial photographs and transposing the location of those sites onto USGS 7.5' topographic maps. The maps were then used to locate the reference sites on the unenhanced, 3-band image. Each site was represented by a single pixel which was described by its true landuse type as determined by aerial photography interpretation. Each reference pixel was compared to its' corresponding pixel in the classified image to estimate the accuracy of classification (Table 13). User's accuracy estimates the probability that a pixel classified in the image actually represents that category on the ground (Congalton 1991). The producer's accuracy gives the probability of a reference pixel being correctly classified. User's accuracy for this classification ranges from 28.3% (mixed forest) to 100.0% (rivers/streams/woodlands). Producer's accuracy ranges from 0.0% (primary roads) to 100.0% (urban). The overall accuracy for this classification is 53% if we include all final landuse categories. However, there was a large degree of error introduced into the classification when the primary roads class was overlayed onto the spectrally classified image. A close look at that class alone overlayed on the raw image shows a poor matchup of pixels representing the class in each image. This displacement error was caused by the transformation of the vector data in the digitized files to gridded data usable by the classified image. If the primary roads category is not used in the accuracy assessment then overall accuracy increases to 60.0%.

An additional source of classification error is the effect of topographic relief on recorded brightness values. Topographic relief can either increase or decrease brightness values of pixels depending on factors such as the slope and aspect of the terrain, and the sun angle. Pixels occurring on slopes facing direct sunlight often have exaggerated brightness values. The opposite is true for pixels on the shaded side of slopes. It is not unusual for pixels in high sunlight or complete shade to have the maximum (255) or minimum (0) brightness value, essentially covering up any spectral information about landuse type that might otherwise be visible. Pixels on east-facing slopes in this data set appeared to have exaggerated brightness values while west-facing slopes and narrow-canyon walls were often hidden in shade.

D. Discussion

Microhabitat

Arkansia wheeleri occurs in both pools and backwaters in the Kiamichi River, not just backwaters as was previously believed. However, while pool and backwater habitats are common in the Kiamichi River, *A. wheeleri* only occurs in a select few of them. Pools and backwaters where *A. wheeleri* occur have in common an (1) abundant and diverse assemblage of mussels, (2) bottom substrata that are stable and contain adequate amounts of fine gravel/coarse sand, (3) low current (but not stagnant), (4) low siltation, and (5) proximity to tributaries, emergent vegetation, riffles and gravel bars.

Although pools and backwaters were considered different habitat types in this study, in most cases they are tightly interconnected and share many characteristics in common. Backwater areas tend to be shallower and have finer substrata. As backwaters merge into the main river channel they turn into deeper pools with coarser substrata and slightly higher current velocity. As stated before, at our sites *A. wheeleri* occurred in both of these microhabitats. In addition we believe *A. wheeleri* moves back and forth between these habitats either voluntarily or through physical displacement of shifting sediments. As described in the Results section, individuals at site three that were repeatedly recaptured had not moved. However, at another site (site five) we found unmarked individuals in the backwater area only for two years (1990 and 1991), and then in the pool area alone in 1992. At this site the backwater and pool were interconnected. This site had undergone a great deal of sediment deposition during the high flow of spring 1992 and a great deal of the original backwater sediment was shifted to the pool area.

Recent studies addressing the substratum preferences of unionids have reached different conclusions and substratum preferences among unionids remain poorly understood. However, mussels are generally believed to be most successful in stable, sand-gravel mixtures and are generally absent from substrata with heavy silt loads (Cooper 1984, Salmon and Green 1983, Stern 1983, Way et al. 1990). Most unionid species can be found on a number of different substrata, but growth rates of individuals in each microhabitat can be quite different (Kat 1982, Hinch et al. 1989). Furthermore, many mussel species can occupy a wide range of habitats as a result of extensive larval dispersal over a heterogenous stream environment (Strayer 1981), but growth and reproduction may be optimized only under the habitat conditions described above. As an example consider *Amblema plicata*, the clearly dominant mussel species in the Kiamichi River. This species occurred in every microhabitat we examined (pool, backwater, riffle, run) and at every site we examined. Its density, however, was not the same in all of these habitats. The greatest numbers of individuals were found in the large, diverse mussel beds where *A. wheeleri* also occurred. It is clearly able to "survive" in a large number of habitats, but its survival and growth is only optimized in "good" habitat (Strayer 1981).

The key to the distribution of *A. wheeleri* in the Kiamichi River is the presence of the large mussel beds where other mussel species thrive. These shoals represent optimal habitat for most mussel species, as evidenced by the large number of species and their high abundance. These shoals usually contain both pool and backwater areas, have significant gravel bar development with accompanying vegetation (dominated by *Justicia americana*), and are close to a tributary (usually within one quarter mile). Shoals are usually adjacent to a major riffle area, although they can be either up or downstream of the riffle.

While other mussel species may survive in less than optimum habitat, *A. wheeleri* clearly cannot. They only survive in the best available habitat. Other studies have shown that these mainstream river shoals in shallower areas with slow, steady current and vegetation and coarse substrate are optimal habitat for lotic unionids because of minimal turbulence, low silt and steady food supply (Salmon and Green 1982).

In summary, *A. wheeleri* does not show a habitat preferences that is unique from other unionids in the Kiamichi River. However, *A. wheeleri* only occurs in the best available habitat for mussels.

Movement , Growth and Survival

Locomotory tendencies differ among different mussel species. For example, *Anodonta grandis* migrate up and down with changes in water level (White 1979) and in this way avoid stranding at low water. Other species such as *Uniomerus tetralasmus* and the introduced *Corbicula fluminea* remain in position and suffer prolonged exposure to air (McMahon 1991). Marked individual *A. wheeleri* in a backwater area (site 3) did not move significantly from July 1990 to July 1992. However, at another site (site 5) unmarked individuals moved from a backwater area into the adjacent pool area. This movement was probably the result of physical displacement of these individuals through sediment scour and redeposition.

In the majority of mussel species the greatest amount of growth occurs in the first few years of life. Shell growth rate then declines exponentially with age, although the rate of tissue biomass accumulation usually remains constant (McMahon 1991). Our examination of live *A. wheeleri* in the Kiamichi River and of relict *A. wheeleri* shells in the museum collections indicate that this growth pattern is also followed by *A. wheeleri*. Early annuli (those near the umbo) are much wider than later annuli near the edge of the shell.

Recruitment, growth and survival of mussels is often assessed by monitoring changes in density and size demography of natural populations (Payne and Miller

1989). We have no quantitative historical data on densities of *A. wheeleri* in the Kiamichi River or anywhere else. Past size distribution, however, can be assessed by examining the size distribution of relict shells. The size distribution of live *A. wheeleri* in the Kiamichi River is skewed to the left (Sokal and Rohlf 1981) (Figure 15) with more large individuals and fewer small individuals than one would expect with a statistically normal distribution. The size distribution of relict shells (Figure 15) follows a more normal distribution, with a greater proportion of smaller individuals than in the live population. Looking at these shell length data alone one would conclude that the size distribution of *A. wheeleri* in the Kiamichi River has changed over time and recruitment has decreased.

External annular rings have long been used to determine mussel age and growth rates. Recently this technique has been heavily criticized as being replete with problems (Downing et al . 1992). Natural erosion and corrosion of shells makes it difficult to distinguish true from false annuli. For example, false annuli can be formed by the incorporation of small substrate particles into mussel shells. It is difficult to count closely deposited growth lines near the margins of old shells. This produces an underestimate of shell age that becomes more erroneous with shell age. Downing et al. (1992) studied populations of *Lampsilis radiata* and *Anondonta grandis* in an oligotrophic lake. In these populations, many mussels showed no new external annuli at all, even several years after individual animals had been marked. They concluded that estimates of growth based on shell annuli consistently overestimated real shell growth. In addition, shell size and growth rates are linked to environmental conditions.

For example, some species form narrower shells in coarser substrates (Hinch et al. 1989) or grow faster in sand than in mud (Hinch et al. 1986).

As described earlier, we counted annuli on relict shells and used the resulting shell height-annuli regression equation to predict number of annuli for live *A. wheeleri*. As pointed out by the above discussion, this method should be assumed to have a large margin of error and probably also underestimates ages of *A. wheeleri*. Using this method, the youngest live *A. wheeleri* we encountered was approximately 12 years of age and there were not significant differences between predicted ages of live individuals versus relict shells. No juveniles were encountered.

Both types of data, shell-size distributions and ages predicted from external annuli, demonstrated that most *A. wheeleri* encountered in the Kiamichi River are old.

Life History

Because of its rarity, the reproductive biology of *A. wheeleri* remains unknown. Like other anodontines, it is probably bradytictic. The closest relative of *A. wheeleri*, *Arcidens confragosus*, becomes gravid in the fall and releases glochidia in the spring (Clarke 1981). We were unable to obtain any gravid *A. wheeleri* and thus obtained no glochidia. *A. wheeleri* glochidia are probably similar to other alasmidontine glochidia. Alasmidontine glochidia are asymmetrical and have a stylet covered with microstylets which facilitate attachment to the fish host. Glochidial releases are probably tied to natural water temperature changes in the spring and fall (Jirka and Neves 1992).

The fish host or hosts of *A. wheeleri* remain unknown. However, we have identified strong possibilities for the fish host species. *A. wheeleri* was positively associated with several cyprinid species which were found to harbor glochidia. *Notropis* (=*Lythrurus) umbratilis*, the redfin shiner, inhabits "sluggish pools lined with water willows (*Justicia americana*) over gravel or sand substrates" (Robison and Buchanan 1988). This is the same habitat occupied by *A. wheeleri*. *N. umbratilis* is widespread in the Mississippi and Ohio valleys and in the southern Great Lakes tributaries as far north as western New York, southern Ontario, southern Michigan and Wisconsin, and southeastern Minnesota. It occurs south in the Mississippi valley to the Red River drainage but is uncommon in tributaries east of the Mississippi River. It occurs west to central Kansas and Oklahoma in the Missouri, Arkansas and Red River drainages.

Notropis spp. (c.f. *rubellus*) is a new species that is currently being described by Drs. Julian Humphries at Cornell University and Robert C. Cashner at the University of New Orleans. The species description will be published in the first issue of *Copeia* (No. 1) in 1994. The range of *Notropis* spp. is from the Blue River throughout the Little River drainage, and includes the Kiamichi River (R.C. Cashner, pers. comm.). The taxonomy of the species in the Ouachita River is unresolved (R.C. Cashner, pers. comm.).

Determining the reproductive biology of *A. wheeleri* will be extremely challenging. It takes an average of four to six hours to locate one individual *A. wheeleri* at a known location. They are extremely rare. Obtaining enough *A. wheeleri* to perform standard life history studies would probably destroy any remaining viability of the existing population. For example, determining the age at which *A. wheeleri* achieves sexual maturity and the number of years gamete production continues would necessitate sacrificing many *A. wheeleri*.

Identification of the fish host might best be done by a molecular genetic approach (DNA fingerprinting). Such analyses are being used by other researchers to identify fish hosts of mussels (White 1993). The technique compares DNA obtained from glochidia found attached to fish to a battery of DNA's from adult mussels in the community. Even this approach would not guarantee identification of the fish host. Identification is contingent upon *A. wheeleri* still reproducing (unknown), fish being collected during the spawning season of *A. wheeleri* (unknown), and collection of the correct fish host (unknown). We have tissue of three *A. wheeleri* from the Kiamichi River stored in an ultracool freezer at the University of Oklahoma. This material could be made available to researchers for DNA fingerprinting once they work out the techniques on more common species. We also have preserved glochidia samples available for analysis.

Effects from Sardis Reservoir

It appears that historically *A. wheeleri* did equally well above and below Jackfork Creek (Clarke 1987). Historically, *A. wheeleri* occurred at at least seven sites between Clayton and Antlers. However, in five years of combined sampling effort by Mehlhop and Miller, 1988-1989, and ourselves,1990-1992, we have only found three subpopulations of *A. wheeleri* below Jackfork Creek. Therefore, only three out of seven or 43% of the known subpopulations of *A. wheeleri* survive below Jackfork

Creek. In contrast, three out of four or 75% of the historical locations of *A. wheeleri* above Jackfork Creek have been confirmed and five new locations have been discovered (Mehlhop and Miller 1989, Vaughn 1991). The fourth historical location above Jackfork Creek has not been adequately surveyed and may well contain a subpopulation of *A. wheeleri*.[2] No new locations have been discovered below Jackfork Creek despite intensive survey efforts. In addition, the relative abundance of *A. wheeleri* is slightly higher above Jackfork Creek than below. Unfortunately, we have no historical abundance data for *A. wheeleri* in the Kiamichi River.

Overall mussel densities vary both above and below Sardis Reservoir and relative abundances of most mussel species are not significantly different above and below the reservoir. However, in any mussel survey it is easier to find large adults than small, secretive juveniles. As shown above with the *A. wheeleri* data, most adult mussels were probably produced before the reservoir was filled. Therefore, a finding of no differences in relative abundances of adult mussels above and below the reservoir may actually be a reflection of habitat conditions before reservoir construction. To determine the effects of Sardis Reservoir on the recruitment of mussels in the Kiamichi River we examined the size distribution of *Amblema plicata*. *A. plicata* is a generalist mussel species that is extremely abundant in the Kiamichi River and occurred at all of our sites. Many juvenile mussels are extremely difficult to identify to species, but juvenile *A. plicata* are readily identifiable. Shell lengths of live

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[2] Biologists that attempted to survey this site from a canoe were threatened by a person on shore with a firearm.

A. plicata from above Sardis reservoir were significantly different than shell lengths of live *A. plicata* from below the reservoir. These data indicate that recruitment of *A. plicata* is reduced below Sardis Reservoir. Smaller *A. plicata* were much more common above Sardis Reservoir than below. Because *A. plicata* is a common, tolerant species, any reductions in its recruitment may signify similar problems with most mussel species in the community.

Recently malacologists have voiced concerns that many North American unionid populations are composed of slowly dwindling numbers of long-lived adults destined for extirpation as pollution and other disturbances prevent juvenile recruitment to aging populations (McMahon 1991).

The lowest average number of glochidia found in the drift occurred at sites 4 and 5, the two sites below and closest to the confluence with Jackfork Creek.

To date we have found no water chemistry differences at sites above and below Sardis Reservoir. However, this study was designed to gather broad information on river habitats used by *A. wheeleri* and is not an intensive investigation of water quality dynamics in proximity to Jackfork Creek. Nevertheless, we have observed large physical differences in water level and flow regime fluctuations above and below Sardis Reservoir. For example, site 4 (Clayton) is almost directly below the confluence with Jackfork Creek. The measured summer flow rates at this site are typically much higher than the other sites because of water being released from the reservoir. Periodic scouring of substrata exposed to high flow velocities can remove both substrata and mussels and prevent their successful resettlement (Young and Williams, 1983; McMahon, 1991). When we visited site 7 during the summer of 1991 water levels had obviously just dropped drastically. Our evidence for this was the large number of small pools on gravel bars that harbored live but rapidly perishing fish and mussels. We counted over 100 stranded mussels at this site. Water level variation can have significant effects on mussel survival and may pose a significant threat to *A. wheeleri* at sites below the confluence of Jackfork Creek. Declining water levels expose relatively immotile mussels for weeks or months to air. It is doubtful that *A. wheeleri* can withstand such long air exposure, especially during the hot southeastern Oklahoma summer. Water temperature in some of the pools of stranded animals exceeded 35^0C. Adult mussels are fairly sedentary in habit. While most species are adapted to seasonal changes in water levels and flow rates, they cannot move fast enough to respond to unpredictable and rapid changes in water level and flow rate.

Historical and Current Land Use

The primary landuse type within the Kiamichi watershed appears to be that of a mixed forest type with an even larger portion of the watershed being covered by mature or near-mature forest of some type. However, this classification also shows how human development has been concentrated along and immediately adjacent to the river channel. This is not surprising given the rugged nature of the landscape outside of the river valley. However, difficulty of access has not completely deterred development in this area as can be seen by the occurrence of many forest cuts in various stages of regrowth. Overall, this watershed still maintains significant coverage by stands of mature forest, but much of this forest is likely to differ dramatically from its' original state prior to being cut. The most significant recent land use change in the watershed is the construction of Hugo and Sardis reservoirs.

E. Threats

The greatest threats to the continued existence of *A. wheeleri* in the Kiamichi River are land use changes. The most serious land use changes are further impoundment of the river, water transfers, timber harvesting, and pollution from agricultural and industrial development. *A. wheeleri* is also threatened by the invasion of exotic bivalve species, particularly the zebra mussel, *Dreissena polymopha*.

Impoundment and Water Transfers

Rivers regulated by dams differ from free-flowing rivers in many ways and alteration in volume of flow and timing of discharge can seriously impact riverine fauna. Stream organisms, including mussels, have evolved in rivers that experience seasonal low-flow and high-flow periods (Meador and Matthews 1992). Fluctuating flows, especially if there will be lower flows for long periods to time, will result in the stranding of many mussels. Unlike fish species which can move rapidly in and out of microhabitats with changes in water levels, mussels move very slowly and are unable to respond to sudden drawdowns. Even if stranding doesn't actually kill a mussel, desiccation and thermal extremes will cause physiological stress and may reduce reproductive potential (McMahon 1991). We have already observed significant stranding of mussel individuals in the Kiamichi River below Sardis Reservoir (Vaughn and Pyron 1992).

Fluctuating flows also mean that transport of particulates will vary. Depending on the flow schedule and the materials normally transported in the water column, there is the potential for loss of organics which are the food base for mussels.

Increased flows associated with river regulation have the potential to alter the distribution of sediment through scour, flushing, and deposition of newly eroded materials from the banks. Increased flows have the potential to activate the bed (i.e. actually cause the bottom of the river to move). Bedload movement will wreak havoc on the survival of many mussels, particularly juveniles (Young and Williams 1983). Erosion caused by increased flows at one location results in deposition of this material further downstream. This "zone of aggradation" results in an increased width/depth ration of that portion of the channel. As width/depth ratios increase the potential for bedload transport also increases. Thus, increased flows cause habitat loss through both sediment deposition and increased bed mobility.

Sediment deposition not only removes habitat, but also clogs mussel siphons (i.e. smothers them) and interferes with feeding and reproduction (Aldridge et al. 1987).

In the long term, higher base flow levels and shorter periods between peak flood periods will decrease habitat complexity by preventing the formation of islands, establishment of macrophyte beds etc... (Frissell 1986). Stabilized sediments, sand bars, and low flow areas, are all preferred unionid habitats (Hartfield and Ebert 1986, Payne and Miller 1989, Stern 1983, Way et al. 1990). It is around these "complex" areas that most mussel beds in the Kiamichi River, and indeed the highest diversity of stream fauna, are found.

Flow regulation not only has the potential to profoundly effect the stream fauna, but riparian fauna as well. Flood waters that normally recharge soils and aquifers may be rapidly exported downriver. Lowered water tables may cause shrinkage of the riparian corridor and shifts in terrestrial species composition (Allan and Flecker 1993, Smith et al. 1991).

Because of their dependence on the appropriate substrate and flow conditions, freshwater mussels, including *A. wheeleri*, are already naturally patchily distributed in rivers. Any further fragmentation, such as the construction of a reservoir, will act to increase patchiness and to increase the distance between patches. These effects may have major consequences for the metapopulation (i.e. local or subpopulations connected by infrequent dispersal) structure of *A. wheeleri* (Vaughn 1993b). As some subpopulations are eliminated and dispersal distances are increased between other subpopulations, demographic and genetic constraints will diminish the ability of this species to respond to even natural stochastic events much less human-induced environmental change (Wilcox 1986, Murphy et al. 1990).

Timber Harvesting

Timber harvesting operations can have significant effects on both stream water quantity and quality. The influence of catchment vegetation on stream discharge is dependent on a large number of variables, many of which are site-specific. However, in general, removal of forest vegetation increases stream runoff (Campbell and Doeg 1989) and leads to many of the effects of increased flows discussed above.

Road-building activities and low water crossings associated with logging can lead to the development of "headcuts", or migrating knickpoints in the channel remote from areas of actual modification. Headcuts result in severe bank erosion, channel widening, and depth reduction and can have devastating effects on the mollusc fauna (Hartfield 1993).

Pollution

Their sedentary life style and filter-feeding habits make mussels especially vulnerable to chemical pollution events. Contaminants can destroy mussel populations directly by exerting toxic effects or indirectly by causing or contributing to the elimination of essential food organisms or host fish (Havlik and Marking 1987). To date, the Kiamichi River has remained relatively unpolluted, and this is one reason it maintains a generally healthy mussel fauna. Rivers near the Kiamichi, which have experienced more development, are rapidly losing their mussel faunas. For example, below the point where the Little River receives effluent from a paper mill, there have been massive mussel die offs (Vaughn 1993a).

Predation

Natural predation does not appear to be a threat to *A. wheeleri* in the Kiamichi River. Fresh shells found opened along the shore are predominately *Corbicula* (Vaughn and Pyron, pers. obs.). *Corbicula* have been shown to be the dominant prey of muskrats in other systems in which it has invaded (Neves and Odum 1989).

Exotic Species

Zebra mussels (*Dreissena polymorpha*) are now found in the Arkansas River system in Oklahoma. The high dispersal capabilities of this species make it highly probable that it will invade the Red River system in the near future (French 1990). Invasion of the Kiamichi would most likely be from the two existing reservoirs, Sardis and Hugo, because this is where boats (with encrusted adults or water containing larvae) would be launched. The zebra mussel could then spread downstream from both reservoirs. Construction of the authorized Tuskahoma Reservoir would provide an additional entryway for zebra mussels into the Kiamichi. The exotic bivalve *Corbicula fluminea* may also pose a threat to *A. wheeleri* (Mehlhop and Miller 1989).

Commercial Harvest

At this time harvest of mussels from the Kiamichi River for commercial purposes is minimal. However, commercial harvest could pose a grave threat in the future as other more accessible rivers are depleted of their mussel fauna.

F. Summary and Conclusions

The only known remaining viable population of *Arkansia wheeleri* in the world occurs within an 80 mile stretch of the Kiamichi River in Pushmataha County, Oklahoma. Within this river *A. wheeleri* occurs only in the best available mussel habitat: backwaters and pools with fine gravel/coarse sand substrata, significant gravel bar and island development, emergent vegetation, and close proximity to riffles and tributaries. These areas harbor large, diverse mussel communities with which *A. wheeleri* is associated. *A. wheeleri* never occur in riffles, runs, stagnant backwaters, silted-in areas or in pools and backwaters lacking the habitat characteristics described above. *A. wheeleri* never occurs as a single species assemblage or in small mussel beds. In its optimal habitat, *A. wheeleri* is always rare: mean relative abundance varies from 0.2 to 0.7% and the average density is 0.27 individuals/m^2.

The reproductive biology and fish host(s) of *A. wheeleri* remain unknown. Two cyprinids, *Notropis umbratilis* and *Notropis* spp (c.f *rubellus*), are the most likely fish hosts. The youngest individual *A. wheeleri* encountered was approximately 12 years of age.

Forty three percent of the historically known subpopulations of *A. wheeleri* below Jackfork Creek have apparently been extirpated and no new subpopulations have been located. *A. wheeleri* survive at at least 75% of the historically known locations above Jackfork Creek and five new subpopulations have been located. The relative abundance of *A. wheeleri* per site is slightly higher above Jackfork Creek than below. In addition, shell length data for live *Amblema plicata*, a dominant mussel species in the Kiamichi River, indicate reduced recruitment below Sardis Reservoir.

Much of the Kiamichi River watershed remains forested and this probably accounts for the high diversity and general health of its mussel community in comparison to other nearby rivers.

G. RECOMMENDATIONS

1. The existing population of *Arkansia wheeleri* in the Kiamichi River should be monitored on a long-term basis. In addition, the entire mussel community in the Kiamichi River should be monitored for any changes in mussel abundance and size class structure. The ten sample locations that we established in this study would

provide good long-term monitoring sites. In addition to *A. wheeleri*, the Kiamichi River contains other rare mussel species and our data indicate that recruitment below Sardis Reservoir is decreasing. Monitoring these trends in a timely manner could well prevent the listing of other mussel species in the Kiamichi system.

2. Maintenance of the entire fish assemblage in the Kiamichi River is essential for the survival of *A. wheeleri*, especially until the fish host is positively identified. Fish populations should be monitored.

3. Continued efforts should be made to determine the reproductive biology and fish host(s) of *Arkansia wheeleri*. We have identified strong possibilities for the host fish species, but without further study the actual host(s) will remain unknown. DNA fingerprinting is a technique which holds much promise in this area. Thin-sectioning of existing *A. wheeleri* shells would provide more accurate information about the historical and current age structure of the Kiamichi population. Studies of the reproductive biology of surrogate species may prove useful and should be pursued, providing that criteria to select appropriate surrogates can be identified.

