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INVESTIGATION OF FRESHWATER MUSSELS (UNIONIDAE) AT SELECTED SITES IN THE LOWER OHIO AND CUMBERLAND RIVERS, SEPTEMBER 1990

by

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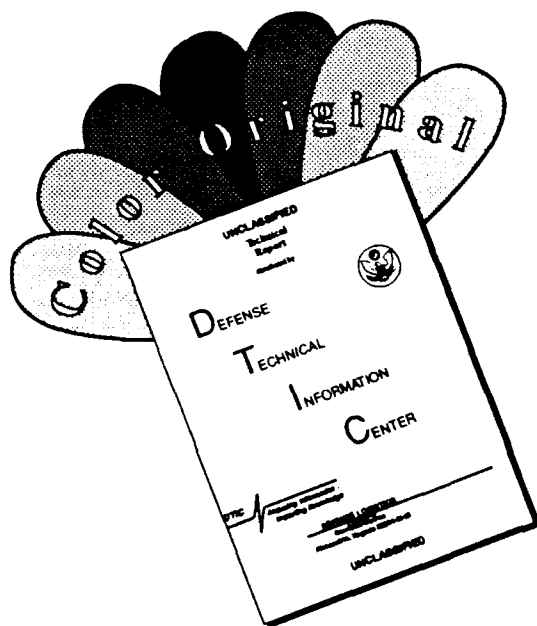


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Preface

A mollusc survey was conducted by the US Army Engineer Waterways Experiment Station (WES) on 22-24 September 1990, for the US Army Engineer District, Louisville (CEORL), Louisville, KY. The purpose was to investigate a reach on the lower Ohio River that could be affected by construction and operation of Olmsted Lock and Dam, and a reach of the lower Cumberland River that could be affected by modifications to Smithland Lock and Dam. Information from these surveys will be used by CEORL to prepare environmental assessments describing proposed actions.

Divers were Larry Neill, Mitchell Marks, Steve McKinny, and Dennis Baxter from the Tennessee Valley Authority. Assistance in the field was provided by Dr. Bill Pearson, Water Resources Laboratory at the University of Louisville, Louisville, KY, and by Ms. Jennifer Marsh and Mr. David Marsh, University of Louisville. Mr. Mike Turner, CEORL, monitored the contract and assisted in the field. This report was edited by Ms. Janean Shirley of the Information Technology Laboratory, WES.

During the conduct of this study Dr. John Harrison was Chief, Environmental Laboratory (EL), WES, Dr. C. J. Kirby was Chief, Environmental Resources Division, EL, WES, and Dr. E. Theriot was Chief of the Aquatic Habitat Group, EL, WES. Authors of this report were Dr. Andrew C. Miller and Dr. Barry S. Payne, WES.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN, and the Technical Director was Dr. Robert W. Whalin.

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Conversion Factors, Non-SI to SI Units Of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (US nautical)	1.852	kilometers



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1 Introduction

Background

The continued use of inland waterways to transport bulk commodities (Dietz et al. 1983) has caused planners and biologists in government agencies to express concern over the possible negative effects of movement of commercial vessels in inland waterways (Rasmussen 1983). The physical effects of commercial vessel movement include wave wash, turbulence, benthic scour, drawdown, current reversals, and periods of increased sediment resuspension (Wright 1982). In addition, secondary effects of increased navigation traffic, such as lock and dam construction or modification, dredging, and water level manipulation, also have the potential for negatively affecting aquatic biota. Freshwater mussels, a resource with economic, ecological, and cultural value, could be affected by these disturbances. Their sedentary lifestyle and reliance on suspended particulate organic matter make them susceptible to turbulence, sedimentation, and fluctuating water levels.

Although physical effects of waterway alteration can be simulated in the laboratory, caution must be exercised when using results of these studies to estimate impacts to natural populations. Responses studied in the laboratory may not occur in the field. In addition, naturally occurring compensatory mechanisms, which are not part of laboratory experiments, usually exist. Biologists should evaluate the effects of man's activities on populations of species in their natural habitats. As an alternative to laboratory simulation, field studies should be conducted to evaluate the biological effects of water resource developments. These studies must be designed to provide quantitative data on biotic parameters, such as density, relative species abundance, community composition, population demography, and rate of growth, of naturally occurring populations. These data cannot be obtained with exploratory devices such as the grab, or qualitative collections by hand (Miller and Payne 1988). Quantitative total substrate samples provide the type of data required to measure the overall health and ultimate survival of a mussel community.

The US Army Engineer District, Louisville (CEORL) requested that personnel from the US Army Engineer Waterways Experiment Station

(WES) conduct a survey of freshwater mussels (Family: Unionidae) at two areas likely to be affected by proposed water resource developments. A reach on the lower Ohio River (LOR) will be affected by construction and operation of Olmsted Lock and Dam, to be located at river mile¹ (RM) 964.4 on the Ohio River. Concern has been expressed that construction and operation of the dam could affect a dense and diverse mussel bed first identified by Williams (1969) between RM 966.0 and 969.2. In addition, CEORL proposes to alter Smithland Locks and Dam, located at RM 918.5. Proposed modifications to the fixed weir on the left descending bank (LDB) could affect flow in the old channel line immediately downriver as well as the lower Cumberland River.