4. Additional rivers should be surveyed for the presence of *Arkansia wheeleri*. Recently, *A. wheeleri* shells (but not live individuals) have been found in the Little River in Oklahoma and in two tributaries to the Red River in Texas.

5. Efforts should be made to deter further habitat alteration in the Kiamichi River watershed. In particular, no further reservoirs should be constructed and clearcutting should be discouraged. Private landowners should be encouraged to leave an intact riparian zone along the rivers edge. The authorized Tuskahoma Reservoir would inundate upper reaches of the river inhabited by *A. wheeleri* and affect the remaining population and its habitat downstream. It should not be built. The proposed addition of hydropower to Sardis Reservoir would detrimentally impact the *A. wheeleri* population below the reservoir. Alterations in the natural flow regime as a result of the proposed water transfer project have the potential to devastate *A. wheeleri* populations in the lower reaches of the river.

IV. Acknowledgements

Principal investigator for this project was Dr. Caryn C. Vaughn. Mark Pyron was a co-investigator in 1991 and 1992. Satellite image interpretation and landuse classification for the Kiamichi watershed was done by David L. Certain. John Alderman, Tambra Browning, David L. Certain, Matthew Craig, Julian Hilliard, Philip Lienesch, David Martinez, Estelle K. Miller, Jeremy Miller, David Partridge, Marjorie Pyron, Christopher M. Taylor and Matthew Winston helped with field work at various times. Shells were cataloged by Estelle K. Miller. Tambra Browning processed sediment and glochidia samples and entered data on the computer. Matthew Craig and Tambra Browning did the annuli counts on *Arkansia wheeleri*. We thank Christopher M. Taylor for assistance with ordination interpretations. We thank John M. Alderman, Drs. Mark E. Gordon and C. Michael Mather, David Martinez, and Estelle K. Miller for sharing with us their knowledge about mussels.

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VI. Prepared by:

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Oklahoma Natural Heritage Inventory
Oklahoma Biological Survey
University of Oklahoma

Date: 12/1/93 1993

Approved: Oklahoma Department of Wildlife Conservation

By: Harold Namminga

Harold Namminga
Federal Aid/Research Coordinator

Band	Spectral range (μm)
1	0.45-0.52 (blue)
2	0.52-0.60 (green)
3	0.63-0.69 (red)
4	0.76-0.90 (reflective-infrared)
5	1.55-1.75 (mid-infrared)
6	2.08-2.35 (mid-infrared)
7	10.4-12.5 (thermal infrared)

Table 1. Characteristics of spectral bands of Landsat 5 Thematic Mapper image.

Table 4. Spearman Rank correlations of mussel relative abundances. Correlations that are signficant at P ≤ .05 are shown in bold type.

	A. ligamentina	*A. plicata*	*A. wheeleri*	*E. lineolata*	*F. flava*	*L. radiata*	*L. ovata*	*L. teres*	*M. nervosa*	*O. reflexa*
A. ligamentina	1									
A. plicata	-0.097	1								
A. wheeleri	0.157	0.219	1							
E. lineolata	0.59	0.096	0.37	1						
F. flava	-0.303	-0.249	-0.273	-0.271	1					
L. radiata	0.262	-0.147	0.109	**0.516**	-0.192	1				
L. ovata	-0.065	0.023	-0.007	0.153	-0.081	0.259	1			
L. teres	-0.219	0.184	**-0.368**	-0.08	0.357	0.015	-0.085	1		
M. nervosa	0.267	-0.024	**0.423**	0.31	-0.215	**0.472**	-0.25	-0.088	1	
O. reflexa	0.149	-0.005	0.351	0.145	0.18	0.026	**-0.484**	-0.15	0.269	1
O. jacksoniana	0.354	-0.073	0.082	**0.518**	-0.13	**0.532**	0.229	-0.254	**0.392**	-0.196
P. purpuratus	0.43	0.084	-0.03	0.56	-0.042	0.3	0.039	-0.137	-0.015	0.19
P. occidentalis	**0.389**	-0.059	0.167	0.36	-0.028	0.197	-0.016	**-0.361**	0.115	0.34
Q. pustulosa	-0.07	**-0.656**	0.085	-0.248	0.117	-0.042	-0.089	**-0.518**	0.148	0.229
Q. quadrula	0.138	-0.154	**0.437**	0.052	-0.086	0.208	0.086	**-0.497**	0.338	0.212
T. verrucosa	0.077	0.244	-0.169	0.066	0.141	-0.206	0.14	**0.468**	-0.153	-0.124
T. truncata	0.019	0.006	0.151	0.338	0.348	0.099	-0.083	0.14	-0.172	0.228
V. arkansasensis	0.016	0.27	-0.081	0.08	0.264	-0.185	-0.241	**0.527**	-0.034	0.333
V. lienosa	-0.063	0.1	-0.167	-0.014	**0.403**	0.005	0.286	0.43	-0.11	-0.171

Table 4. Spearman Rank correlations of mussel relative abundances. Correlations that are signficant at P ≤ .05 are shown in bold type.

O. jacksoniana	*P. purpuratus*	*P. occidentalis*	*Q. pustulosa*	*Q. quadrula*	*T. verrucosa*	*T. truncata*	*V. arkansasensis*	*V. lienosa*
1								
0.262	1							
0.135	**0.429**	1						
-0.006	0.025	0.205	1					
0.354	-0.021	0.336	**0.487**	1				
-0.336	-0.318	0.096	**-0.425**	-0.267	1			
0.095	0.284	0.314	-0.325	-0.226	0.052	1		
-0.145	-0.11	0.041	-0.311	-0.207	0.353	0.27	1	
-0.012	-0.074	0.215	-0.146	-0.088	**0.489**	0.235	**0.437**	1

Table 3. Mean physical and chemical habitat parameters for the ten sites.

	1	2	3	4	5	6	7	8	9	10
Average Flow (cm/s)	6	6	3.5	20	10	4	4	4	8	3
pH	7.3	7	7	7	7.4	7.6	7.6	7.1	7	7
Water temperature (oC)	29	29	26	29	30	28	28	30	30	28
Average Depth (cm)	29	91	55	59	79	120	80	76	45	110
Conductivity (umho/cm2)	44	52	47	50	50	52	53	55	40	40
Dissolved Oxygen (mg/l)	6.3	7	6.7	6.2	6.7	7	6.8	6.6	7	7
% Sand	9	9.3	25.6	8.5	4.6	16.8	11.3	7.8	20.7	9
% Fine Gravel	26.4	36	37.7	39.6	34	34.8	34.8	43	25.5	35.5
% Coarse Gravel	33.6	32	19.8	33.8	31.3	30.9	30.9	37	32.3	29.1
%Pebble	28	18.2	15.7	17.5	26.6	16.2	16.2	11	19.9	20.8
%Cobble	3.1	4.4	1.2	0.6	3.4	1.3	1.3	1.2	1.6	5.6

Table 2. Densities of mussel species (No./M2) by site. Species which were found during timed samples but didn't occur in quadrats are not shown. Data are means for 1991 - 1992.

	1	2	3	4	5	6	7	8	9	10
Actinonaias ligamentina	6.67	0.80	6.93	12.40	2.83	4.93	9.87	5.30	0.80	3.20
Amblema plicata	19.47	7.47	3.07	8.00	13.13	5.47	26.40	12.30	1.07	5.33
Arkansia wheeleri	0.00	0.00	0.00	0.00	0.00	0.27	0.27	0.00	0.00	0.00
Ellipsaria lineolata	0.00	0.00	0.00	0.80	0.00	0.40	1.60	12.27	0.00	0.27
Fusconaia flava	2.53	0.40	0.00	1.33	1.30	1.47	2.13	0.00	0.27	1.60
Lampsilis ovata	1.73	1.20	1.33	1.73	1.70	2.40	0.80	0.00	0.00	1.33
Lampsilis radiata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00
Lampsilis teres	1.33	0.00	0.13	0.00	0.13	0.27	0.00	0.27	0.00	0.00
Megalonaias nervosa	0.13	0.00	0.00	0.00	0.00	0.00	0.67	0.80	0.00	0.00
Obliquaria reflexa	0.00	0.13	0.53	0.27	0.50	0.40	0.27	0.00	0.53	0.40
Obovaria jacksoniana	2.67	0.13	0.13	0.13	0.30	0.00	0.13	0.27	0.00	0.27
Potamilus purpuratus	0.00	0.40	0.53	0.27	0.00	0.27	0.00	0.00	0.00	0.00
Ptychobranchus occidentalis	0.13	0.13	1.87	0.53	0.00	0.00	0.00	1.33	0.00	0.00
Quadrula pustulosa	2.80	4.67	9.73	7.47	6.77	12.00	5.47	5.87	16.80	11.87
Quadrula quadrula	0.80	0.27	0.40	0.40	0.13	0.13	0.13	0.27	0.00	0.67
Tritogonia verrucosa	2.67	1.07	2.00	0.67	0.13	0.00	0.93	1.60	0.00	0.80
Truncilla truncata	0.40	0.00	0.53	0.27	0.13	0.40	0.67	0.00	0.27	0.27
Villosa lienosa	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13

Table 5. Results of Jaccard Index for Mussel Presence/Absence

		JI			JI
A. ligamentina	*A. plicata*	0.773	*E. lineolata*	*F. flava*	0.4
A. ligamentina	*A. wheeleri*	0.353	*E. lineolata*	*L. radiata*	0.5
A. ligamentina	*E. lineolata*	0.471	*E. lineolata*	*L. ovata*	0.421
A. ligamentina	*F. flava*	0.762	*E. lineolata*	*L. teres*	0.25
A. ligamentina	*L. radiata*	0.429	*E. lineolata*	*M. nervosa*	0.4
A. ligamentina	*L. ovata*	0.714	*E. lineolata*	*O. reflexa*	0.429
A. ligamentina	*L. teres*	0.263	*E. lineolata*	*O. jacksoniana*	0.545
A. ligamentina	*M. nervosa*	0.353	*E. lineolata*	*P. purpuratus*	0.571
A. ligamentina	*O. reflexa*	0.444	*E. lineolata*	*P. occidentalis*	0.462
A. ligamentina	*O. jacksoniana*	0.611	*E. lineolata*	*Q. pustulosa*	0.364
A. ligamentina	*P. purpuratus*	0.632	*E. lineolata*	*Q. quadrula*	0.462
A. ligamentina	*P. occidentalis*	0.556	*E. lineolata*	*T. verrucosa*	0.4
A. ligamentina	*Q. pustulosa*	0.773	*E. lineolata*	*T. truncata*	0.571
A. ligamentina	*Q. quadrula*	0.556	*E. lineolata*	*V. arkansasensis*	0.417
A. ligamentina	*T. verrucosa*	0.85	*E. lineolata*	*V. lienosa*	0.2
A. ligamentina	*T. truncata*	0.632	*F. flava*	*L. radiata*	0.65
A. ligamentina	*V. arkansasensis*	0.176	*F. flava*	*L. ovata*	0.773
A. ligamentina	*V. lienosa*	0.167	*F. flava*	*L. teres*	0.35
A. plicata	*A. wheeleri*	0.273	*F. flava*	*M. nervosa*	0.3
A. plicata	*E. lineolata*	0.364	*F. flava*	*O. reflexa*	0.6
A. plicata	*F. flava*	0.909	*F. flava*	*O. jacksoniana*	0.45
A. plicata	*L. radiata*	0.591	*F. flava*	*P. purpuratus*	0.7
A. plicata	*L. ovata*	0.864	*F. flava*	*P. occidentalis*	0.55
A. plicata	*L. teres*	0.318	*F. flava*	*Q. pustulosa*	0.909
A. plicata	*M. nervosa*	0.273	*F. flava*	*Q. quadrula*	0.55
A. plicata	*O. reflexa*	0.545	*F. flava*	*T. verrucosa*	0.818
A. plicata	*O. jacksoniana*	0.409	*F. flava*	*T. truncata*	0.619
A. plicata	*P. purpuratus*	0.636	*F. flava*	*V. arkansasensis*	0.15
A. plicata	*P. occidentalis*	0.5	*F. flava*	*V. lienosa*	0.2
A. plicata	*Q. pustulosa*	1	*L. radiata*	*L. ovata*	0.6
A. plicata	*Q. quadrula*	0.5	*L. radiata*	*L. teres*	0.25
A. plicata	*T. verrucosa*	0.909	*L. radiata*	*M. nervosa*	0.357
A. plicata	*T. truncata*	0.636	*L. radiata*	*O. reflexa*	0.471
A. plicata	*V. arkansasensis*	0.136	*L. radiata*	*O. jacksoniana*	0.467
A. plicata	*V. lienosa*	0.182	*L. radiata*	*P. purpuratus*	0.588
A. wheeleri	*E. lineolata*	0.556	*L. radiata*	*P. occidentalis*	0.5
A. wheeleri	*F. flava*	0.238	*L. radiata*	*Q. pustulosa*	0.591
A. wheeleri	*L. radiata*	0.357	*L. radiata*	*Q. quadrula*	0.5
A. wheeleri	*L. ovata*	0.316	*L. radiata*	*T. verrucosa*	0.5
A. wheeleri	*L. teres*	0.083	*L. radiata*	*T. truncata*	0.5
A. wheeleri	*M. nervosa*	0.333	*L. radiata*	*V. arkansasensis*	0.067
A. wheeleri	*O. reflexa*	0.385	*L. radiata*	*V. lienosa*	0.133
A. wheeleri	*O. jacksoniana*	0.364	*L. ovata*	*L. teres*	0.238
A. wheeleri	*P. purpuratus*	0.333	*L. ovata*	*M. nervosa*	0.316
A. wheeleri	*P. occidentalis*	0.308	*L. ovata*	*O. reflexa*	0.471
A. wheeleri	*Q. pustulosa*	0.273	*L. ovata*	*O. jacksoniana*	0.474
A. wheeleri	*Q. quadrula*	0.417	*L. ovata*	*P. purpuratus*	0.65
A. wheeleri	*T. verrucosa*	0.3	*L. ovata*	*P. occidentalis*	0.5
A. wheeleri	*T. truncata*	0.429	*L. ovata*	*Q. pustulosa*	0.864
A. wheeleri	*V. arkansasensis*	0.125	*L. ovata*	*Q. quadrula*	0.579

Table 5. Results of Jaccard Index for Mussel Presence/Absence

A. wheeleri	*V. lienosa*	0.111	*L. ovata*	*T. verrucosa*	0.857
L. teres	*M. nervosa*	0.182	*L. ovata*	*T. truncata*	0.571
L. teres	*O. reflexa*	0.188	*L. ovata*	*V. arkansasensis*	0.1
L. teres	*O. jacksoniana*	0.143	*L. ovata*	*V. lienosa*	0.211
L. teres	*P. purpuratus*	0.235	*M. nervosa*	*O. reflexa*	0.385
L. teres	*P. occidentalis*	0.125	*M. nervosa*	*O. jacksoniana*	0.5
L. teres	*Q. pustulosa*	0.318	*M. nervosa*	*P. purpuratus*	0.333
L. teres	*Q. quadrula*	0.125	*M. nervosa*	*P. occidentalis*	0.417
L. teres	*T. verrucosa*	0.35	*M. nervosa*	*Q. pustulosa*	0.273
L. teres	*T. truncata*	0.313	*M. nervosa*	*Q. quadrula*	0.417
L. teres	*V. arkansasensis*	0.429	*M. nervosa*	*T. verrucosa*	0.3
L. teres	*V. lienosa*	0.375	*M. nervosa*	*T. truncata*	0.333
O. reflexa	*O. jacksoniana*	0.313	*M. nervosa*	*V. arkansasensis*	0.125
O. reflexa	*P. purpuratus*	0.625	*M. nervosa*	*V. lienosa*	0.111
O. reflexa	*P. occidentalis*	0.643	*O. jacksoniana*	*P. purpuratus*	0.533
O. reflexa	*Q. pustulosa*	0.545	*O. jacksoniana*	*P. occidentalis*	0.429
O. reflexa	*Q. quadrula*	0.643	*O. jacksoniana*	*Q. pustulosa*	0.409
O. reflexa	*T. verrucosa*	0.524	*O. jacksoniana*	*Q. quadrula*	0.538
O. reflexa	*T. truncata*	0.529	*O. jacksoniana*	*T. verrucosa*	0.381
O. reflexa	*V. arkansasensis*	0.25	*O. jacksoniana*	*T. truncata*	0.533
O. reflexa	*V. lienosa*	0.143	*O. jacksoniana*	*V. arkansasensis*	0.091
P. purpuratus	*P. occidentalis*	0.667	*O. jacksoniana*	*V. lienosa*	0.182
P. purpuratus	*Q. pustulosa*	0.636	*P. occidentalis*	*Q. pustulosa*	0.5
P. purpuratus	*Q. quadrula*	0.563	*P. occidentalis*	*Q. quadrula*	0.692
P. purpuratus	*T. verrucosa*	0.619	*P. occidentalis*	*T. verrucosa*	0.476
P. purpuratus	*T. truncata*	0.647	*P. occidentalis*	*T. truncata*	0.563
P. purpuratus	*V. arkansasensis*	0.133	*P. occidentalis*	*V. arkansasensis*	0.167
P. purpuratus	*V. lienosa*	0.2	*P. occidentalis*	*V. lienosa*	0.25
Q. pustulosa	*Q. quadrula*	0.5	*Q. quadrula*	*T. verrucosa*	0.476
Q. pustulosa	*T. verrucosa*	0.909	*Q. quadrula*	*T. truncata*	0.471
Q. pustulosa	*T. truncata*	0.636	*Q. quadrula*	*V. arkansasensis*	0.167
Q. pustulosa	*V. arkansasensis*	0.136	*Q. quadrula*	*V. lienosa*	0.25
Q. pustulosa	*V. lienosa*	0.182	*T. truncata*	*V. arkansasensis*	0.214
T. verrucosa	*T. truncata*	0.619	*T. truncata*	*V. lienosa*	0.286
T. verrucosa	*V. arkansasensis*	0.15	*V. arkansasensis*	*V. lienosa*	0.4

Table 6a. Principal component loadings for mussels.

Species	Mussel PC1	Mussel PC2	Mussel PC3
V. lienosa	0.947	0.040	0.089
V. arkansasensis	0.874	0.048	0.250
T. verrucosa	0.788	0.245	0.250
Q. quadrula	-0.788	0.209	0.456
O. jacksoniana	0.724	0.483	0.432
O. reflexa	-0.721	0.556	0.177
L. teres	0.710	0.443	0.505
F. flava	0.658	0.518	-0.176
Q. pustulosa	-0.589	0.376	0.590
A. ligamentina	-0.553	0.481	-0.385
M. nervosa	-0.504	0.742	0.114
L. radiata	0.150	0.898	-0.272
T. truncata	-0.050	0.746	0.349
A. wheeleri	0.164	-0.684	-0.246
L. ovata	0.134	0.523	-0.772
A. plicata	0.141	0.415	-0.783
E. lineolata	-0.401	0.354	-0.264
P. occidentalis	-0.168	0.010	0.245
P. purpuratus	-0.373	-0.485	0.156

Table 6b. Principal component loadings from fish.

Species	Fish PC1	Fish PC2	Fish PC3
L. sicculus	-0.906	0.303	0.104
P. copelandi	0.862	-0.176	0.146
N. atherinoides	-0.850	0.324	0.192
C. whipplei	-0.831	0.308	-0.333
M. punctulatus	0.805	0.489	0.291
N. umbratilis	0.774	-0.541	0.017
E. radiosum	0.716	0.559	0.123
P. notatus	-0.687	-0.063	-0.335
F. notatus	0.557	0.617	0.333
P. vigilax	-0.522	-0.046	0.575
G. affinis	0.265	0.901	-0.183
L. megalotis	0.450	0.847	0.071
N. sutkussi	0.356	-0.824	-0.117
L. macrochirus	0.107	-0.818	-0.035
N. volucellus	0.412	-0.756	-0.137
F. olivaceus	-0.446	-0.609	0.402
L. cyanellus	0.015	0.059	0.844
N. boops	0.240	0.126	-0.627
P. sciera	0.082	0.469	-0.566
C. anomalum	0.478	-0.203	-0.240

Table 6c. Pearson correlation coefficients between environmental variables and principal components scores from fish and mussel PCA's.

Variable	Fish PC1	Fish PC2	Mussel PC1	Mussel PC2
Flow	0.073	-0.036	-0.159	-0.058
Depth	-0.247	-0.183	-0.322	-0.104
Habitat	-0.177	0.470	0.053	0.562
Position	-0.775	-0.117	-0.768	0.462
Reservoir	-0.479	-0.163	-0.657	0.233
Sand	-0.602	0.273	-0.378	-0.179
Fine gravel	-0.407	-0.404	-0.557	-0.295
Coarse gravel	0.381	0.120	0.270	0.418
Pebble	0.738	-0.006	0.665	-0.017
Vegetation	0.647	0.652	0.856	0.322
Bars	0.280	0.307	0.362	0.176

	1st Axis	2nd Axis
Site 1	1.000	
Site 2	0.097	1.000
Flow	0.482	-0.218
Depth	-0.258	-0.065
Conductivity	-0.192	0.202
H Type	0.020	0.309
S Type	0.287	0.144

Table 7. Pearson correlations of habitat factors with Reciprocal Averaging Axes.

Table 8. Numbers of fish collected.

	SITE 1	SITE 1	SITE 2	SITE 3	SITE 3	SITE 3	SITE 4	SITE 4	SITE 4	SITE 4	SITE 5	SITE 6	SITE 7	SITE 7	SITE 7	SITE 7	SITE 10	SITE 10	SITE 10
	Jul-91	Jul-92	Jul-92	Oct-91	Dec-91	Jun-92	Aug-91	Oct-91	Dec-91	Jul-92	Jul-92	Sep-92	Jul-91	Oct-91	Dec-91	Sep-92	Oct-91	Dec-91	Oct-92
Lepisosteus platostomus													1						
Ictiobus bubalus				1															
Noturus gyrinus																			
Noturus nocturnus											1	1				1			2
Moxostoma erythrurum				1															
Dorosoma petenense											2	1							
Labidesthes sicculus	1	1	2	33	4	3		33	3	9	3	8		68		7	60		1
Minytrema melanops		1																	
Cyprinella venusta														2			7		2
Cyprinella whipplei	1	2	4	25	26	15		49	16	26	6	13	1	107	10	11	50		6
Opsopoedus emiliae														9					
Notropis atherinoides	4			28	137			61	33	1	3	21		68	14	15	127		8
Notropis boops	2		3		6			9		31	4	3		30		1	7		
Notropis sp. (rubellus)			13			45	53	1		76	40	2				6	3		
Notropis umbratilis		5	16							3	24	1							
Notropis volucellus			1			1		7	7	1	3				2				
Campostoma anomalum	1	2	13	5	3	8	6	4	9	8	1		1	22	3	1	3		
Pimephales notatus			1	2	2	3		9	1	1		1		4	3	1	4	1	
Pimephales vigilax				3				6	5	1				1	1		5	2	5
Gambusia affinis		4		3		1	1	11		2		4	1	3	16	1			1
Fundulus notatus	1						6						1				1		
Fundulus olivaceus			2	5		5		4		6	2			9	2		3		10
Micropterus punctulatus	2	1	1			1	4	1		2	1		1						
Micropterus salmoides												1					2		
Lepomis cyanellus		1					1	2			2		1	1		2			11
Lepomis gulosus						1													
Lepomis macrochirus			4			1	18	7		17	13	1	9	14	4	1	15		1
Lepomis megalotis	1	1				9		39		14		5		7		9			9
Pomoxis annularis										1	5			2					
Morone chrysops														1					
Crystallaria asprella																	4		
Etheostoma gracile																			1
Etheostoma nigrum				1					2					2				2	
Etheostoma radiosum	8		6	5	4	3		26	7	12		2		2	2		5	1	1
Percina caprodes								3					3	1			1		
Percina copelandi		3	5		2	4		1	2		5			1		2	2		
Percina phoxocephala				1													2		
Percina sciera	1		2	1				9		1		4		1		1			2

Table 9. Glochidial infection rates for fish from the Kiamichi River.

	SITE 1	SITE 1	SITE 2	SITE 3	SITE 3	SITE 3	SITE 4	SITE 4	SITE 4	SITE 4	SITE 5	SITE 6	SITE 7	SITE 7	SITE 7	SITE 7	SITE 1	SITE 10	SITE 10
	'Jul-91	'Jul-92	Jul-92	Oct-91	Dec-91	Jun-92	Aug-91	Oct-91	Dec-91	Jul-92	Jul-92	Sep-92	Jul-91	Oct-91	Dec-91	Sep-92	Oct-91	Dec-91	Oct-92
Lepisosteus platostomus													1						
Ictiobus bubalus				0															
Noturus gyrinus																			
Noturus nocturnus											0	0				0			0
Moxostoma erythrurum				0															
Dorosoma petenense											0	0							
Labidesthes sicculus	0	0	0	0	0	0		0	1	0	0	0		0		0	0		0
Minytrema melanops		0																	
Cyprinella venusta														0			0.714		0
Cyprinella whipplei	0	0.5	0	0.28	20-Jul	0.333		0.75	1	0.1	0.167	0.769	0	0.7	0.5	0.455	0.5		0.833
Opsopoedus emiliae														0					
Notropis atherinoides	0			0.2	0.35			0.75	1	0	1	0.381		0.5	0.214	0.6	0.6		0.25
Notropis boops	0		0		0			0		0.05	0.25	0		0.233		0	0.429		
Notropis sp. (rubellus)			0.385			0.3	1	1		0.55	0.6	1				0.667	0		
Notropis umbratilis		0	0							0.3	0.45	0							
Notropis volucellus			0			1		0.286	1	0	0.3				0				
Campostoma anomalum	0	0	0	0	0	0	0	0	1	0	0		0.2	22	0	0	0		
Pimephales notatus			1	0.5	1	0		0.889	1	1		1		0.25	1	1	0.75	1	
Pimephales vigilax				0.3				0.667	1	1				0	1		0.6	1	0.6
Gambusia affinis		0		0		0	0	0		0		0	0	0.3	0	0			0
Fundulus notatus	0						0						0				0		
Fundulus olivaceus			0	0		0		0		0	0			0	0		0		0
Micropterus punctulatus	0	0	0			0	0	0		0	0		0						
Micropterus salmoides												0					0.5		
Lepomis cyanellus		0					0	0			0		0	0		0			0
Lepomis gulosus						0													
Lepomis macrochirus			0			0	0	0		0	0	0	0	0	0	0	0		0
Lepomis megalotis	0	0	0			0		0		0		0		0.143		0			0
Pomoxis annularis										0	0			0					
Morone chrysops														0					
Crystallaria asprella																	0		
Etheostoma gracile																			0
Etheostoma nigrum				0					1					0				0	
Etheostoma radiosum	0		0	0	0	0		0	1	0		0		0	0		0	0	0
Percina caprodes								0					1	0			0		
Percina copelandi		0	0		0	0		0	1		0			0		0	0		
Percina phoxocephala				0													0		
Percina sciera	0		0	0				0		0		0		0		0			0.

Table 10. Spearman Rank correlations of mussel vs. fish relative abundances. Figures shown in bold type are significant at $P \leq .05$.

	L. sicculus	*C. whipplei*	*N. atherinoides*	*N. boops*	*N. rubellus*	*N. umbratilis*	*N. volucellus*	*C. anomalum*	*P. notatus*
A. ligamentina	**0.643**	**0.714**	0.548	0.253	0.048	**-0.837**	-0.101	-0.108	**0.946**
A. plicata	-0.048	-0.095	-0.429	0.193	-0.119	0.381	-0.127	0.347	-0.109
A. wheeleri	-0.376	-0.073	-0.097	-0.356	0.291	0.491	0.187	0.195	-0.204
E. lineolata	**0.738**	0.881	0.714	-0.157	-0.594	-0.545	-0.71	-0.393	0.182
F. flava	-0.263	-0.395	-0.527	0.236	-0.323	0.402	-0.147	0.271	-0.531
L. radiata	0.69	**0.667**	0.476	0.157	**-0.857**	-0.52	**-0.862**	-0.06	0.109
L. ovata	-0.286	-0.048	-0.524	**0.868**	0.214	0.038	0.254	**0.719**	0.473
L. teres	0.503	0.356	0.54	-0.36	**-0.896**	-0.268	**-0.817**	-0.167	-0.3
M. nervosa	**0.873**	**0.655**	0.518	-0.055	-0.546	-0.48	**-0.697**	-0.466	0.208
O. reflexa	**0.814**	0.599	**0.659**	0.055	-0.252	**-0.868**	-0.338	-0.542	0.549
O. jacksoniana	0.374	0.12	0.06	0.372	**-0.699**	-0.244	-0.578	0.042	-0.037
P. purpuratus	0.096	0.374	0.506	-0.36	0.337	-0.308	0.148	-0.624	0.037
P. occidentalis	0.323	0.419	0.563	0.042	-0.263	**-0.727**	-0.179	0.12	0.512
Q. pustulosa	**0.905**	**0.762**	**0.929**	-0.398	-0.476	**-0.748**	-0.621	**-0.695**	0.255
Q. quadrula	**0.707**	0.491	**0.683**	-0.188	0	**-0.727**	-0.14	**-0.663**	0.512
T. verrucosa	-0.357	-0.19	-0.214	0.157	-0.19	0.127	0.025	**0.85**	0.073
T. truncata	0.446	0.169	0.482	-0.268	-0.602	-0.558	-0.392	0.127	0.202
V. arkansasensis	-0.302	-0.206	-0.399	0.188	-0.385	0.63	-0.344	0.346	-0.567
V. lienosa	**-0.764**	**-0.764**	**-0.791**	0.124	-0.027	**0.843**	0.189	0.604	**-0.667**

Table 10. Spearman Rank correlations of mussel vs. fish relative abundances. Figures shown in bold type are significant at P ≤ .05.

P. vigilax	*G. affinis*	*F. notatus*	*F. olivaceus*	*Micropterus*	*L. cyanellus*	*L. macrochirus*	*L. megalotus*	*E. radiosum*	*P. copelandi*	*P. sciera*
0.464	0.084	-0.164	0.275	-0.561	-0.33	0.275	0.119	-0.311	-0.611	-0.156
-0.518	-0.323	-0.409	0.395	-0.122	0.368	0.395	-0.452	-0.372	0.503	0.012
-0.5	-0.25	**-0.722**	0.091	0.112	-0.562	-0.232	-0.521	0.116	0.482	0.159
-0.082	0.527	-0.3	-0.108	**-0.781**	0.101	-0.263	0.214	-0.443	-0.419	0
-0.439	0.084	0.302	-0.163	0.27	**0.791**	0.163	0.06	-0.127	0.47	-0.09
0	**0.731**	0.3	-0.192	-0.415	0.495	-0.371	0.595	-0.108	-0.263	0.108
-0.327	0.12	0.055	-0.156	0.39	-0.254	0.443	0.19	0.18	0.204	0.156
0.155	0.58	0.422	-0.117	-0.176	0.51	**-0.827**	0.479	0.21	-0.056	0.123
0.219	0.165	-0.094	0.288	**-0.839**	0.392	0.027	0.109	-0.48	-0.508	0.082
0.713	0.223	0.288	0.127	**-0.65**	0.179	0.12	0.371	-0.337	**-0.855**	-0.169
0.262	0.588	**0.856**	-0.261	0.111	0.488	-0.345	**0.807**	0.424	-0.261	0.382
0.028	0.182	-0.387	-0.388	-0.42	-0.411	-0.012	-0.036	-0.388	-0.503	-0.267
0.494	0.494	0.439	-0.145	0.049	-0.134	-0.422	0.539	0.277	-0.289	-0.193
0.546	0.323	0.027	0.12	**-0.805**	0.127	-0.347	0.262	-0.299	**-0.731**	-0.06
0.796	-0.036	0.082	0.265	-0.638	-0.121	0.072	0.132	-0.253	**-0.855**	-108
-0.191	0.156	0.218	0.012	**0.659**	-0.051	-0.395	0.119	0.551	**0.683**	-0.012
0.594	0.109	0.511	0.406	-0.049	0.578	-0.4	0.193	0.042	0.061	-0.424
-0.567	0.436	0.22	-0.463	0.493	-0.044	-0.581	0.385	**0.726**	0.394	**0.788**
-0.563	-0.096	0.219	-0.178	**0.811**	0.262	-0.137	-0.082	0.466	**0.851**	0.192

Table 11. Results of Jaccard Index for Fish and Mussel Presence/Absence.

Fish species	Mussel species	JI	Fish species	Mussel species	JI
Noturus nocturnus	*A. ligamentina*	0.375	*Gambusia affinis*	*A. ligamentina*	0.625
Noturus nocturnus	*A. plicata*	0.375	*Gambusia affinis*	*A. plicata*	0.625
Noturus nocturnus	*A. wheeleri*	0.25	*Gambusia affinis*	*A. wheeleri*	0.5
Noturus nocturnus	*E. lineolata*	0.375	*Gambusia affinis*	*E. lineolata*	0.625
Noturus nocturnus	*F. flava*	0.375	*Gambusia affinis*	*F. flava*	0.625
Noturus nocturnus	*L. radiata*	0.375	*Gambusia affinis*	*L. radiata*	0.625
Noturus nocturnus	*L. ovata*	0.375	*Gambusia affinis*	*L. ovata*	0.625
Noturus nocturnus	*L. teres*	0.25	*Gambusia affinis*	*L. teres*	0.5
Noturus nocturnus	*M. nervosa*	0.25	*Gambusia affinis*	*M. nervosa*	0.25
Noturus nocturnus	*O. reflexa*	0.375	*Gambusia affinis*	*O. reflexa*	0.625
Noturus nocturnus	*O. jacksoniana*	0.375	*Gambusia affinis*	*O. jacksoniana*	0.625
Noturus nocturnus	*P. purpuratus*	0.375	*Gambusia affinis*	*P. purpuratus*	0.625
Noturus nocturnus	*P. occidentalis*	0.25	*Gambusia affinis*	*P. occidentalis*	0.625
Noturus nocturnus	*Q. pustulosa*	0.375	*Gambusia affinis*	*Q. pustulosa*	0.625
Noturus nocturnus	*Q. quadrula*	0.375	*Gambusia affinis*	*Q. quadrula*	0.625
Noturus nocturnus	*T. verrucosa*	0.375	*Gambusia affinis*	*T. verrucosa*	0.625
Noturus nocturnus	*T. truncata*	0.375	*Gambusia affinis*	*T. truncata*	0.625
Noturus nocturnus	*V. arkansasensis*	0.125	*Gambusia affinis*	*V. arkansasensis*	0.25
Noturus nocturnus	*V. lienosa*	0.125	*Gambusia affinis*	*V. lienosa*	0.125
Dorosoma petenense	*A. ligamentina*	0.25	*Fundulus notatus*	*A. ligamentina*	0.25
Dorosoma petenense	*A. plicata*	0.25	*Fundulus notatus*	*A. plicata*	0.25
Dorosoma petenense	*A. wheeleri*	0.25	*Fundulus notatus*	*A. wheeleri*	0.125
Dorosoma petenense	*E. lineolata*	0.25	*Fundulus notatus*	*E. lineolata*	0.25
Dorosoma petenense	*F. flava*	0.25	*Fundulus notatus*	*F. flava*	0.25
Dorosoma petenense	*L. radiata*	0.25	*Fundulus notatus*	*L. radiata*	0.25
Dorosoma petenense	*L. ovata*	0.25	*Fundulus notatus*	*L. ovata*	0.25
Dorosoma petenense	*L. teres*	0.125	*Fundulus notatus*	*L. teres*	0.125
Dorosoma petenense	*M. nervosa*	0.125	*Fundulus notatus*	*M. nervosa*	0
Dorosoma petenense	*O. reflexa*	0.215	*Fundulus notatus*	*O. reflexa*	0.25
Dorosoma petenense	*O. jacksoniana*	0.25	*Fundulus notatus*	*O. jacksoniana*	0.25
Dorosoma petenense	*P. purpuratus*	0.25	*Fundulus notatus*	*P. purpuratus*	0.25
Dorosoma petenense	*P. occidentalis*	0.125	*Fundulus notatus*	*P. occidentalis*	0.25
Dorosoma petenense	*Q. pustulosa*	0.25	*Fundulus notatus*	*Q. pustulosa*	0.25
Dorosoma petenense	*Q. quadrula*	0.25	*Fundulus notatus*	*Q. quadrula*	0.25
Dorosoma petenense	*T. verrucosa*	0.25	*Fundulus notatus*	*T. verrucosa*	0.25
Dorosoma petenense	*T. truncata*	0.25	*Fundulus notatus*	*T. truncata*	0.25
Dorosoma petenense	*V. arkansasensis*	0.125	*Fundulus notatus*	*V. arkansasensis*	0.125
Dorosoma petenense	*V. lienosa*	0.125	*Fundulus notatus*	*V. lienosa*	0.125
Labidesthes sicculus	*A. ligamentina*	1	*Pimephales vigilax*	*A. ligamentina*	0.375
Labidesthes sicculus	*A. plicata*	1	*Pimephales vigilax*	*A. plicata*	0.375
Labidesthes sicculus	*A. wheeleri*	0.75	*Pimephales vigilax*	*A. wheeleri*	0.125
Labidesthes sicculus	*E. lineolata*	1	*Pimephales vigilax*	*E. lineolata*	0.375
Labidesthes sicculus	*F. flava*	1	*Pimephales vigilax*	*F. flava*	0.375
Labidesthes sicculus	*L. radiata*	0.875	*Pimephales vigilax*	*L. radiata*	0.375
Labidesthes sicculus	*L. ovata*	1	*Pimephales vigilax*	*L. ovata*	0.375
Labidesthes sicculus	*L. teres*	0.625	*Pimephales vigilax*	*L. teres*	0.25
Labidesthes sicculus	*M. nervosa*	0.375	*Pimephales vigilax*	*M. nervosa*	0.125
Labidesthes sicculus	*O. reflexa*	1	*Pimephales vigilax*	*O. reflexa*	0.375
Labidesthes sicculus	*O. jacksoniana*	1	*Pimephales vigilax*	*O. jacksoniana*	0.375
Labidesthes sicculus	*P. purpuratus*	1	*Pimephales vigilax*	*P. purpuratus*	0.375

Table 11. Results of Jaccard Index for Fish and Mussel Presence/Absence.

Labidesthes sicculus	*P. occidentalis*	0.75	*Pimephales vigilax*	*P. occidentalis*	0.375
Labidesthes sicculus	*Q. pustulosa*	1	*Pimephales vigilax*	*Q. pustulosa*	0.375
Labidesthes sicculus	*Q. quadrula*	1	*Pimephales vigilax*	*Q. quadrula*	0.375
Labidesthes sicculus	*T. verrucosa*	1	*Pimephales vigilax*	*T. verrucosa*	0.375
Labidesthes sicculus	*T. truncata*	1	*Pimephales vigilax*	*T. truncata*	0.375
Labidesthes sicculus	*V. arkansasensis*	0.375	*Pimephales vigilax*	*V. arkansasensis*	0
Labidesthes sicculus	*V. lienosa*	0.375	*Pimephales vigilax*	*V. lienosa*	0
Minytrema melanops	*A. ligamentina*	0.125	*Fundulus olivaceous*	*A. ligamentina*	0.75
Minytrema melanops	*A. plicata*	0.125	*Fundulus olivaceous*	*A. plicata*	0.75
Minytrema melanops	*A. wheeleri*	0.125	*Fundulus olivaceous*	*A. wheeleri*	0.5
Minytrema melanops	*E. lineolata*	0.125	*Fundulus olivaceous*	*E. lineolata*	0.75
Minytrema melanops	*F. flava*	0.125	*Fundulus olivaceous*	*F. flava*	0.75
Minytrema melanops	*L. radiata*	0.125	*Fundulus olivaceous*	*L. radiata*	0.625
Minytrema melanops	*L. ovata*	0.125	*Fundulus olivaceous*	*L. ovata*	0.75
Minytrema melanops	*L. teres*	0.125	*Fundulus olivaceous*	*L. teres*	0.375
Minytrema melanops	*M. nervosa*	0	*Fundulus olivaceous*	*M. nervosa*	0.25
Minytrema melanops	*O. reflexa*	0.125	*Fundulus olivaceous*	*O. reflexa*	0.75
Minytrema melanops	*O. jacksoniana*	0.125	*Fundulus olivaceous*	*O. jacksoniana*	0.75
Minytrema melanops	*P. purpuratus*	0.125	*Fundulus olivaceous*	*P. purpuratus*	0.75
Minytrema melanops	*P. occidentalis*	0.125	*Fundulus olivaceous*	*P. occidentalis*	0.5
Minytrema melanops	*Q. pustulosa*	0.125	*Fundulus olivaceous*	*Q. pustulosa*	0.75
Minytrema melanops	*Q. quadrula*	0.125	*Fundulus olivaceous*	*Q. quadrula*	0.75
Minytrema melanops	*T. verrucosa*	0.125	*Fundulus olivaceous*	*T. verrucosa*	0.75
Minytrema melanops	*T. truncata*	0.125	*Fundulus olivaceous*	*T. truncata*	0.75
Minytrema melanops	*V. arkansasensis*	0.125	*Fundulus olivaceous*	*V. arkansasensis*	0.125
Minytrema melanops	*V. lienosa*	0.125	*Fundulus olivaceous*	*V. lienosa*	0.25
Cyprinella whipplei	*A. ligamentina*	1	*Micropterus punctulatus*	*A. ligamentina*	0.5
Cyprinella whipplei	*A. plicata*	1	*Micropterus punctulatus*	*A. plicata*	0.5
Cyprinella whipplei	*A. wheeleri*	0.75	*Micropterus punctulatus*	*A. wheeleri*	0.375
Cyprinella whipplei	*E. lineolata*	1	*Micropterus punctulatus*	*E. lineolata*	0.5
Cyprinella whipplei	*F. flava*	1	*Micropterus punctulatus*	*F. flava*	0.5
Cyprinella whipplei	*L. radiata*	0.875	*Micropterus punctulatus*	*L. radiata*	0.375
Cyprinella whipplei	*L. ovata*	1	*Micropterus punctulatus*	*L. ovata*	0.5
Cyprinella whipplei	*L. teres*	0.625	*Micropterus punctulatus*	*L. teres*	0.125
Cyprinella whipplei	*M. nervosa*	0.375	*Micropterus punctulatus*	*M. nervosa*	0
Cyprinella whipplei	*O. reflexa*	1	*Micropterus punctulatus*	*O. reflexa*	0.5
Cyprinella whipplei	*O. jacksoniana*	1	*Micropterus punctulatus*	*O. jacksoniana*	0.5
Cyprinella whipplei	*P. purpuratus*	1	*Micropterus punctulatus*	*P. purpuratus*	0.5
Cyprinella whipplei	*P. occidentalis*	0.75	*Micropterus punctulatus*	*P. occidentalis*	0.25
Cyprinella whipplei	*Q. pustulosa*	1	*Micropterus punctulatus*	*Q. pustulosa*	0.5
Cyprinella whipplei	*Q. quadrula*	1	*Micropterus punctulatus*	*Q. quadrula*	0.5
Cyprinella whipplei	*T. verrucosa*	1	*Micropterus punctulatus*	*T. verrucosa*	0.5
Cyprinella whipplei	*T. truncata*	1	*Micropterus punctulatus*	*T. truncata*	0.125
Cyprinella whipplei	*V. arkansasensis*	0.375	*Micropterus punctulatus*	*V. arkansasensis*	0.125
Cyprinella whipplei	*V. lienosa*	0.375	*Micropterus punctulatus*	*V. lienosa*	0.125
Notropis atherinoides	*A. ligamentina*	0.875	*Micropterus salmoides*	*A. ligamentina*	0.25
Notropis atherinoides	*A. plicata*	1	*Micropterus salmoides*	*A. plicata*	0.25
Notropis atherinoides	*A. wheeleri*	0.625	*Micropterus salmoides*	*A. wheeleri*	0.125
Notropis atherinoides	*E. lineolata*	0.875	*Micropterus salmoides*	*E. lineolata*	0.25
Notropis atherinoides	*F. flava*	0.875	*Micropterus salmoides*	*F. flava*	0.25
Notropis atherinoides	*L. radiata*	0.875	*Micropterus salmoides*	*L. radiata*	0.25

Table 11. Results of Jaccard Index for Fish and Mussel Presence/Absence.

Notropis atherinoides	*L. ovata*	0.875	*Micropterus salmoides*	*L. ovata*	0.25
Notropis atherinoides	*L. teres*	0.625	*Micropterus salmoides*	*L. teres*	0.25
Notropis atherinoides	*M. nervosa*	0.375	*Micropterus salmoides*	*M. nervosa*	0.25
Notropis atherinoides	*O. reflexa*	0.875	*Micropterus salmoides*	*O. reflexa*	0.25
Notropis atherinoides	*O. jacksoniana*	0.875	*Micropterus salmoides*	*O. jacksoniana*	0.25
Notropis atherinoides	*P. purpuratus*	0.875	*Micropterus salmoides*	*P. purpuratus*	0.25
Notropis atherinoides	*P. occidentalis*	0.75	*Micropterus salmoides*	*P. occidentalis*	0.25
Notropis atherinoides	*Q. pustulosa*	0.875	*Micropterus salmoides*	*Q. pustulosa*	0.25
Notropis atherinoides	*Q. quadrula*	0.875	*Micropterus salmoides*	*Q. quadrula*	0.25
Notropis atherinoides	*T. verrucosa*	0.875	*Micropterus salmoides*	*T. verrucosa*	0.25
Notropis atherinoides	*T. truncata*	0.875	*Micropterus salmoides*	*T. truncata*	0.25
Notropis atherinoides	*V. arkansasensis*	0.25	*Micropterus salmoides*	*V. arkansasensis*	0.125
Notropis atherinoides	*V. lienosa*	0.25	*Micropterus salmoides*	*V. lienosa*	0
Notropis boops	*A. ligamentina*	1	*Lepomis cyanellus*	*A. ligamentina*	0.5
Notropis boops	*A. plicata*	1	*Lepomis cyanellus*	*A. plicata*	0.5
Notropis boops	*A. wheeleri*	0.75	*Lepomis cyanellus*	*A. wheeleri*	0.375
Notropis boops	*E. lineolata*	1	*Lepomis cyanellus*	*E. lineolata*	0.5
Notropis boops	*F. flava*	1	*Lepomis cyanellus*	*F. flava*	0.5
Notropis boops	*L. radiata*	0.875	*Lepomis cyanellus*	*L. radiata*	0.5
Notropis boops	*L. ovata*	1	*Lepomis cyanellus*	*L. ovata*	0.5
Notropis boops	*L. teres*	0.625	*Lepomis cyanellus*	*L. teres*	0.375
Notropis boops	*M. nervosa*	0.375	*Lepomis cyanellus*	*M. nervosa*	0.25
Notropis boops	*O. reflexa*	1	*Lepomis cyanellus*	*O. reflexa*	0.5
Notropis boops	*O. jacksoniana*	1	*Lepomis cyanellus*	*O. jacksoniana*	0.5
Notropis boops	*P. purpuratus*	1	*Lepomis cyanellus*	*P. purpuratus*	0.5
Notropis boops	*P. occidentalis*	0.75	*Lepomis cyanellus*	*P. occidentalis*	0.375
Notropis boops	*Q. pustulosa*	1	*Lepomis cyanellus*	*Q. pustulosa*	0.5
Notropis boops	*Q. quadrula*	1	*Lepomis cyanellus*	*Q. quadrula*	0.5
Notropis boops	*T. verrucosa*	1	*Lepomis cyanellus*	*T. verrucosa*	0.5
Notropis boops	*T. truncata*	1	*Lepomis cyanellus*	*T. truncata*	0.5
Notropis boops	*V. arkansasensis*	0.375	*Lepomis cyanellus*	*V. arkansasensis*	0.125
Notropis boops	*V. lienosa*	0.375	*Lepomis cyanellus*	*V. lienosa*	0.25
Notropis rubellus	*A. ligamentina*	0.875	*Lepomis macrochirus*	*A. ligamentina*	0.75
Notropis rubellus	*A. plicata*	0.875	*Lepomis macrochirus*	*A. plicata*	0.75
Notropis rubellus	*A. wheeleri*	0.625	*Lepomis macrochirus*	*A. wheeleri*	0.625
Notropis rubellus	*E. lineolata*	0.875	*Lepomis macrochirus*	*E. lineolata*	0.75
Notropis rubellus	*F. flava*	0.875	*Lepomis macrochirus*	*F. flava*	0.75
Notropis rubellus	*L. radiata*	0.75	*Lepomis macrochirus*	*L. radiata*	0.625
Notropis rubellus	*L. ovata*	0.875	*Lepomis macrochirus*	*L. ovata*	0.75
Notropis rubellus	*L. teres*	0.5	*Lepomis macrochirus*	*L. teres*	0.375
Notropis rubellus	*M. nervosa*	0.375	*Lepomis macrochirus*	*M. nervosa*	0.375
Notropis rubellus	*O. reflexa*	0.875	*Lepomis macrochirus*	*O. reflexa*	0.75
Notropis rubellus	*O. jacksoniana*	0.875	*Lepomis macrochirus*	*O. jacksoniana*	0.75
Notropis rubellus	*P. purpuratus*	0.875	*Lepomis macrochirus*	*P. purpuratus*	0.75
Notropis rubellus	*P. occidentalis*	0.625	*Lepomis macrochirus*	*P. occidentalis*	0.5
Notropis rubellus	*Q. pustulosa*	0.875	*Lepomis macrochirus*	*Q. pustulosa*	0.75
Notropis rubellus	*Q. quadrula*	0.875	*Lepomis macrochirus*	*Q. quadrula*	0.75
Notropis rubellus	*T. verrucosa*	0.875	*Lepomis macrochirus*	*T. verrucosa*	0.75
Notropis rubellus	*T. truncata*	0.875	*Lepomis macrochirus*	*T. truncata*	0.75
Notropis rubellus	*V. arkansasensis*	0.25	*Lepomis macrochirus*	*V. arkansasensis*	0.25
Notropis rubellus	*V. lienosa*	0.25	*Lepomis macrochirus*	*V. lienosa*	0.25

Table 11. Results of Jaccard Index for Fish and Mussel Presence/Absence.