Purpose

The purpose of this study was to describe community composition, density, areal extent, recruitment rates, and presence of endangered species of freshwater mussels at selected sites in the lower Ohio and lower Cumberland Rivers.

¹ A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page vii.

2 Study Area and Methods

Study Area

In the LOR near Olmsted, IL, quantitative samples were collected at RM 967.2 (Site Q1) and 966.5 (Site Q2, see Figure 1 and Table 1). Qualitative collections were made at four sites: RM 957.8 (Sites 1 and 2), RM 963.8 (Site 3), and RM 967.2 (Site 4). In addition, divers intensively searched a series of sites along the LDB immediately up- and downriver of Lock and Dam 53. Ten areas were intensively searched for mussels downriver of Smithland Lock and Dam (Figure 2).

Methods

Preliminary reconnaissance

All underwater work was accomplished by a dive crew equipped with surface air supply and communication equipment. Before intensive sampling was initiated, a single diver conducted a preliminary survey. He obtained information on substrate type, water velocity, and presence of mussels. Qualitative sampling was initiated if the substrate appeared stable and if there was moderate to high mussel density (i.e., greater than 3-5 individuals/sq m).

Qualitative mussel collections

The majority of the qualitative samples were obtained by having three divers collect simultaneously. Each diver placed a specific number of live mussels in each of four nylon bags; five mussels were placed in the first bag and 20 were placed in each of the other three bags. The divers were instructed to obtain mussels without bias toward size or type. They attempted to exclude the Asiatic clam, *Corbicula fluminea*. If *C. fluminea* was inadvertently collected, it was later eliminated. All mussels were brought to the surface, counted, and identified. Data were recorded on

standard data sheets and returned to WES for analysis and plotting. Shells of voucher specimens for each species were placed in plastic zipper-lock bags and labeled with high-rag-content paper. Mussels not needed for voucher were returned to the river. Methods for sampling mussels are based on techniques described in Coker (1919); Brice and Lewis (1979); Miller and Nelson (1983); Isom and Gooch (1986); Kovalak, Dennis, and Bates (1986); and Miller and Payne (1988). Mussel identification was based on taxonomic keys and descriptive information in Murray and Leonard (1962); Parmalee (1967); Starrett (1971); and Burch (1975).

Quantitative mussel collections

Quantitative samples (that included unionids as well as *C. fluminea*), were obtained at RM 966.5 and RM 967.2 in the LOR. At each site, either 5 or 10 quadrats (0.25 sq m) were positioned approximately 1 m apart and arranged in a 2 by 2 or a 2 by 5 matrix. A diver excavated all sand, gravel, shells, and live clams to a depth of 10-15 cm. Material was sent to the surface in a 20-L bucket and transported to shore. Sediment was screened through a sieve series (finest screen with apertures of 6.4 mm). All live mussels and *C. fluminea* removed from samples were placed in 4-L zipper-lock bags. Each bivalve was then identified and total shell length (SL) measured to the nearest 0.1 mm with dial calipers.

Data analysis

Species diversity was determined with the following formula:

$$H' = -\sum p_j \log p_j$$

where p_j is the proportion of the population that is of the j th species (Shannon and Weaver 1949). All calculations were performed with programs written in BASIC or SAS (Statistical Analytical System) on an IBM XT or AT personal computer. Discussion of statistical procedures that were used can be found in Green (1979) and Hurlbert (1984). Species area curves and dominance-diversity curves were constructed from qualitative and quantitative biological data. More information on methods used for this survey can be found in McNaughton and Wolf (1973); Isom and Gooch (1986); Kovalak, Dennis, and Bates (1986); Hughes (1986); and Miller and Payne (1988).

3 Results

Unionid Community Characteristics

Twenty-three species of freshwater mussels (Family: Unionidae) were collected using qualitative methods at RM 957.8, 963.8, and 967.2 in the LOR on 22-25 September, 1990 (Table 2). The fauna was dominated by *Fusconaia ebena* (40.9 percent), *Quadrula pustulosa pustulosa* (10.76 percent), *Quadrula quadrula* (10.6 percent), and *Amblema plicata plicata* (9.0 percent). *Fusconaia ebena* was approximately four times as abundant as the latter three species; together these four species comprised 71.4 percent of the fauna. Eleven species were considered uncommon and comprised less than 1 percent of the assemblage. The native fauna was dominated by thick or moderately thick-shelled species. *Leptodea fragilis* comprised only 0.24 percent of the collection, and other thin-shelled species (*Anodonta grandis* and *Anodonta imbecillis*) usually associated with fine sand or silt substratum, were not found. A plot of species rank versus percent abundance for the total qualitative collection (Figure 3) illustrates the strong dominance of *F. ebena* and the relatively even distribution of the remaining mussels in the assemblage.