Notropis umbratilis	*A. ligamentina*	0.5	*Lepomis megalotis*	*A. ligamentina*	0.875
Notropis umbratilis	*A. plicata*	0.5	*Lepomis megalotis*	*A. plicata*	0.875
Notropis umbratilis	*A. wheeleri*	0.375	*Lepomis megalotis*	*A. wheeleri*	0.75
Notropis umbratilis	*E. lineolata*	0.5	*Lepomis megalotis*	*E. lineolata*	0.875
Notropis umbratilis	*F. flava*	0.5	*Lepomis megalotis*	*F. flava*	0.875
Notropis umbratilis	*L. radiata*	0.375	*Lepomis megalotis*	*L. radiata*	0.75
Notropis umbratilis	*L. ovata*	0.5	*Lepomis megalotis*	*L. ovata*	0.875
Notropis umbratilis	*L. teres*	0.25	*Lepomis megalotis*	*L. teres*	0.625
Notropis umbratilis	*M. nervosa*	0.125	*Lepomis megalotis*	*M. nervosa*	0.375
Notropis umbratilis	*O. reflexa*	0.5	*Lepomis megalotis*	*O. reflexa*	0.875
Notropis umbratilis	*O. jacksoniana*	0.5	*Lepomis megalotis*	*O. jacksoniana*	0.875
Notropis umbratilis	*P. purpuratus*	0.5	*Lepomis megalotis*	*P. purpuratus*	0.875
Notropis umbratilis	*P. occidentalis*	0.25	*Lepomis megalotis*	*P. occidentalis*	0.75
Notropis umbratilis	*Q. pustulosa*	0.5	*Lepomis megalotis*	*Q. pustulosa*	0.875
Notropis umbratilis	*Q. quadrula*	0.5	*Lepomis megalotis*	*Q. quadrula*	0.875
Notropis umbratilis	*T. verrucosa*	0.5	*Lepomis megalotis*	*T. verrucosa*	0.875
Notropis umbratilis	*T. truncata*	0.5	*Lepomis megalotis*	*T. truncata*	0.875
Notropis umbratilis	*V. arkansasensis*	0.375	*Lepomis megalotis*	*V. arkansasensis*	0.25
Notropis umbratilis	*V. lienosa*	0.375	*Lepomis megalotis*	*V. lienosa*	0.25
Notropis volucellus	*A. ligamentina*	0.375	*Etheostoma radiosum*	*A. ligamentina*	0.875
Notropis volucellus	*A. plicata*	0.375	*Etheostoma radiosum*	*A. plicata*	0.875
Notropis volucellus	*A. wheeleri*	0.25	*Etheostoma radiosum*	*A. wheeleri*	0.625
Notropis volucellus	*E. lineolata*	0.375	*Etheostoma radiosum*	*E. lineolata*	0.875
Notropis volucellus	*F. flava*	0.375	*Etheostoma radiosum*	*F. flava*	0.875
Notropis volucellus	*L. radiata*	0.25	*Etheostoma radiosum*	*L. radiata*	0.75
Notropis volucellus	*L. ovata*	0.375	*Etheostoma radiosum*	*L. ovata*	0.875
Notropis volucellus	*L. teres*	0	*Etheostoma radiosum*	*L. teres*	0.625
Notropis volucellus	*M. nervosa*	0	*Etheostoma radiosum*	*M. nervosa*	0.375
Notropis volucellus	*O. reflexa*	0.375	*Etheostoma radiosum*	*O. reflexa*	0.875
Notropis volucellus	*O. jacksoniana*	0.375	*Etheostoma radiosum*	*O. jacksoniana*	0.875
Notropis volucellus	*P. purpuratus*	0.375	*Etheostoma radiosum*	*P. purpuratus*	0.875
Notropis volucellus	*P. occidentalis*	0.125	*Etheostoma radiosum*	*P. occidentalis*	0.75
Notropis volucellus	*Q. pustulosa*	0.375	*Etheostoma radiosum*	*Q. pustulosa*	0.875
Notropis volucellus	*Q. quadrula*	0.375	*Etheostoma radiosum*	*Q. quadrula*	0.875
Notropis volucellus	*T. verrucosa*	0.375	*Etheostoma radiosum*	*T. verrucosa*	0.875
Notropis volucellus	*T. truncata*	0.375	*Etheostoma radiosum*	*T. truncata*	0.875
Notropis volucellus	*V. arkansasensis*	0.125	*Etheostoma radiosum*	*V. arkansasensis*	0.375
Notropis volucellus	*V. lienosa*	0.25	*Etheostoma radiosum*	*V. lienosa*	0.25
Campostoma anomalum	*A. ligamentina*	0.875	*Percina copelandi*	*A. ligamentina*	0.75
Campostoma anomalum	*A. plicata*	0.875	*Percina copelandi*	*A. plicata*	0.75
Campostoma anomalum	*A. wheeleri*	0.625	*Percina copelandi*	*A. wheeleri*	0.625
Campostoma anomalum	*E. lineolata*	0.875	*Percina copelandi*	*E. lineolata*	0.75
Campostoma anomalum	*F. flava*	0.875	*Percina copelandi*	*F. flava*	0.75
Campostoma anomalum	*L. radiata*	0.75	*Percina copelandi*	*L. radiata*	0.625
Campostoma anomalum	*L. ovata*	0.875	*Percina copelandi*	*L. ovata*	0.75
Campostoma anomalum	*L. teres*	0.5	*Percina copelandi*	*L. teres*	0.5
Campostoma anomalum	*M. nervosa*	0.25	*Percina copelandi*	*M. nervosa*	0.25
Campostoma anomalum	*O. reflexa*	0.875	*Percina copelandi*	*O. reflexa*	0.75
Campostoma anomalum	*O. jacksoniana*	0.875	*Percina copelandi*	*O. jacksoniana*	0.75
Campostoma anomalum	*P. purpuratus*	0.875	*Percina copelandi*	*P. purpuratus*	0.75
Campostoma anomalum	*P. occidentalis*	0.625	*Percina copelandi*	*P. occidentalis*	0.5

Table 11. Results of Jaccard Index for Fish and Mussel Presence/Absence.

Campostoma anomalum	*Q. pustulosa*	0.875	*Percina copelandi*	*Q. pustulosa*	0.75
Campostoma anomalum	*Q. quadrula*	0.875	*Percina copelandi*	*Q. quadrula*	0.75
Campostoma anomalum	*T. verrucosa*	0.875	*Percina copelandi*	*T. verrucosa*	0.75
Campostoma anomalum	*T. truncata*	0.875	*Percina copelandi*	*T. truncata*	0.75
Campostoma anomalum	*V. arkansasensis*	0.25	*Percina copelandi*	*V. arkansasensis*	0.25
Campostoma anomalum	*V. lienosa*	0.375	*Percina copelandi*	*V. lienosa*	0.375
Pimephales notatus	*A. ligamentina*	0.75	*Percina sciera*	*A. ligamentina*	0.75
Pimephales notatus	*A. plicata*	0.75	*Percina sciera*	*A. plicata*	0.75
Pimephales notatus	*A. wheeleri*	0.5	*Percina sciera*	*A. wheeleri*	0.5
Pimephales notatus	*E. lineolata*	0.75	*Percina sciera*	*E. lineolata*	0.75
Pimephales notatus	*F. flava*	0.75	*Percina sciera*	*F. flava*	0.75
Pimephales notatus	*L. radiata*	0.625	*Percina sciera*	*L. radiata*	0.625
Pimephales notatus	*L. ovata*	0.75	*Percina sciera*	*L. ovata*	0.75
Pimephales notatus	*L. teres*	0.5	*Percina sciera*	*L. teres*	0.5
Pimephales notatus	*M. nervosa*	0.375	*Percina sciera*	*M. nervosa*	0.375
Pimephales notatus	*O. reflexa*	0.75	*Percina sciera*	*O. reflexa*	0.75
Pimephales notatus	*O. jacksoniana*	0.75	*Percina sciera*	*O. jacksoniana*	0.75
Pimephales notatus	*P. purpuratus*	0.75	*Percina sciera*	*P. purpuratus*	0.75
Pimephales notatus	*P. occidentalis*	0.625	*Percina sciera*	*P. occidentalis*	0.625
Pimephales notatus	*Q. pustulosa*	0.75	*Percina sciera*	*Q. pustulosa*	0.75
Pimephales notatus	*Q. quadrula*	0.75	*Percina sciera*	*Q. quadrula*	0.75
Pimephales notatus	*T. verrucosa*	0.75	*Percina sciera*	*T. verrucosa*	0.75
Pimephales notatus	*T. truncata*	0.75	*Percina sciera*	*T. truncata*	0.75
Pimephales notatus	*V. arkansasensis*	0.25	*Percina sciera*	*V. arkansasensis*	0.375
Pimephales notatus	*V. lienosa*	0.125	*Percina sciera*	*V. lienosa*	0.25

Class Value	#Pixels	%Total Pixels	Class Description
1	32274	0.33	Urban
2	16667	0.17	Primary Roads
3	2360400	24.05	Pasture/Regrowth/Cropland
4	1099017	11.20	Deciduous Forest
5	1438093	14.65	Coniferous Forest
6	4578552	46.65	Mixed Forest
7	41738	0.43	Rivers/Streams/Wetland
8	156394	1.59	Reservoirs
9	91128	0.93	Clouds/Cloud Shadows

Table 12. Number and percentage of pixels for each category in the final classification.

	Reference Data										
Classified Data	1	2	3	4	5	6	7	8	**Totals**	User's Accuracy	Producer's Accuracy
1. Urban	**20**	1	0	0	0	0	0	0	**21**	95.2%	100.0%
2. Primary Roads	0	**0**	0	0	0	0	0	0	**0**	--------	0.0%
3. Pasture/Regrowth/Cropland	0	14	**17**	1	0	2	0	0	**34**	50.0%	85.0%
4. Deciduous Forest	0	1	3	**3**	0	2	0	0	**9**	33.3%	13.6%
5. Coniferous Forest	0	0	0	2	**13**	4	9	1	**29**	44.8%	35.0%
6. Mixed Forest	0	6	0	16	7	**13**	2	2	**46**	28.3%	61.9%
7. Rivers/Streams/Wetland	0	0	0	0	0	0	**8**	0	**8**	100.0%	34.8%
8. Reservoirs	0	0	0	0	0	0	4	**17**	**21**	81.0%	85.0%
Totals	**20**	**22**	**20**	**22**	**20**	**21**	**23**	**20**	**168**		
Overall Accuracy = 89/168 = 53.0%											

Table 13. Error matrix showing both user's and producer's accuracy estimates along with overall accuracy for all categories except for *Clouds/Cloud Shadows*.

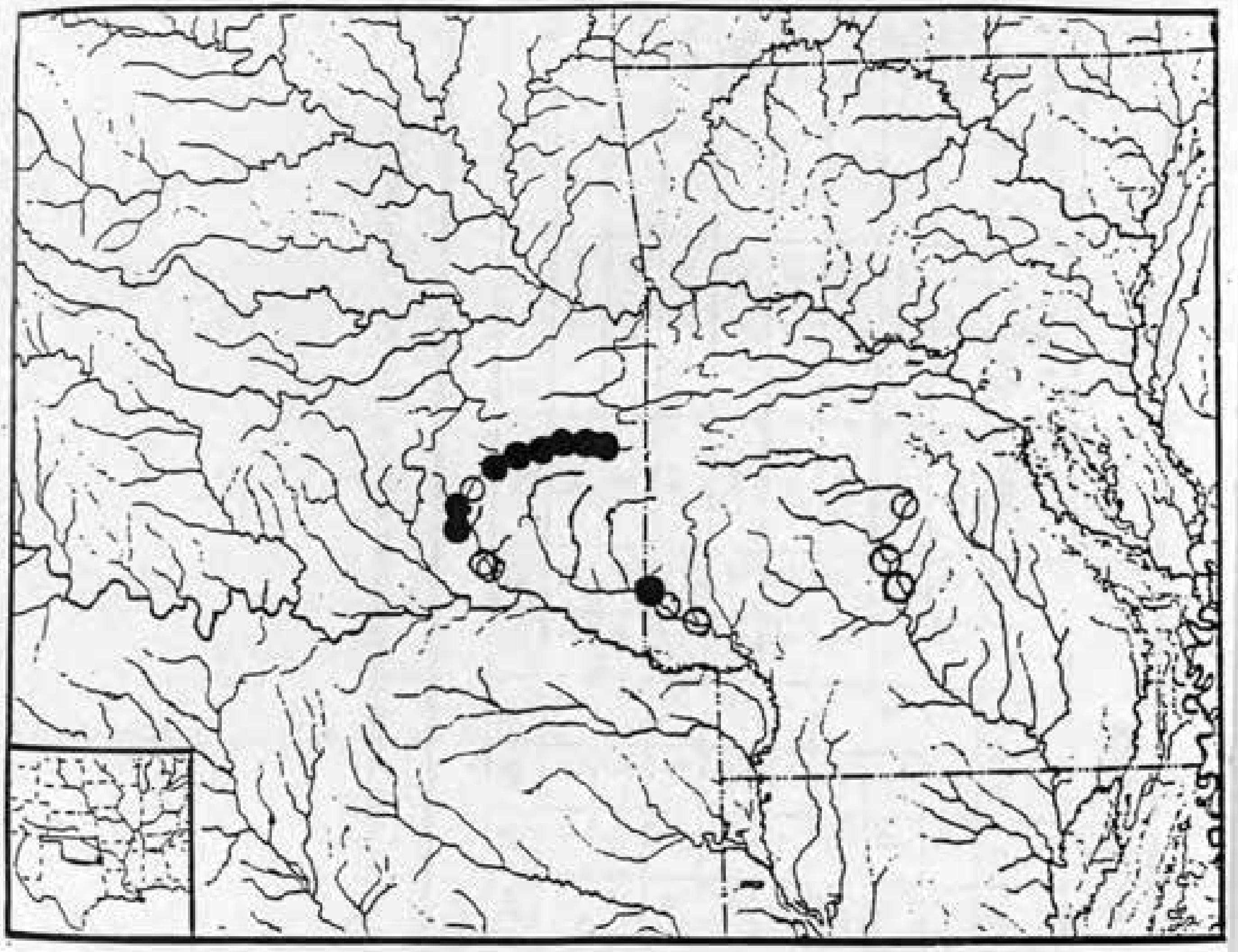


Figure 1. Historical and present distribution of *Arkansia wheeleri*. Solid circles indicate extant sites and open circles represent extirpated sites. In this figure sites in close proximity to one another appear as one dot.

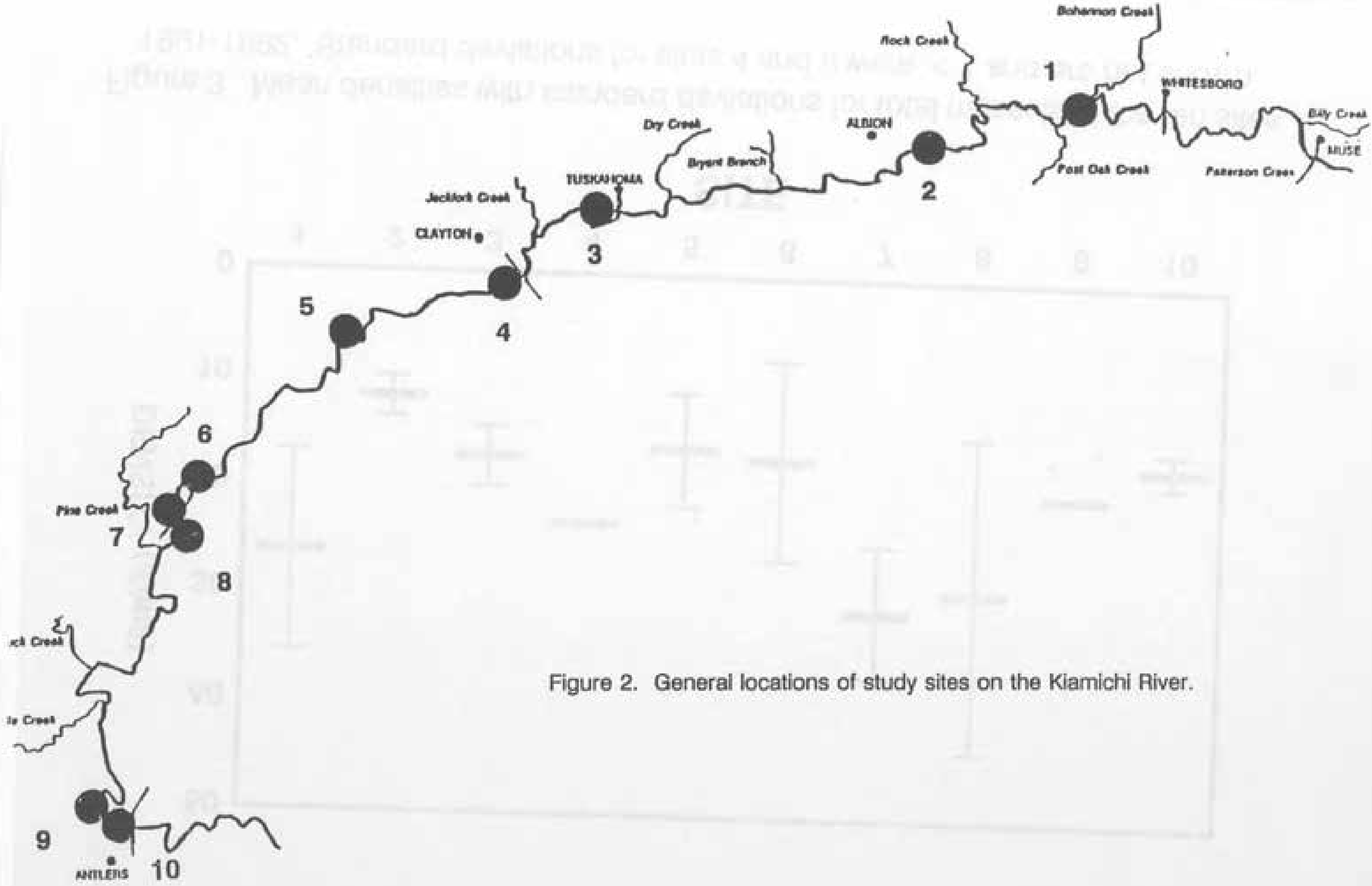


Figure 2. General locations of study sites on the Kiamichi River.

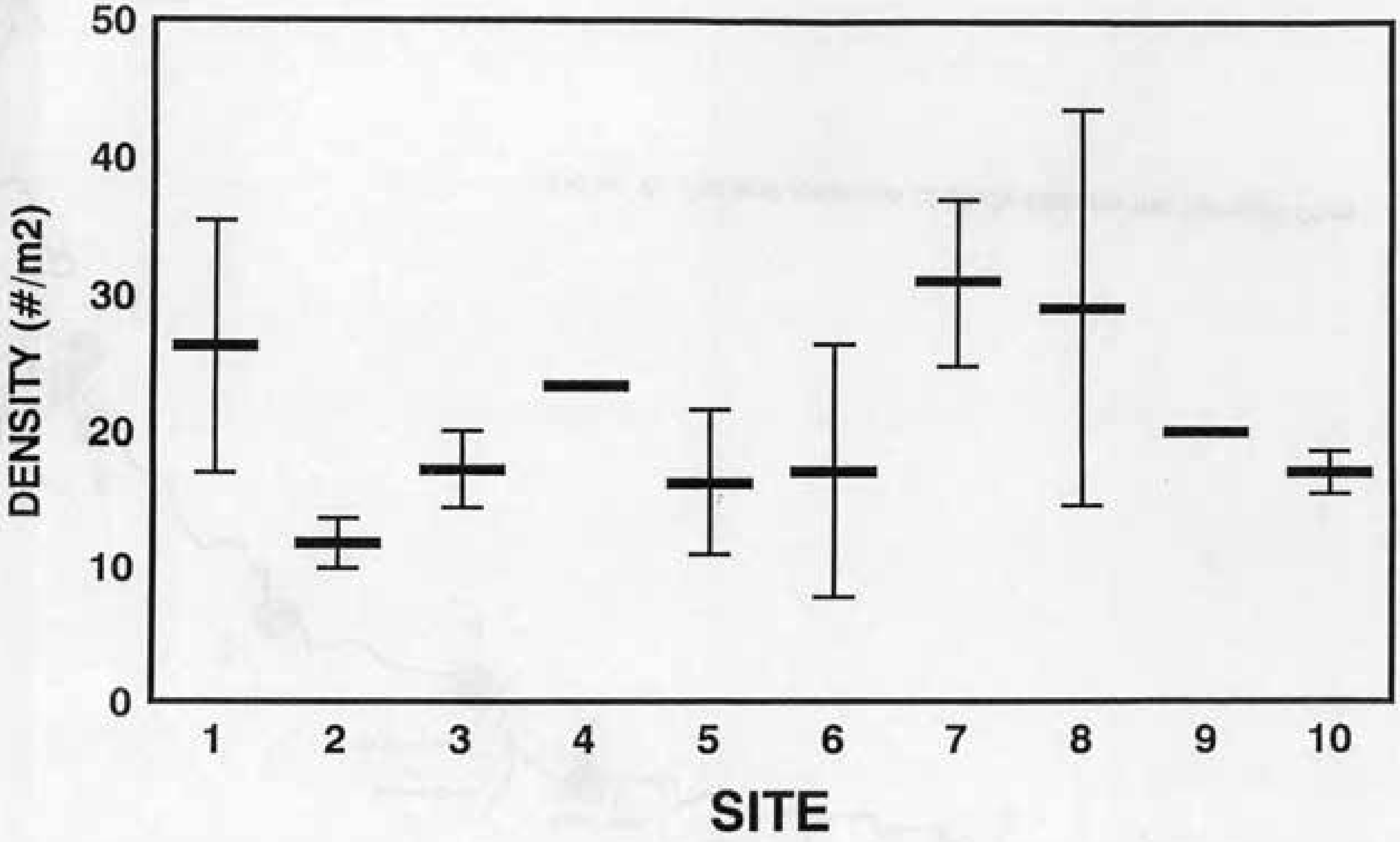


Figure 3. Mean densities with standard deviations for total mussels at the ten sites, 1991-1992. Standard deviations for sites 4 and 9 were < 1 and are not shown.

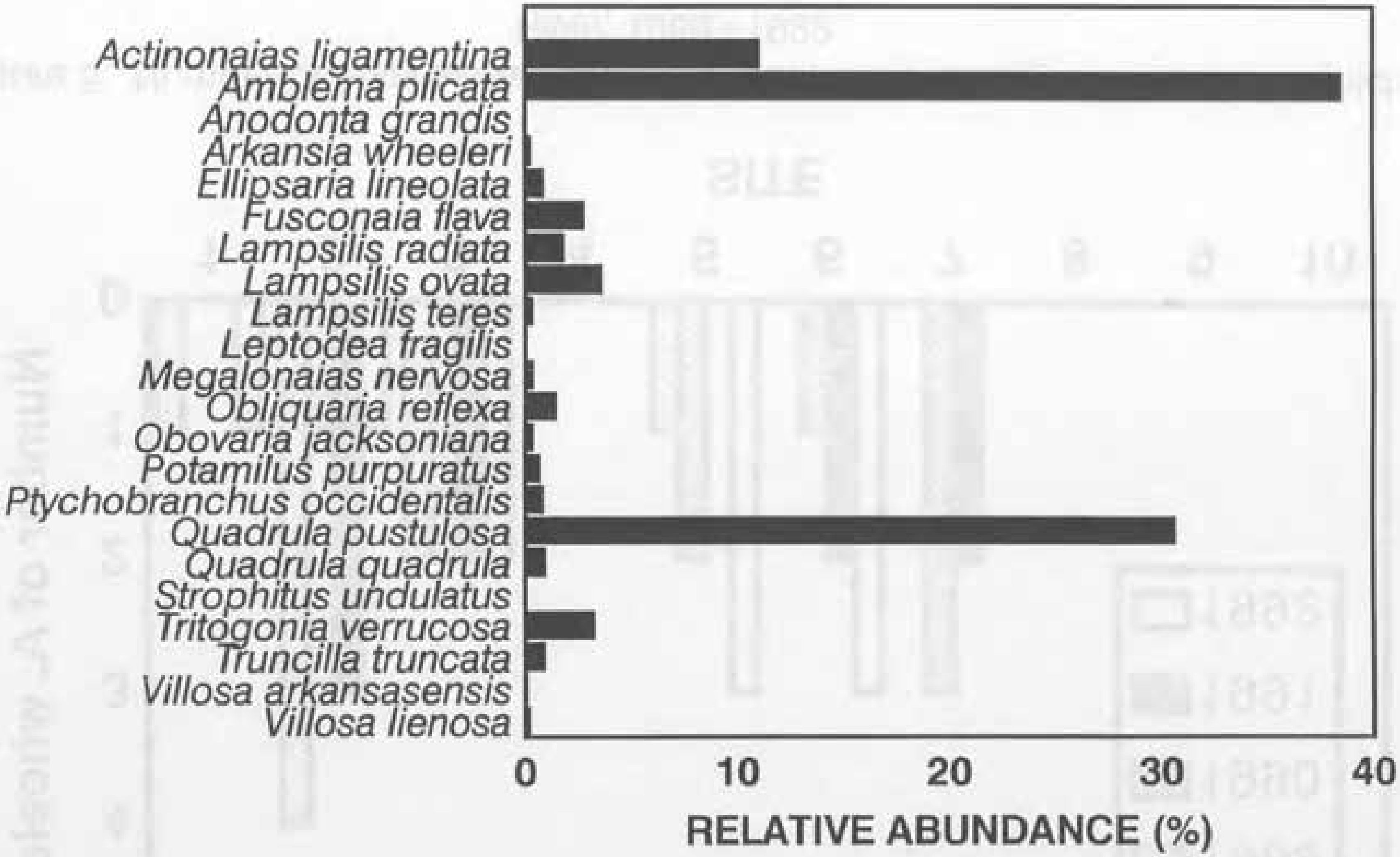


Figure 4. Mean relative abundance of mussel species in the Kiamichi River 1990-92.

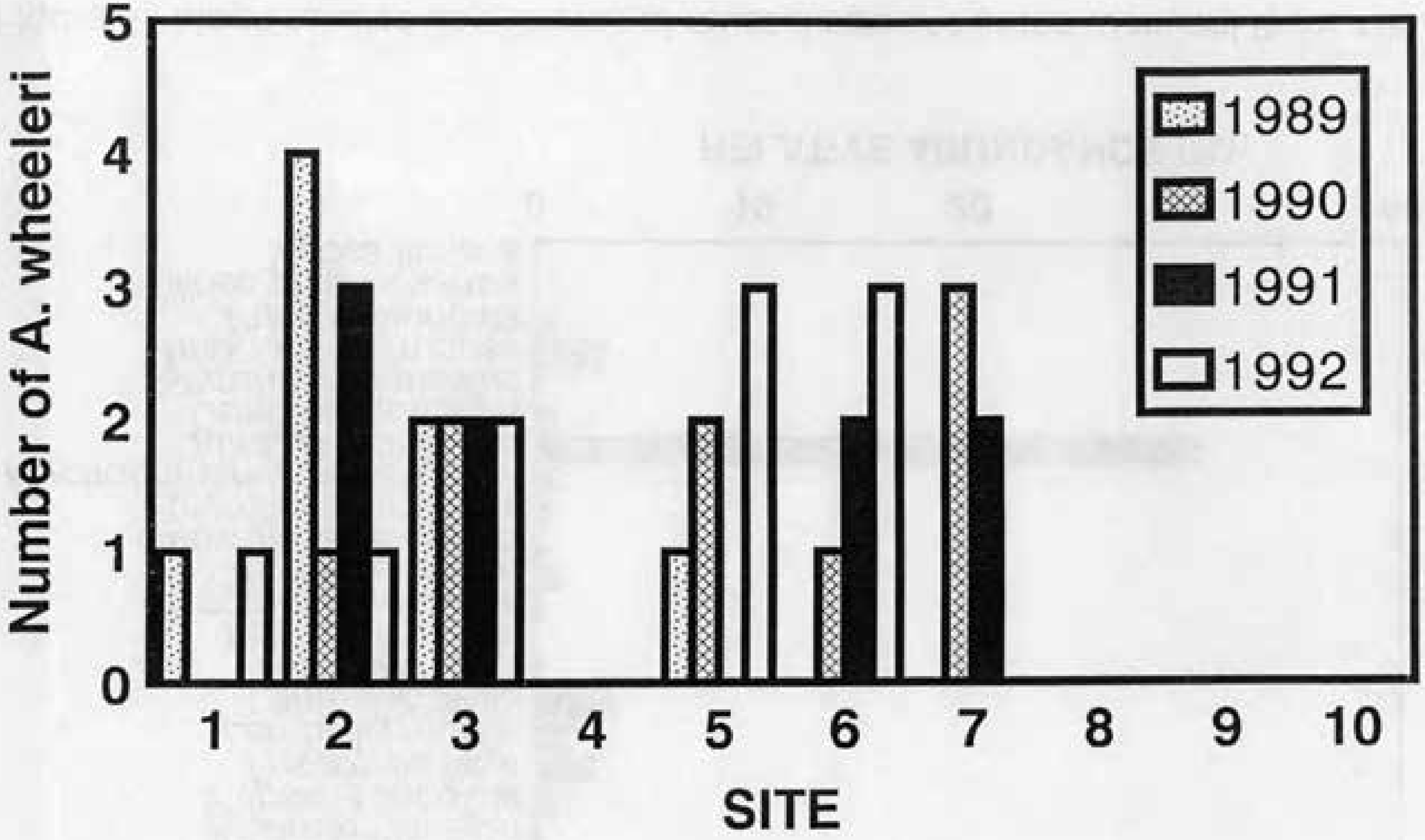


Figure 5. Number of Arkansia wheeleri found at the ten study sites on the Kiamichi River, 1989 - 1992.

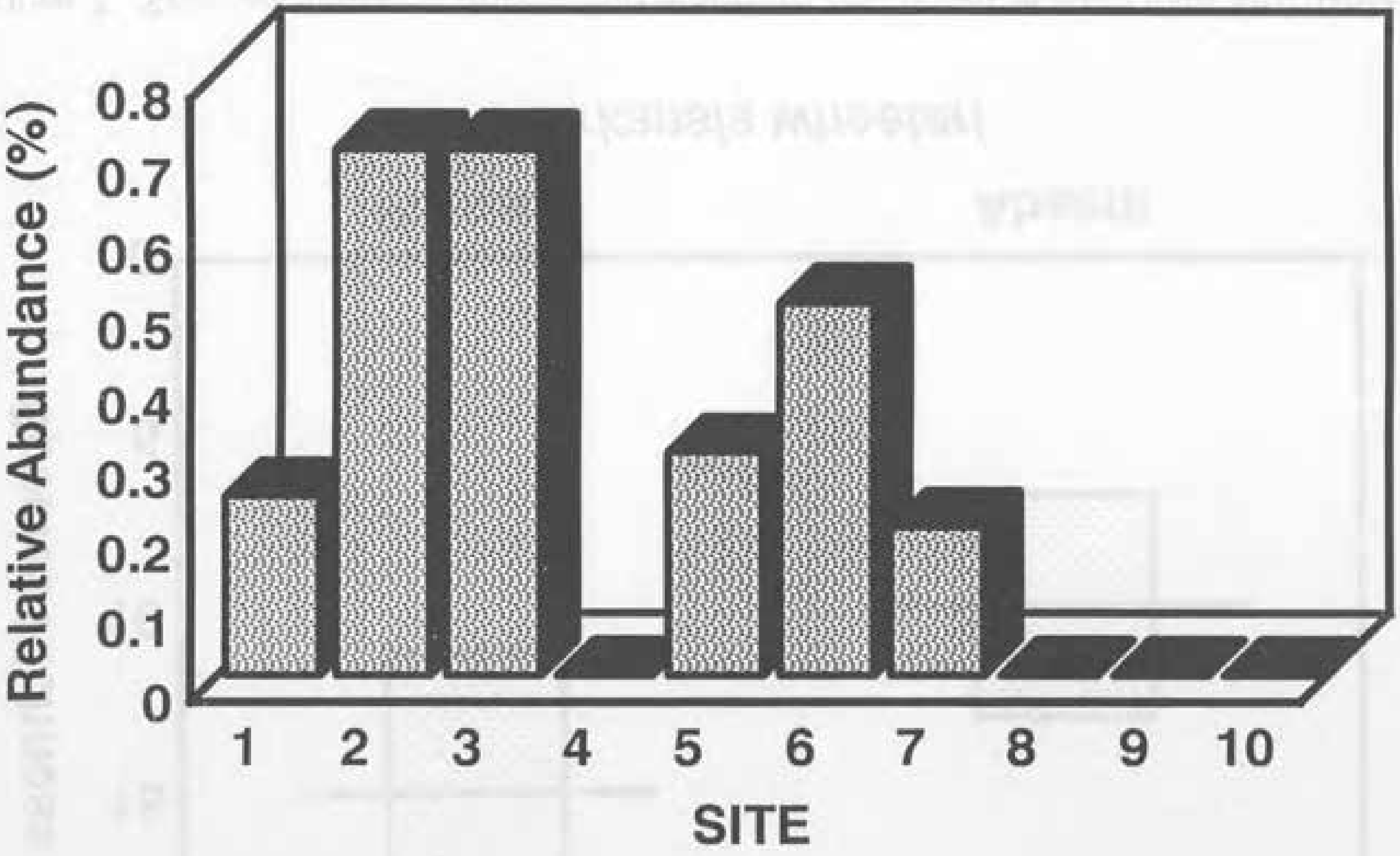


Figure 6. Relative abundance of Arkansia wheeleri at ten sites in the Kiamichi River, 1990-1992.

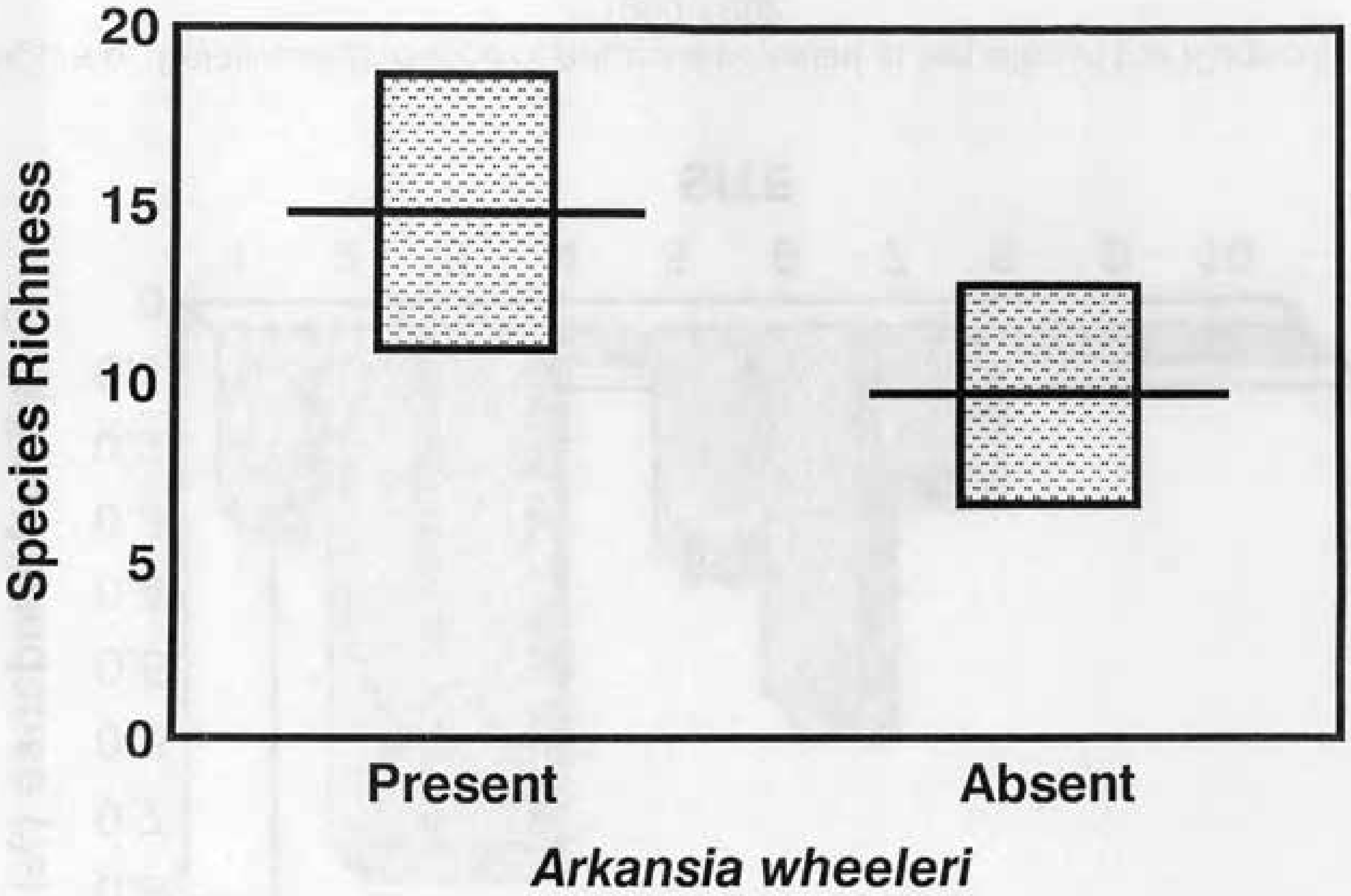
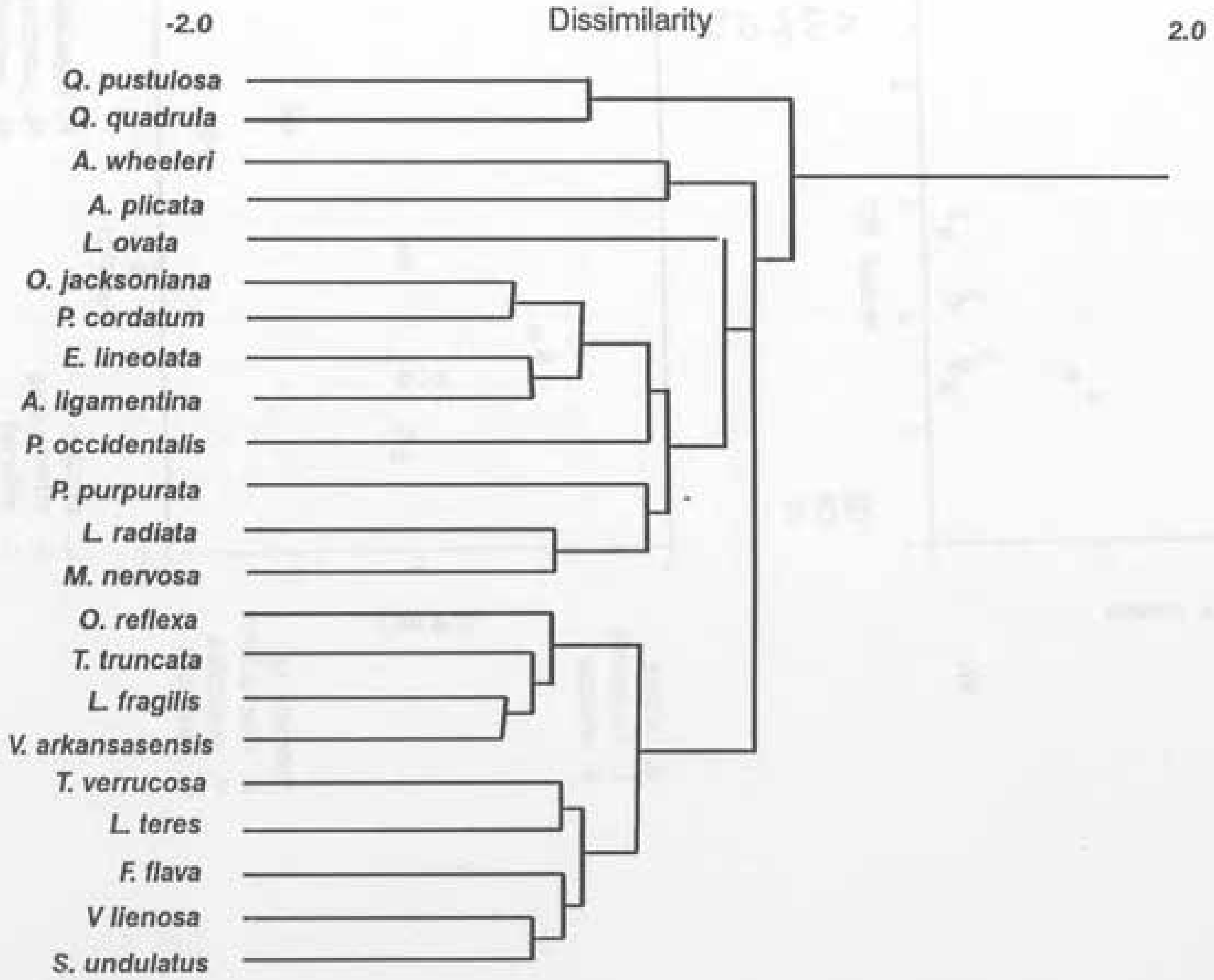


Figure 7. Species richness (mean and standard deviation) at sites with and without Arkansia wheeleri (t=3.18, df=15, P=.006). Data are from the 22 sites sampled in 1990.

Figure 8. Cluster analysis for 22 sites in the Kiamichi River sampled in 1990.



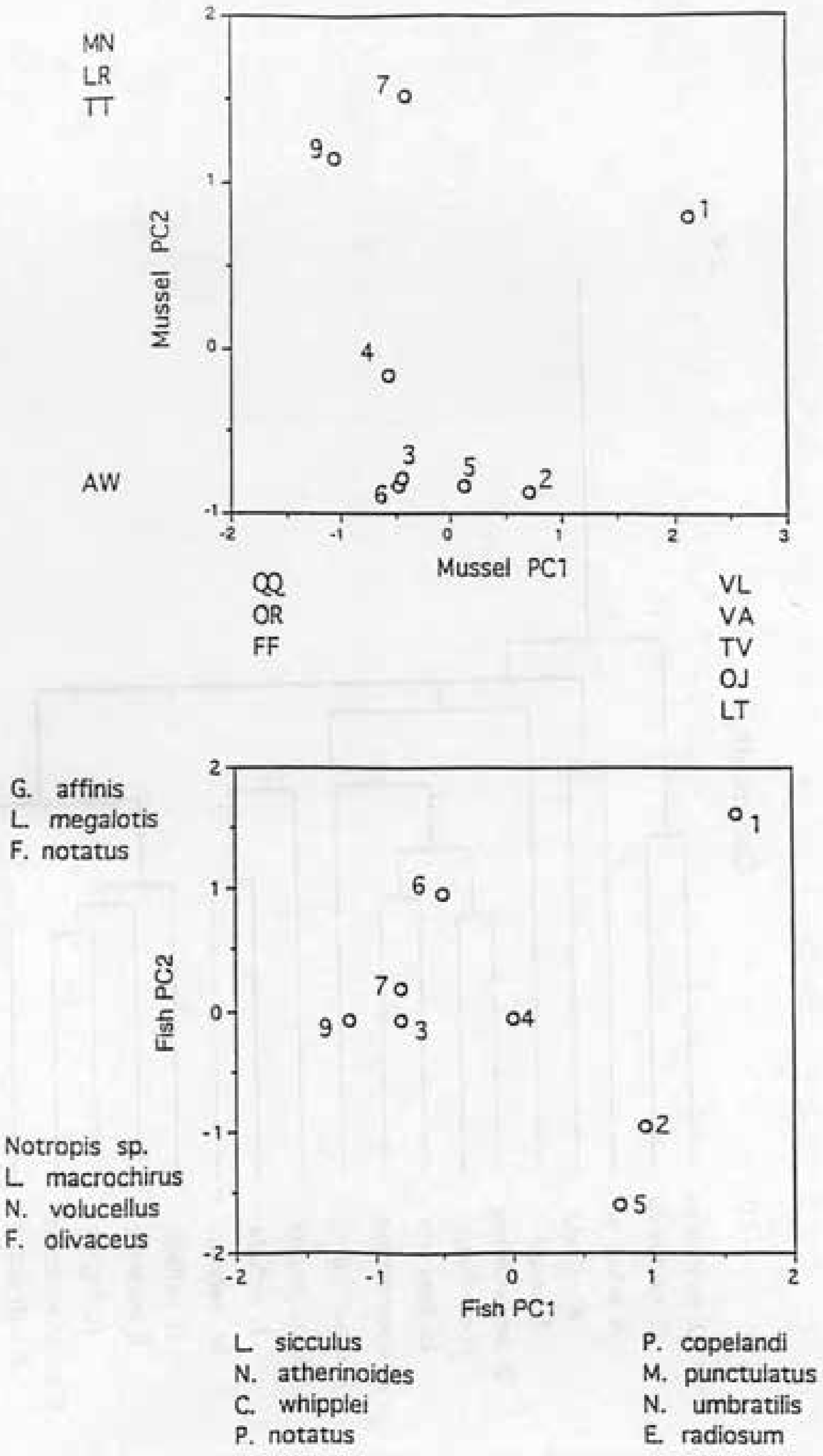


Figure 9. Principal components ordination. Data are means from 1991-1992 for eig sites.

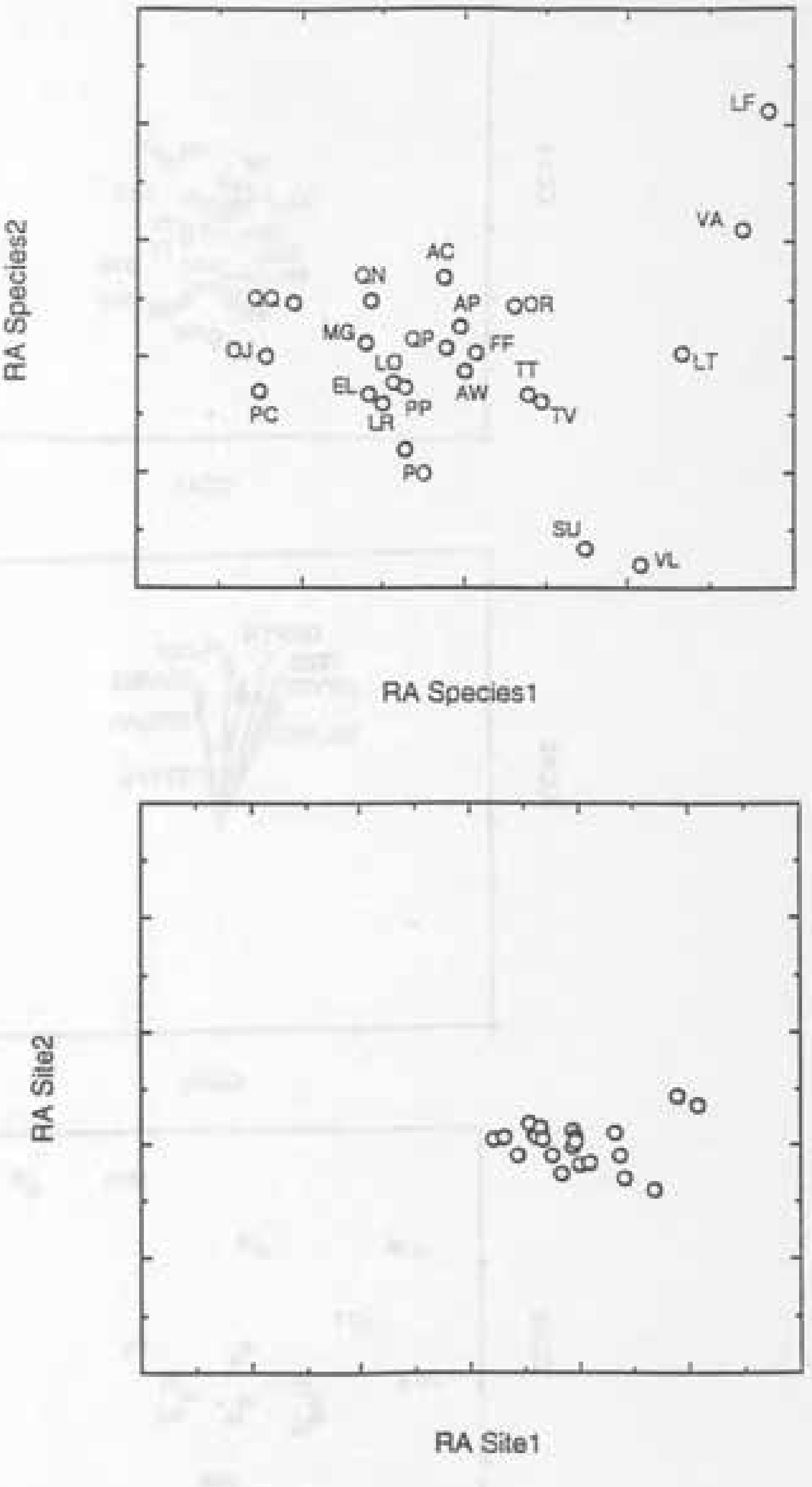


Figure 10. Reciprocal averaging ordination. Data are means from 1991-1992 for eight sites.

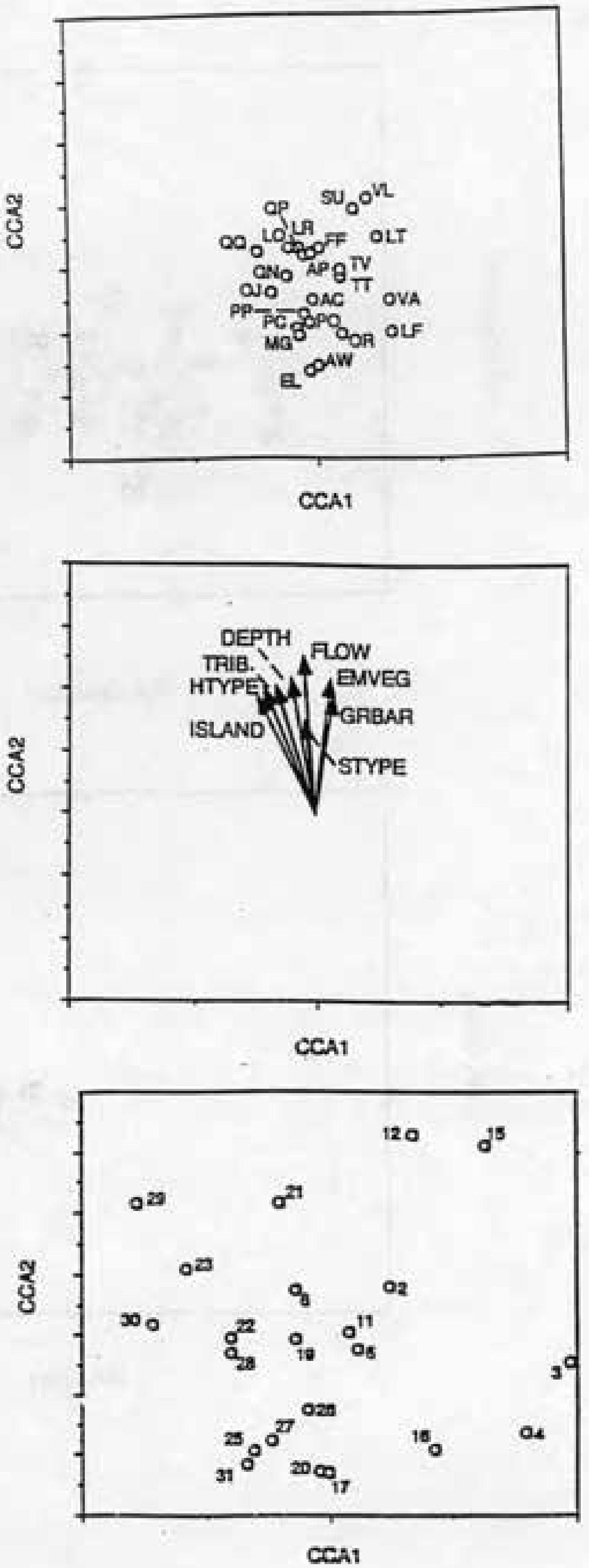


Figure 11. Results of canonical correspondence analysis for data from 1990. The top graph shows the approximate centers of species distributions along the first tw CCA axes, the middle graph shows the location of habitat vectors along the axes, a the bottom graph shows the positions of the twenty two sites.

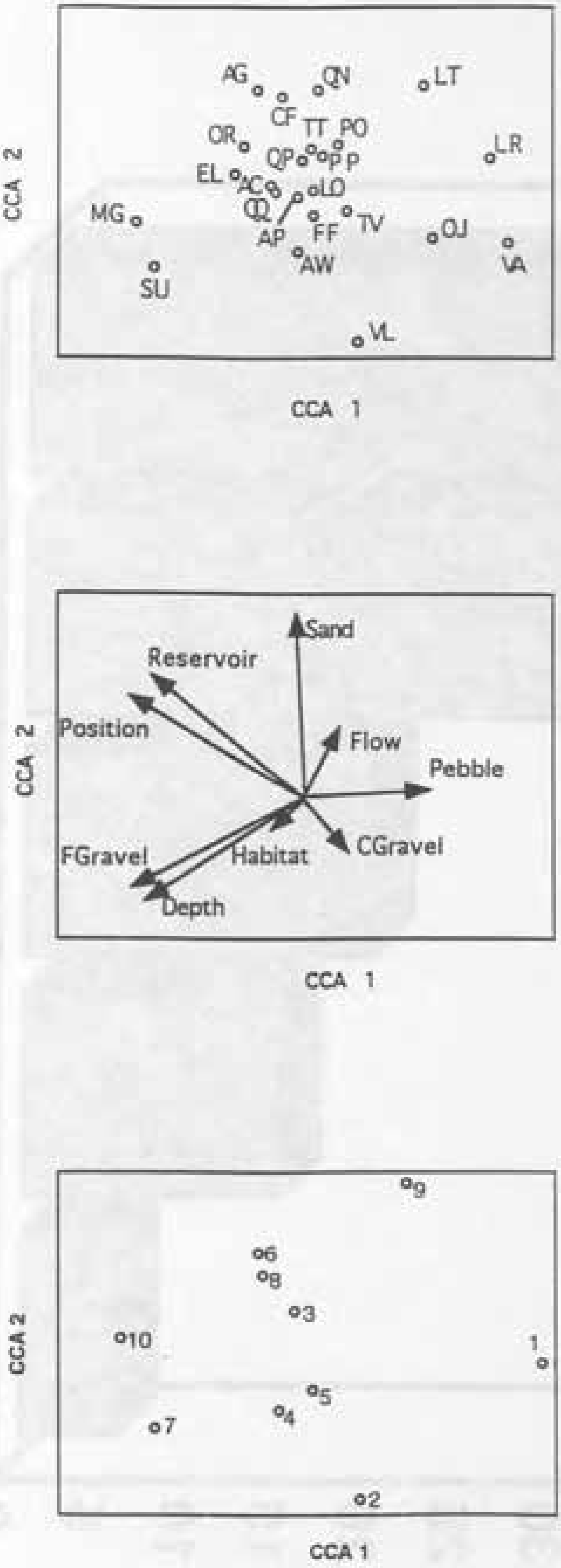


Figure 12. Results of canonical correspondence analysis for data from 1991-1992. The top graph shows the approximate centers of species distributions along the first two CCA axes, the middle graph shows the location of habitat vectors along the axes, and the bottom graph shows the positions of the ten study sites. Data used in this analysis were means for 1991-1992.

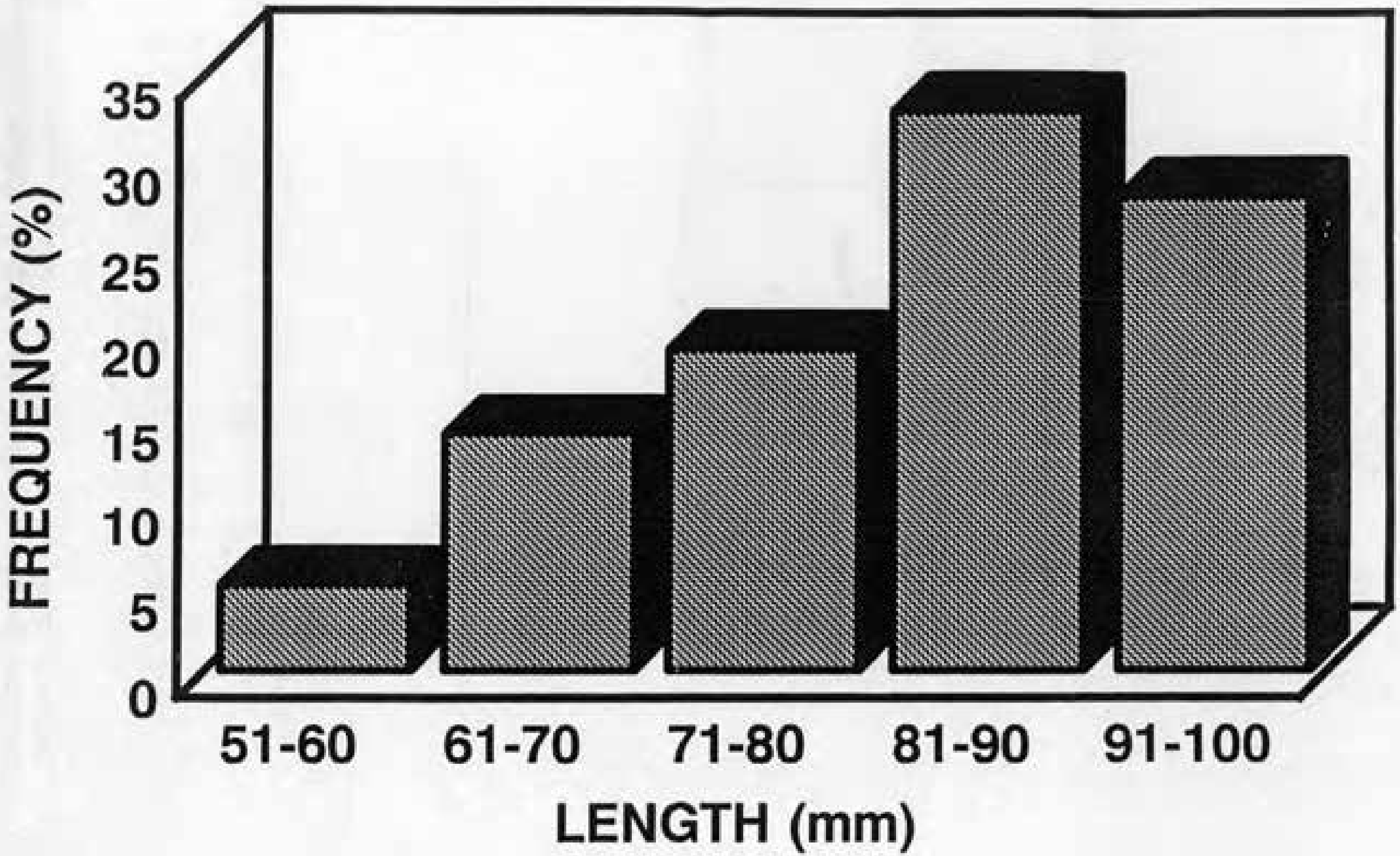


Figure 13. Total lengths of live Arkansia wheeleri from the Kiamichi River, 1989 - 1992.

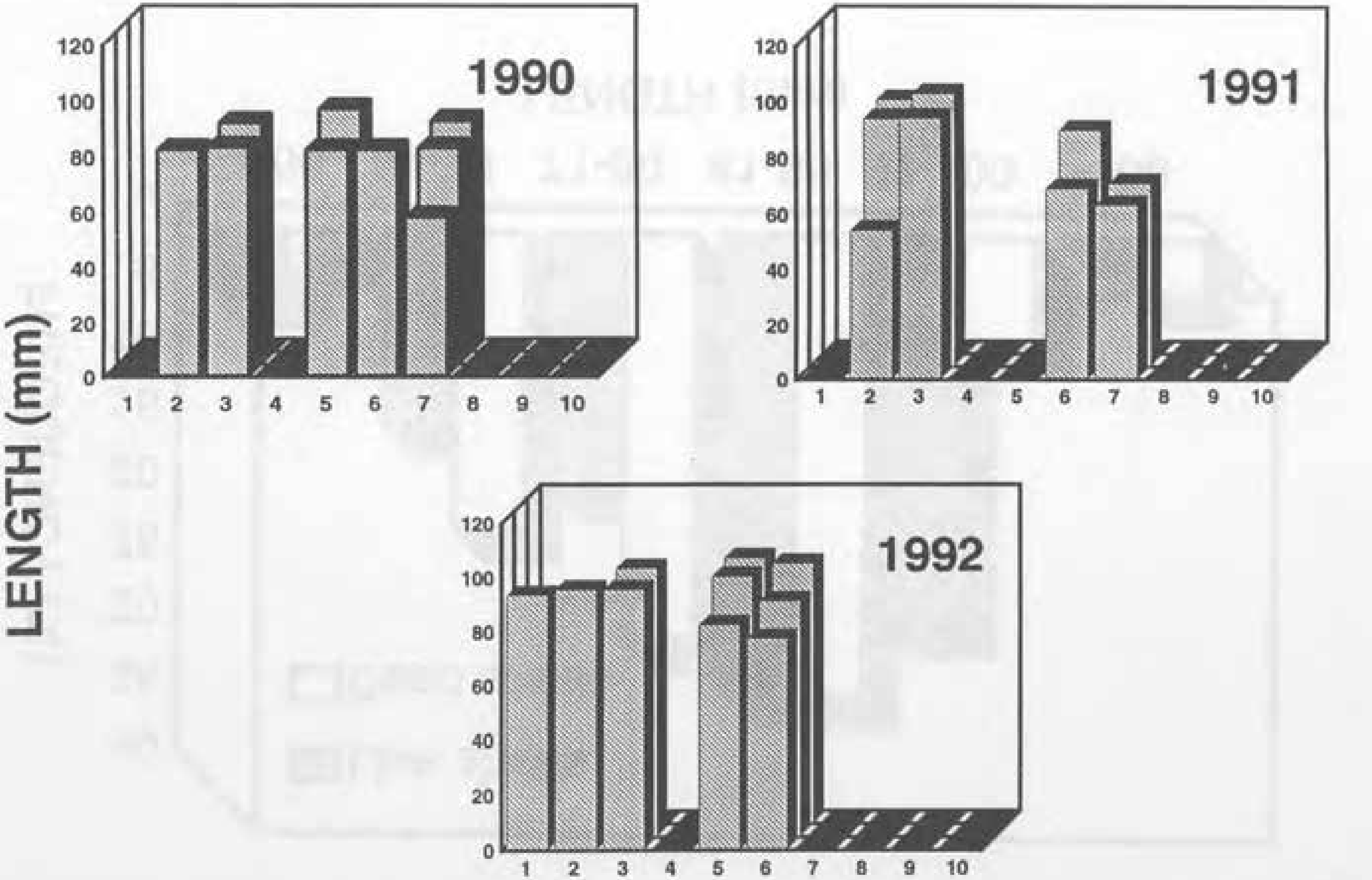


Figure 14. Lengths (mm) of Arkansia wheeleri found at ten study sites on the Kiamichi River 1990-92. Each bar represents an individual mussel.

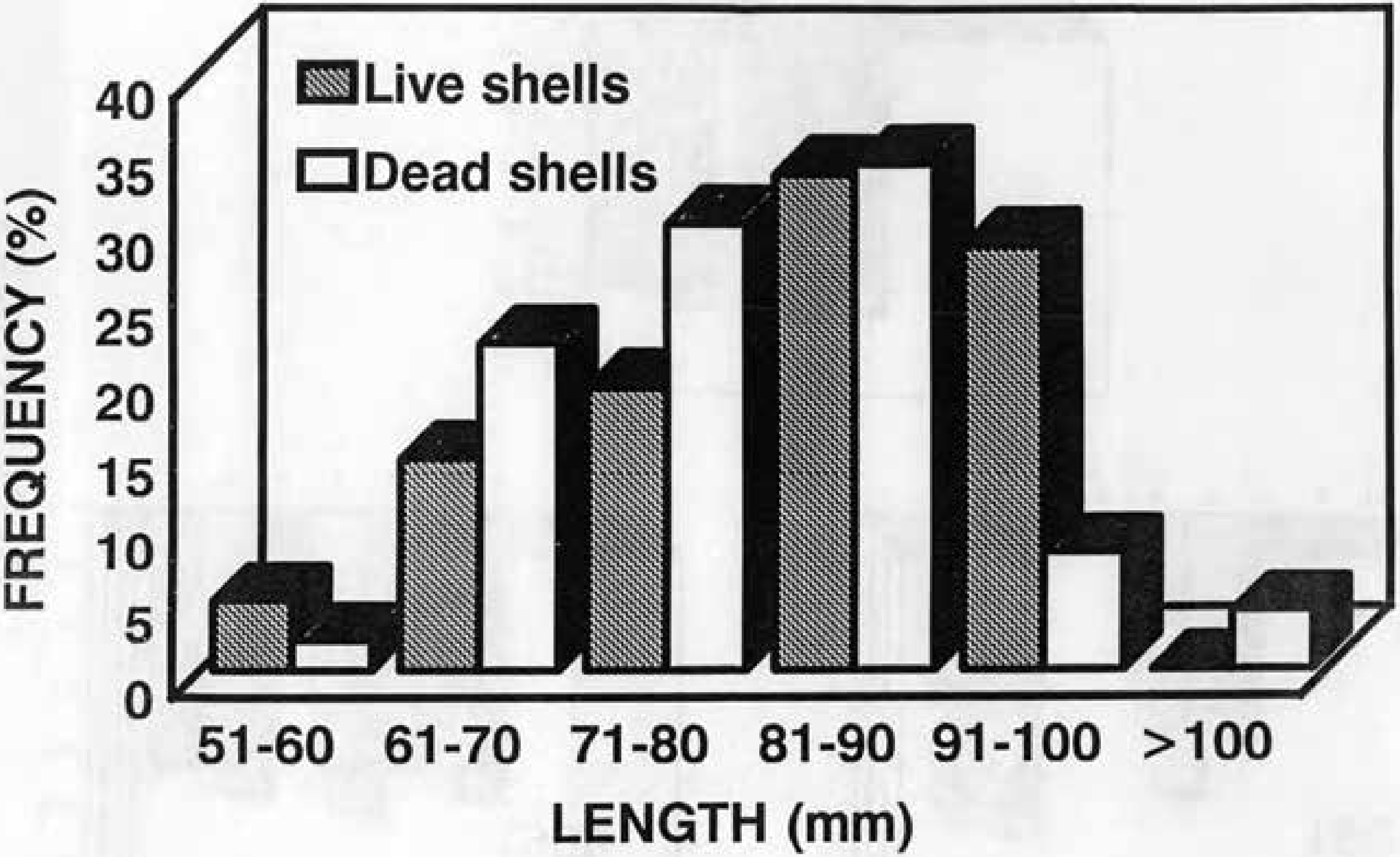


Figure 15. Total lengths of live Arkansia wheeleri compared to relict shells from the Kiamichi River (t=1.9, df=78, P=0.03).

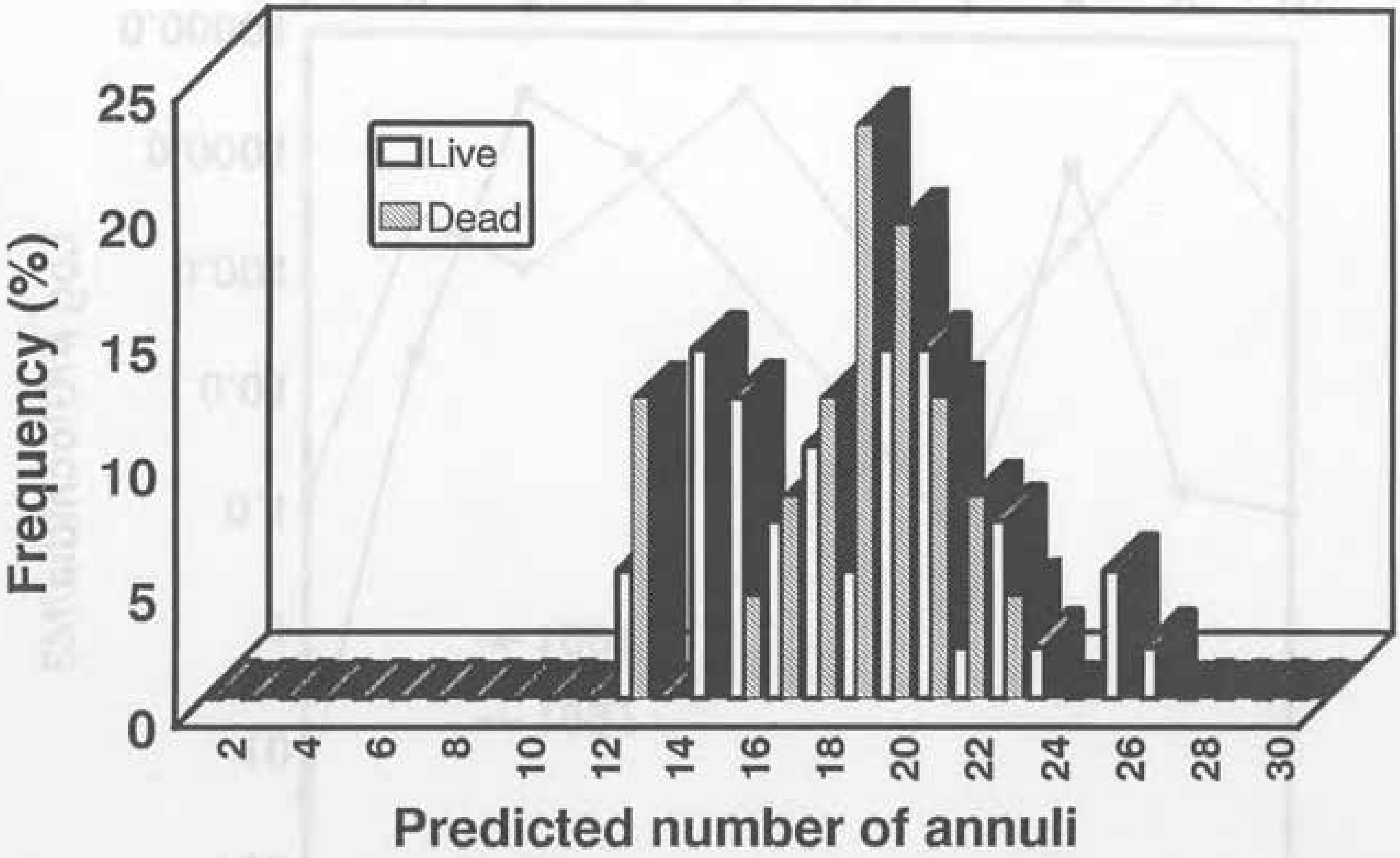


Figure 16. Predicted number of annuli for live Arkansia wheeleri versus relict shells from the Kiamichi River (t=0.84, df=54, P=0.19).

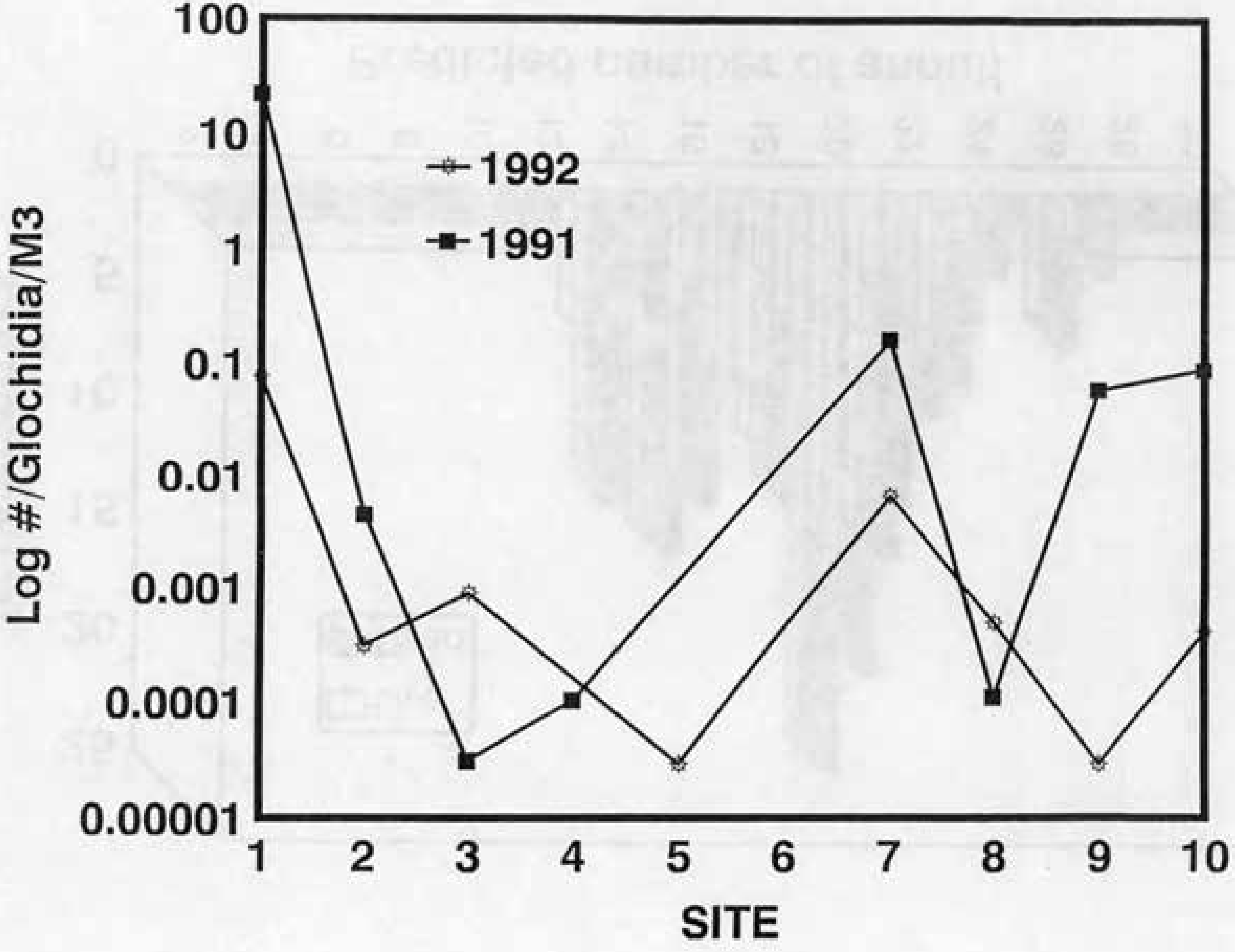


Figure 17. Densities of drifting glochidia.

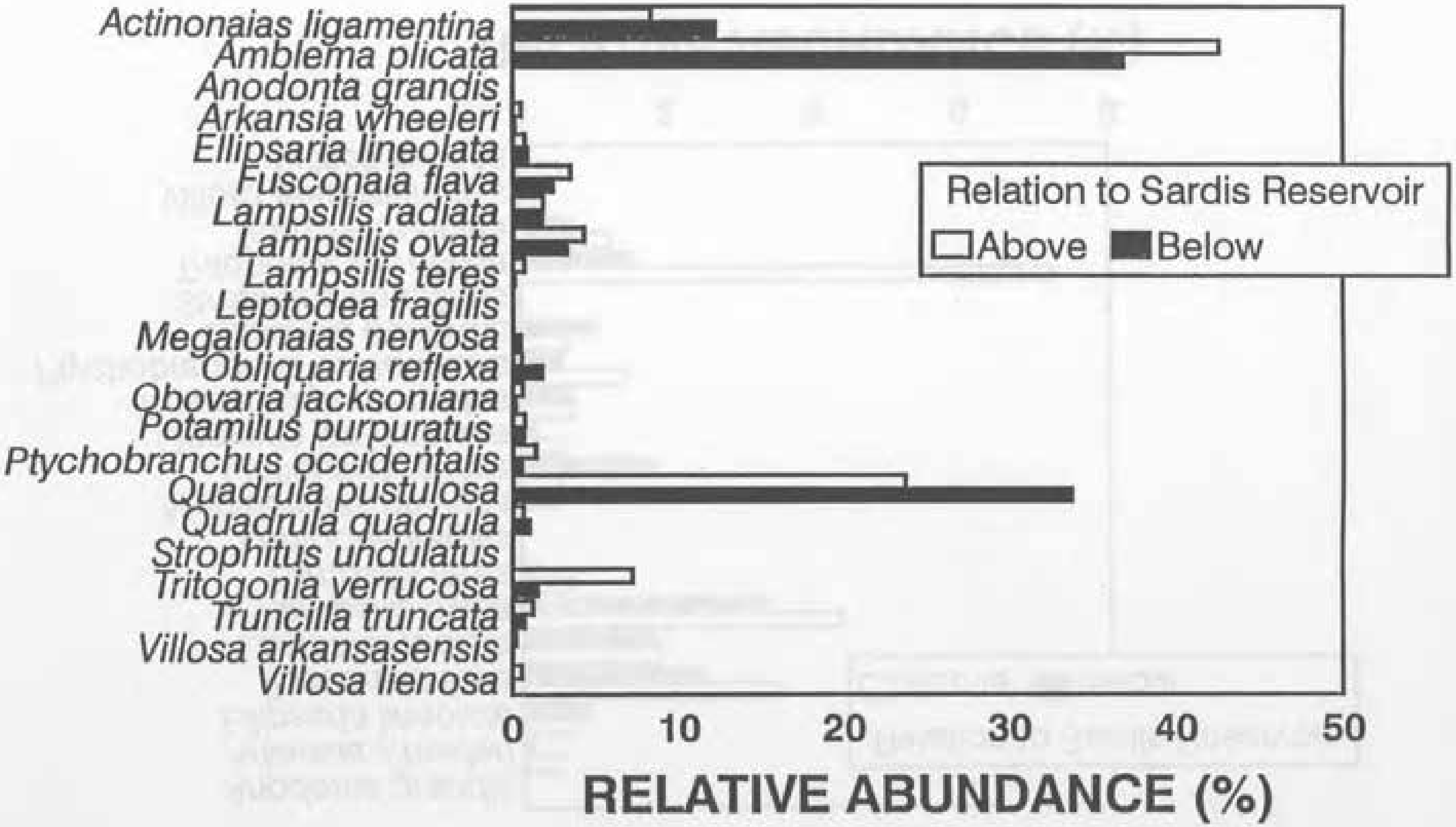


Figure 18. Mean relative abundance of all mussel species at sites above and below Sardis Reservoir, 1990-1992.

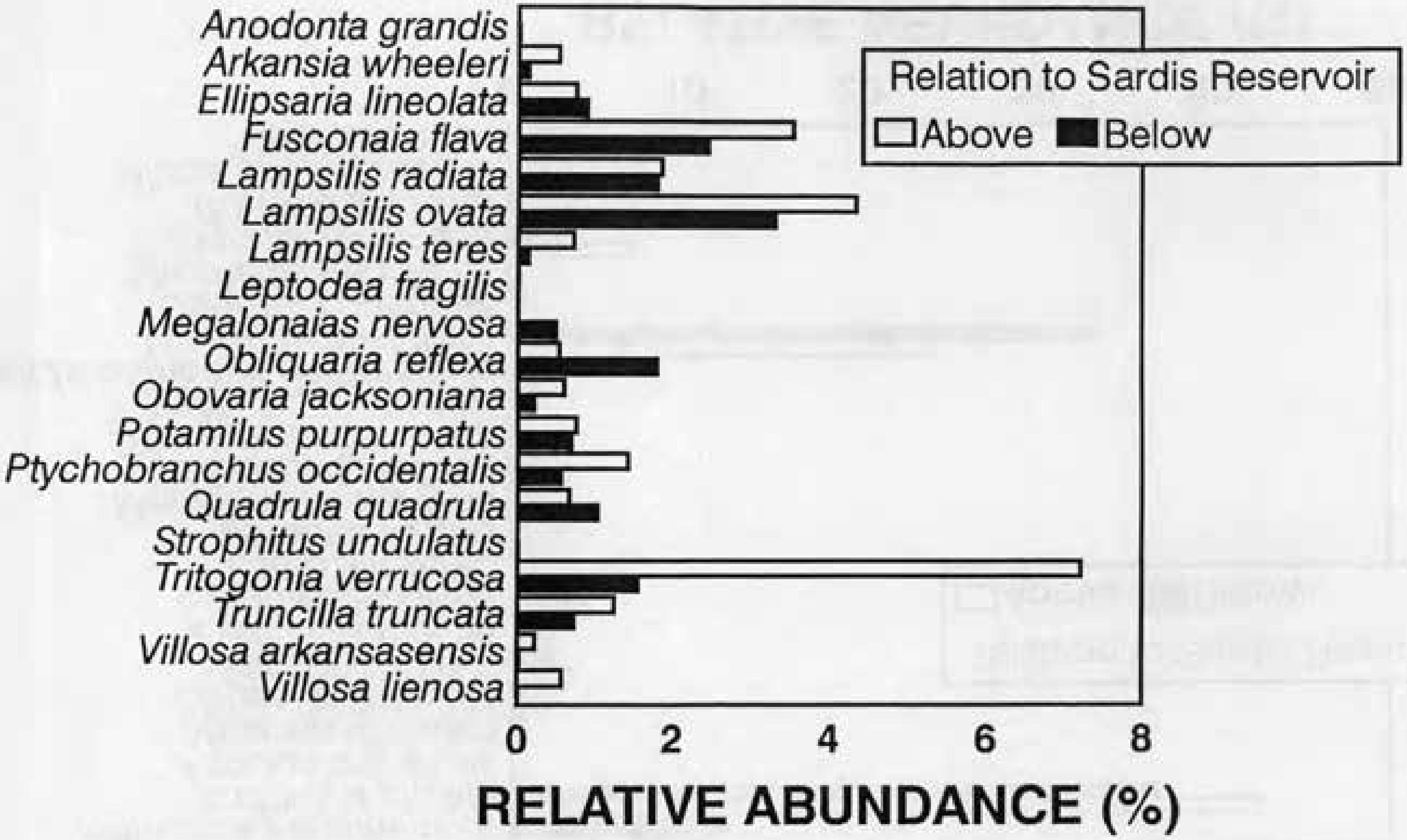


Figure 19. Mean relative abundance of less dominant mussel species at sites above and below Sardis Reservoir, 1990-92.

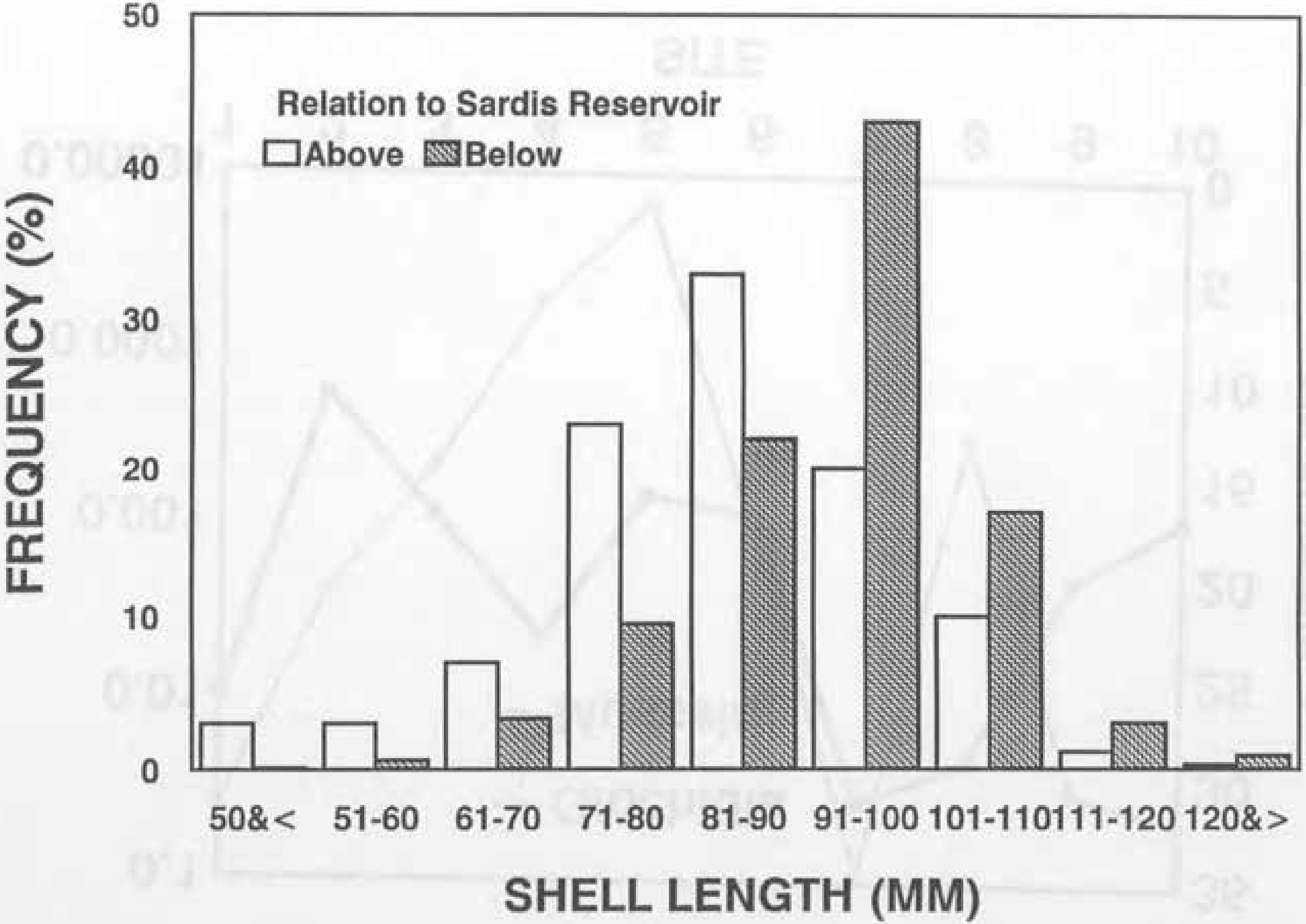


Figure 20. Lengths (mm) of live Amblema plicata from sites above and below Sardis Reservoir in 1991.

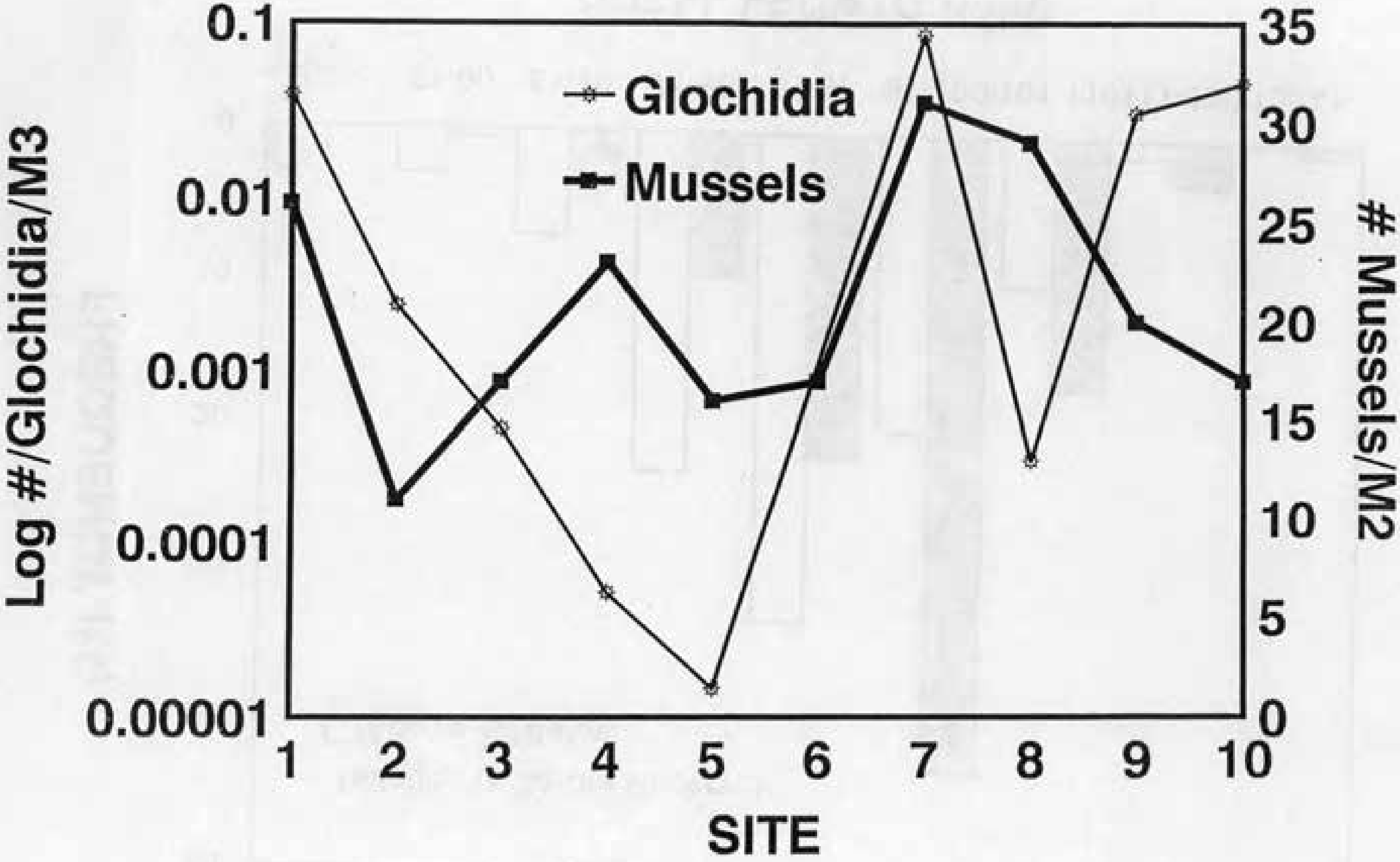


Figure 21. Mean densities of glochidia and mussels by site, 1991-92.

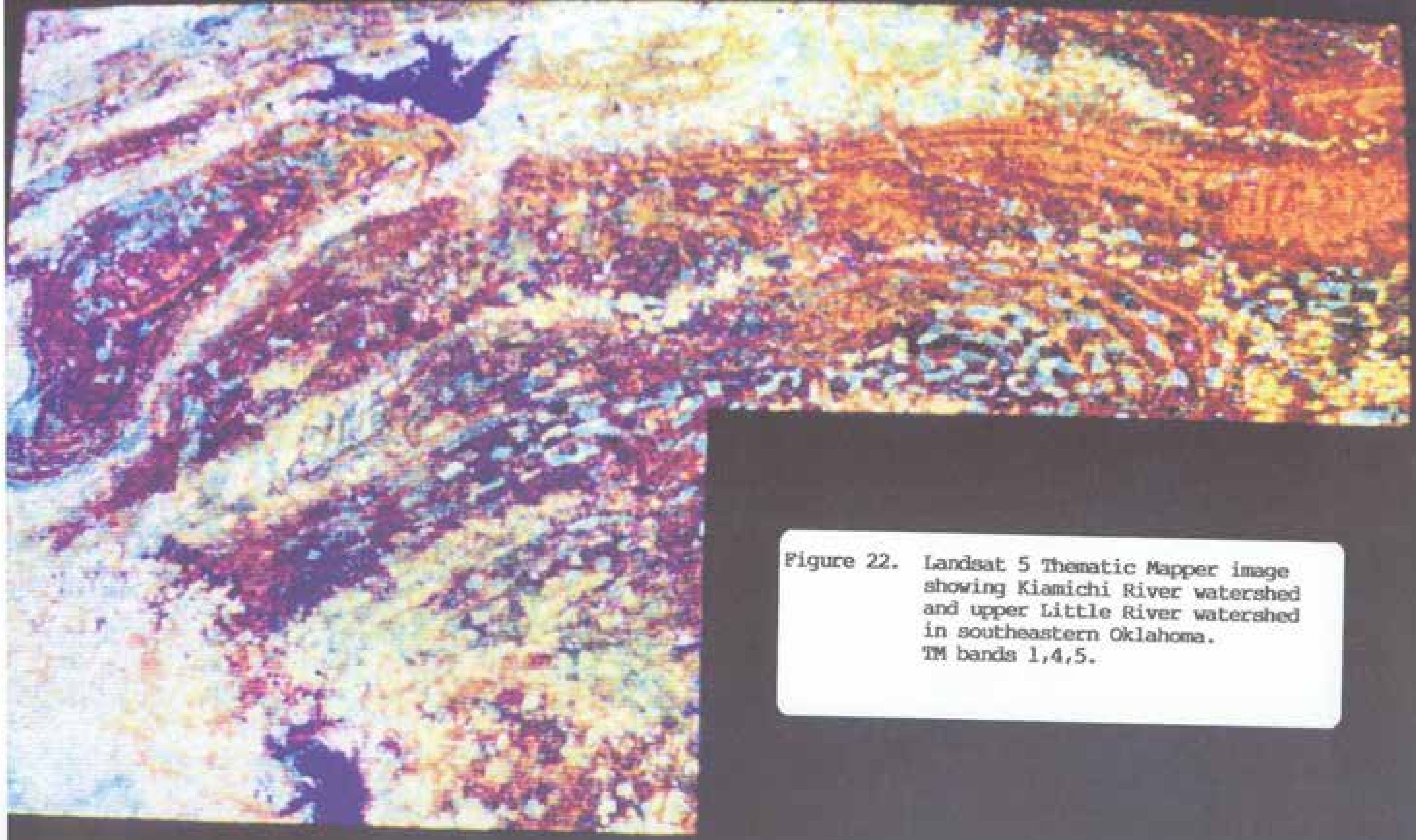


Figure 22. Landsat 5 Thematic Mapper image showing Kiamichi River watershed and upper Little River watershed in southeastern Oklahoma. TM bands 1,4,5.

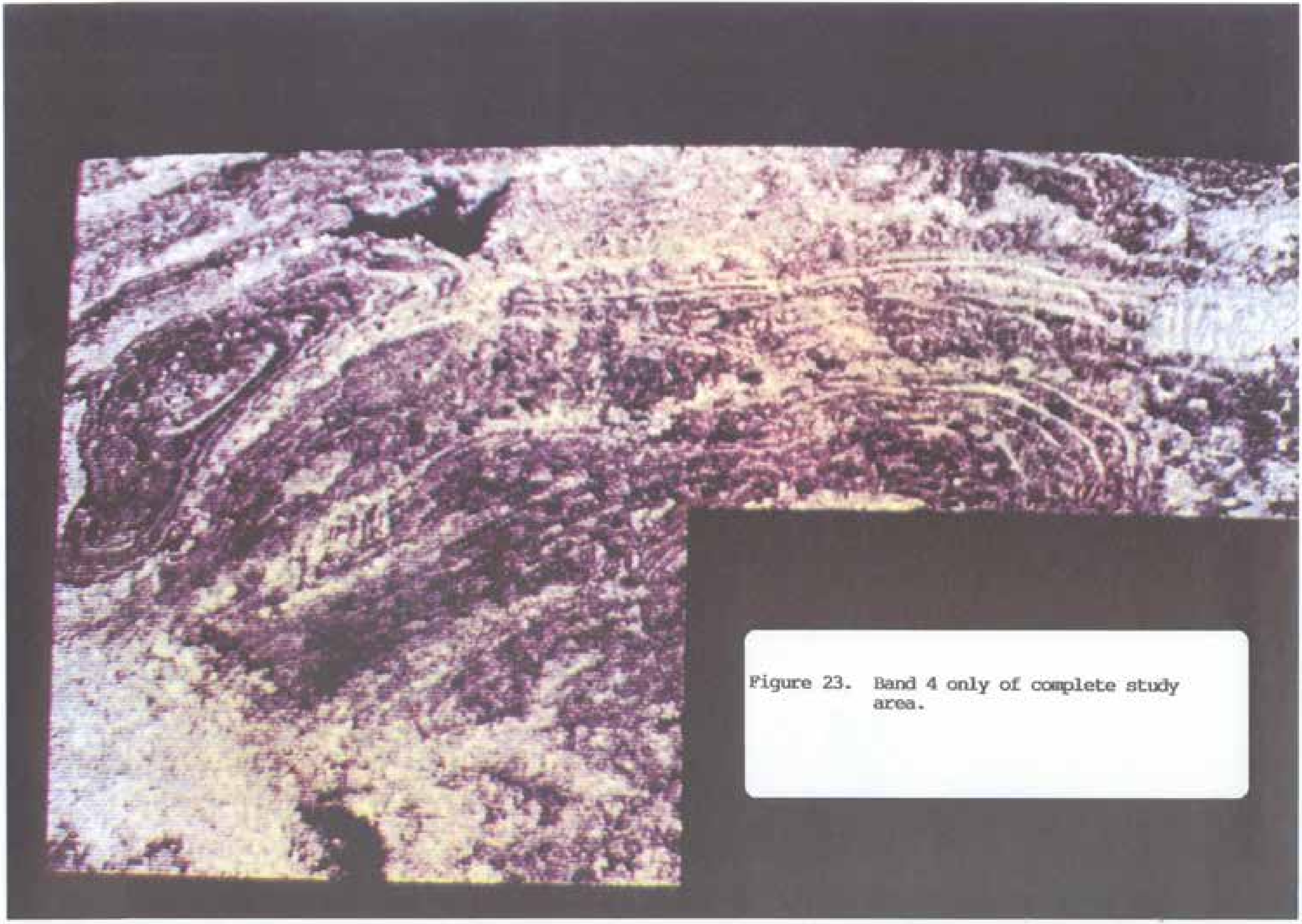


Figure 23. Band 4 only of complete study area.

Figure 24. Closeup of Clayton, OK/Sardis Reservoir area using band 4 only.

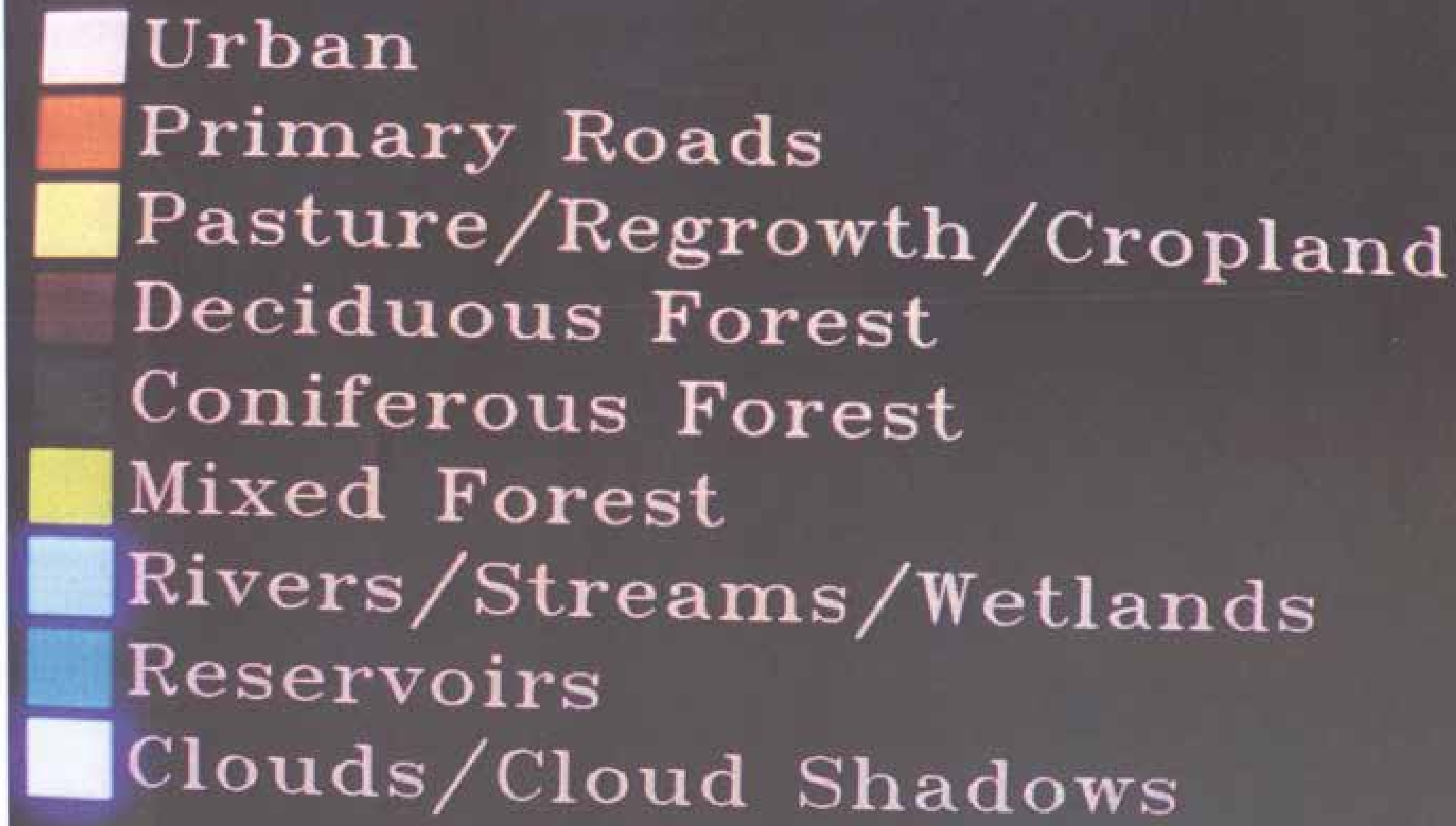


Figure 25. Map colors and categories associated with final classification.

⬜ Urban

🟧 Primary Roads

🟨 Pasture/Regrowth/Cropland

🟫 Deciduous Forest

⬛ Coniferous Forest

🟨 Mixed Forest

🟦 Rivers/Streams/Wetlands

🟦 Reservoirs

⬜ Clouds/Cloud Shadows

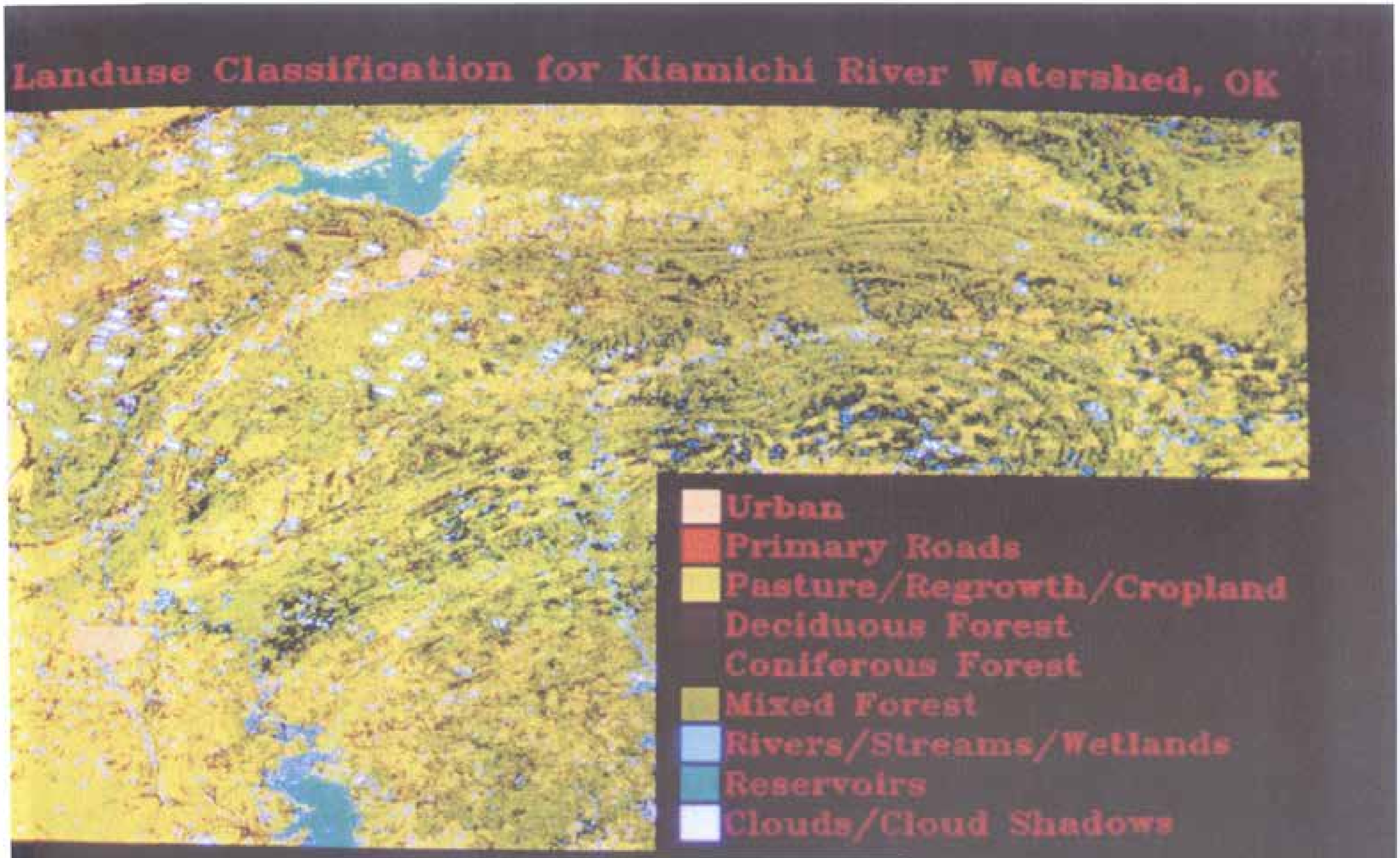
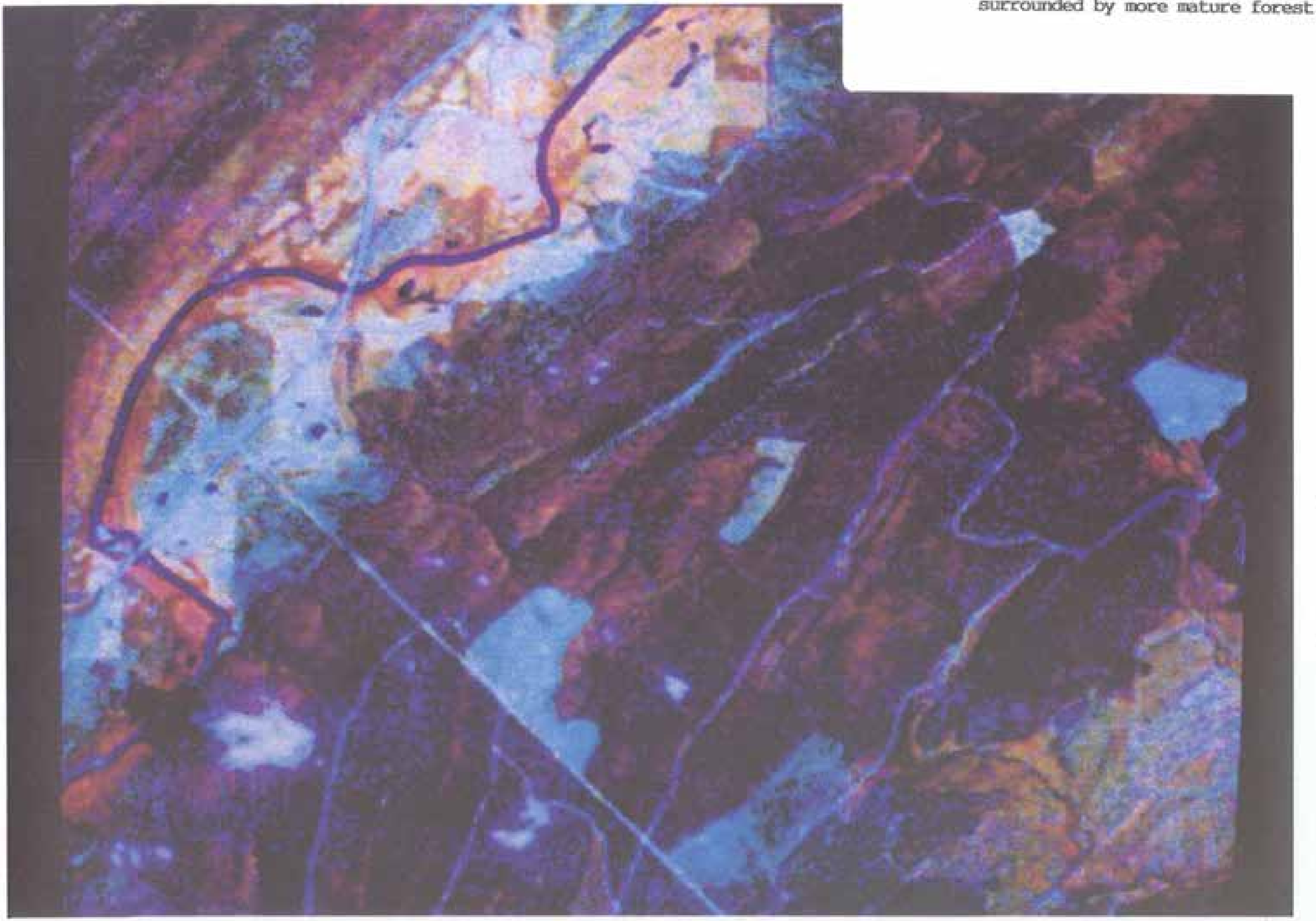


Figure 26. Final classification of Kiamichi River and upper Little River watersheds.

clearcuts in turquoise and
surrounded by more mature forest.



APPENDIX 1

ADDITIONAL WATER QUALITY DATA

SAMPLE NUMBER 199113
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
COLLECTED BY CV

00000

DEPTH CODE

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OKLA. BIOLOGICAL SURVEY
2001 PRIESTLY AVE., BLD. 605
NORMAN, OK 73019-0543
ATTN. CARYN VAUGHN, PH.D.

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GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER			PARAMETER		
NITRITE-NITRATE AS N	<	0.5 MG/L	PHOSPHOURS,TOTAL P		0.137

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV2
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL
¼ ¼ ¼ SEC T R M

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199114 00000
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION DEPTH CODE
COLLECTED BY CV

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CONCENTRATION IN SAMPLE

PARAMETER		VALUE	[illegible]	PARAMETER		VALUE	
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P		0.014	MG

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV2 21 AUG
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

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SAMPLER'S COMMENTS

ANALYST'S COMMENTS

AMPLE NUMBER 199115

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ATE COLLECTED 08/21/90
ATE RECEIVED 02/11/91
ATE COMPLETED 02/27/91
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CONCENTRATION IN SAMPLE

PARAMETER		VALUE		PARAMETER		VALUE
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

CV4
OKLA. BIOLOGICAL SURVEY
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SAMPLE NUMBER 199116 00000
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION DEPTH CODE
COLLECTED BY CV

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CONCENTRATION IN SAMPLE

PARAMETER		VALUE		PARAMETER			VALUE	
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS, TOTAL	P	<	0.005	MG

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV11
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

SEC T R M

SAMPLER'S
COMMENTS

[illegible]

SAMPLE NUMBER 199 117
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
DEPTH CODE
COLLECTED BY CV

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CONCENTRATION IN SAMPLE

PARAMETER		VALUE	[illegible]	PARAMETER		VALUE
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS, TOTAL P	<	0.005

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV14
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S
COMMENTS

SAMPLE NUMBER 199118
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
DEPTH CODE
COLLECTED BY CV

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CONCENTRATION IN SAMPLE

PARAMETER		VALUE	UNITS	PARAMETER		VALUE	UNITS
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005	MG

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV16
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

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LEGAL

SEC

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199119
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
DEPTH CODE
COLLECTED BY CV

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CONCENTRATION IN SAMPLE

PARAMETER	[illegible]	[illegible]	PARAMETER	VALUE
NITRITE-NITRATE AS N <	0.5	MG/L	PHOSPHOURS,TOTAL P	0.019

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV19
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY
CITY

LEGAL

SEC

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199120 00000
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION DEPTH CODE
COLLECTED BY C7

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NORMAN, OK 73019-0543
ATTN. CARYN VAUGHN, PH.D.

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CONCENTRATION IN SAMPLE

PARAMETER		VALUE		PARAMETER		VALUE
ITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS, TOTAL P	<	0.005 MG/

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV20
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY
CITY

LEGAL

SEC

SAMPLER'S
COMMENTS

[illegible]

SAMPLE NUMBER 199121
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
COLLECTED BY CV

DEPTH CODE

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ATTN. CARYN VAUGHN, PH.D.

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GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETERS	VALUE	[illegible]	PARAMETERS	VALUE
NITRITE-NITRATE AS N <	0.5	MG/L	PHOSPHOURS,TOTAL P <	0.005

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

CV21
OKLA. BIOLOGICAL SURVEY

CITY

LEGAL

SEC

SAMPLE NUMBER 199122
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
DEPTH CODE
COLLECTED BY CV

00000

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NORMAN, OK 73019-0543
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GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER		VALUE	UNITS	PARAMETER		VALUE	
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005	MG

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV22
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY
CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199123
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
COLLECTED BY CV

00000

DEPTH CODE

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NORMAN, OK 73019-0543
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GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER	VALUE	UNITS	PARAMETER	VALUE
NITRITE-NITRATE AS N	< 0.5	MG/L	PHOSPHOURS,TOTAL P	< 0.0

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV25
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S
COMMENTS

ANALYST'S
COMMENTS

SAMPLE NUMBER 199124 00000
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION DEPTH CODE
COLLECTED BY CV

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NORMAN, OK 73019-0543
ATTN. CARYN VAUGHN, PH.D.

COPY

GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER		VALUE	UNITS	PARAMETER		VALUE
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005 MG

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV 26
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199125
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
COLLECTED BY CV

00000

DEPTH CODE

OKLAHOMA STATE DEPARTMENT OF H
STATE ENVIRONMENTAL LABORATORY S
REPORT OF ANALYSIS

OKLA. BIOLOGICAL SURVEY
2001 PRIESTLY AVE., BLD. 605
NORMAN, OK 73019-0543
ATTN. CARYN VAUGHN, PH.D.

COPY

GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER		VALUE	UNITS	PARAMETER		VALUE
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV29
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

SAMPLE NUMBER 199126
DATE COLLECTED 08/21/90
DATE RECEIVED 02/11/91
DATE COMPLETED 02/27/91
STATION
COLLECTED BY CV

00000

DEPTH CODE

OKLAHOMA STATE DEPARTMENT OF HEAL
STATE ENVIRONMENTAL LABORATORY SER
REPORT OF ANALYSIS

OKLA. BIOLOGICAL SURVEY
2001 PRIESTLY AVE., BLD. 605
NORMAN, OK 73019-0543
ATTN. CARYN VAUGHN, PH.D.

COPY

GENERAL PROJECTS

CONCENTRATION IN SAMPLE

PARAMETER		VALUE	[illegible]	PARAMETER		VALUE	
NITRITE-NITRATE AS N	<	0.5	MG/L	PHOSPHOURS,TOTAL P	<	0.005	MG,

REMARK CODE EXPLANATIONS

< LESS THAN DETECTION LIMIT

SOURCE CV31
PROGRAM OKLA. BIOLOGICAL SURVEY
COUNTY

CITY

LEGAL

¼ ¼ ¼ SEC T R M

SAMPLER'S COMMENTS

ANALYST'S COMMENTS

07335700 KIAMICHI RIVER NEAR BIG CEDAR, OK
(Hydrologic benchmark station)

LOCATION.-- Lat 34°38'10", long 94°36'45", in SW 1/4 SE 1/4 sec.18, T.2 N., R.26 E., Le Flore County, Hydrologic Unit 11140105, Ouachita National Forest, on downstream side of right bank pier of bridge on State Highway 63, 0.2 mi upstream from Rattlesn Creek, 1.1 mi upstream from Big Branch, 2.1 mi east of Big Cedar, and at mile 157.6.

DRAINAGE AREA.-- 40.1 mi².

WATER-DISCHARGE RECORDS

PERIOD OF RECORD -- October 1965 to current year.

GAGE.-- Water-stage recorder. Datum of gage is 886.97 ft above National Geodetic Vertical Datum of 1929.

REMARKS.-- Records good.

AVERAGE DISCHARGE.-- 26 years, 82.7 ft³/s, 28.0 in/yr, 59,920 acre-ft/yr.

EXTREMES FOR PERIOD OF RECORD.-- Maximum discharge, 27,400 ft³/s, May 19, 1990, gage height, 19.60 ft; from rating curve exter above 9,000 ft³/s; no flow at times in most years.

EXTREMES FOR CURRENT YEAR.-- Peak discharges greater than base discharge of 2,000 ft³/s and maximum (*):

Date	Time	Discharge (ft³/s)	Gage Height (ft)	Date	Time	Discharge (ft³/s)	Gage Height (ft)
Oct. 7	1900	2,270	9.52	Apr. 13	1645	10,100	14.51
Oct. 8	1500	8,910	13.99	May 3	0415	2,180	9.06
Mar. 22	0815	*11,200	*14.98	July 27	1515	3,930	10.98
Apr. 12	0630	8,120	13.62	July 28	0730	10,200	14.56

Minimum daily discharge, 0.68 ft³/s July 23.

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1990 TO SEPTEMBER 1991
DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	7.0	9.8	87	197	33	154	124	83	20	7.2	50	2.8
2	6.5	11	79	188	30	146	100	67	22	5.9	35	2.3
3	8.8	11	227	159	29	104	124	882	18	5.9	26	2.6
4	20	57	147	133	28	84	103	297	13	8.9	19	2.4
5	21	82	114	128	41	72	88	250	11	6.1	14	6.5
6	17	60	92	533	96	64	82	170	10	4.9	10	5.9
7	577	51	75	413	86	54	159	122	8.2	4.2	8.3	6.1
8	1840	45	63	217	80	46	185	95	7.5	3.6	6.5	20
9	1400	141	53	177	73	40	140	76	6.4	3.1	5.5	17
10	325	124	42	408	65	35	109	64	5.7	2.6	4.4	12
11	185	97	39	314	57	32	90	53	16	2.3	3.9	9.0
12	105	77	37	212	52	31	1880	43	12	1.9	3.3	7.3
13	75	64	33	163	51	28	3240	36	9.1	1.6	4.5	6.2
14	56	53	30	132	45	26	909	30	7.5	1.5	5.4	5.4
15	43	46	28	390	38	24	403	26	7.7	1.3	3.4	4.7
16	35	39	29	383	35	22	246	27	56	1.2	3.4	6.0
17	30	34	13	208	35	44	193	24	34	1.1	4.5	22
18	25	31	65	172	34	39	950	19	22	1.0	4.0	29
19	21	28	99	172	31	35	325	19	17	.97	2.9	28
20	18	26	90	145	28	35	205	24	13	.89	2.4	24
21	26	28	112	122	26	40	153	41	9.9	.81	2.5	20
22	23	27	101	108	24	2370	142	45	73	.70	2.7	16
23	19	24	86	95	22	469	108	58	159	.68	2.1	13
24	16	22	77	81	21	237	83	43	55	104	1.8	11
25	14	20	66	70	21	161	84	108	37	132	1.5	9.3
26	13	23	60	62	19	126	68	102	28	61	1.5	7.6
27	11	63	77	56	18	215	157	70	21	775	1.5	6.5
28	11	99	94	52	17	174	153	51	16	2300	2.1	5.7
29	9.8	85	652	45	---	249	149	39	13	286	1.6	5.2
30	9.3	75	627	42	---	204	107	31	9.5	122	1.6	4.6
31	9.1	---	281	37	---	157	---	25	---	73	2.3	---
TOTAL	5036.5	1550.8	3655	5532	1135	5517	10859	3090	737.5	3981.43	237.6	318.1
MEAN	162	51.7	118	178	40.5	178	362	99.7	24.6	128	7.66	10.6
MAX	1840	141	652	533	96	2370	3240	882	159	2300	50	29
MIN	6.5	9.8	13	37	17	22	68	19	5.7	.68	1.5	2.3
AC-FT	9990	3080	7250	10970	2250	10940	21540	6130	1460	7900	471	631
CFSM	4.05	1.29	2.94	4.45	1.01	4.44	9.03	2.49	.61	3.20	.19	.26
IN.	4.67	1.44	3.39	5.13	1.05	5.12	10.07	2.87	.68	3.69	.22	.30

CAL YR 1990 TOTAL 57107.13 MEAN 156 MAX 5360 MIN .15 AC-FT 113300 CFSM 3.90 IN. 52.98
WTR YR 1991 TOTAL 41649.93 MEAN 114 MAX 3240 MIN .68 AC-FT 82610 CFSM 2.85 IN. 38.64

UNPUBLISHED RECORDS
SUBJECT TO REVISION