Two specimens of the orange-footed pimpleback (*Plethobasus cooperianus*), listed as endangered by the US Fish and Wildlife Service (1987) were collected qualitatively. One individual was found at RM 957.8 (500 ft from the right descending bank (RDB)), and one was found at RM 967.2 (700 ft from the RDB, see Table 3). Although this species is listed as endangered, it was not the least common in the collection. Only a single specimen was found of the following species: *Actinonaias ligamentina*, *Ligumia recta*, and *Plethobasus cyphus* (Table 2).

In these qualitative collections *Fusconaia ebena* was more abundant in samples taken at farshore as opposed to nearshore sites (Figure 4). *Amblema plicata* was consistently more common in nearshore as compared with farshore sites. Three other species (*Quadrula pustulosa*, *Quadrula quadrula*, and *Megalonaias nervosa*) did not exhibit any strong or consistent nearshore/farshore trends. Species diversity ($\log_2 3026$), based on a sample of approximately 200 individuals at each of the four sites, ranged from 1.19 to 2.27, and evenness ranged from 0.45 to 0.82

(Table 3). The low diversity and evenness at RM 967.2 were primarily the result of extreme dominance of a single species, *F. ebena*. Conversely, the high values at RM 957.8 (350 ft from the RDB) were the result of the fairly even distribution of three dominant species (*F. ebena*, *Q. pustulosa*, and *A. plicata*) (Table 3).

The most abundant bivalve, *F. ebena*, was taken in 95.8 percent of the 48 qualitative samples (Tables 2 and 4). Two species that were about 25 percent as common as *F. ebena*, *Q. pustulosa*, and *Q. quadrula* were taken in 33.3 to 91.7 percent of the samples (Table 4). Approximately half of the mussels collected at each site using qualitative methods were taken in only 1 or 2 of the 12 samples. A plot of cumulative species versus cumulative individuals collected qualitatively illustrates the relationship between sampling effort and the ability to find uncommon species (Figure 5). After 400 individuals had been collected, 22 species had been identified. After approximately 200 additional individuals were collected only 1 more new species was found. Based on these results it appears unlikely that additional species would be found with more sampling effort. If a rare species were present and not collected, it would have comprised less than 0.12 percent of the assemblage (Table 2).

Bivalve Density

Total unionid densities were moderate and ranged from 37.6 to 68.0 individuals/sq m (Table 5 and Figure 6) at two locations in the LOR. *Corbicula fluminea* densities ranged from 11.2 to 26.8 individuals/sq m. *Fusconaia ebena* was strongly dominant at RM 967.2 (60.4-62.8 percent of the assemblage), and less common (48.2-58.2 percent) at RM 966.5. The high dominance of *F. ebena* in the total quantitative collection is displayed graphically in Figure 7a. The second-most-abundant species in the quantitative collection (*Q. pustulosa*) comprised only 10 percent of the assemblage. This species, unlike *F. ebena*, was most common at RM 966.5. The relationship between cumulative species and cumulative individuals in the quantitative collection is depicted in Figure 7b. The relationship between cumulative species and cumulative individuals was similar regardless of whether mussels were collected qualitatively or quantitatively. After 400 individuals had been collected, 22 species had been identified (compare Figures 5 and 7b).

Demographic analysis of dominant bivalve populations

Fusconaia ebena. Although *Fusconaia ebena* spanned the SL range of 30 to 92 mm, 81 percent of the sample was comprised of individuals between 48 and 64 mm SL (Figure 8a). Previous work has established that these mussels from 48-64 mm SL represent an exceptionally abundant year class of 1981 recruits (Payne and Miller 1989). Sampling in the fall

of 1983 established that the 1981 year class of recruits represented approximately 70 percent of the total population. The single year class had an average SL of 16 mm in 1983. Subsequent sampling indicated that this cohort achieved an average SL of 56 mm by the fall of 1990. The growth of the 1981 cohort is summarized in Figure 8b. Furthermore, from 1983 to the present there has been no indication of strong recruitment to this population. The paucity of mussels less than 40 mm SL in Figure 8a indicates that little recent recruitment has occurred.

Ellipsaria lineolata. The relatively small sample (n=16) of this population did not allow detailed analysis of size demography. Individuals spanned the SL range of 44 to 88 mm (Figure 9).

Quadrula pustulosa. *Quadrula pustulosa* ranged from 4 to 62 mm SL, but the sample was not sufficiently large (n=17) for detailed analysis of size demography. Only two individuals were less than 34 mm SL; these two mussels were recent recruits measuring only 4-8 mm SL (Figure 10).

Corbicula fluminea. The population of the Asiatic clam exhibited clear differences in size structure of farshore (Figure 11a) versus nearshore (Figure 11b) locations. Samples collected 700 ft from shore at a depth of 14 ft were dominated by small recruits ranging in SL from 6 to 14 mm (these individuals were probably recruited in spring 1990). Only 12 of the 67 individuals collected at the farshore site were greater than 22 mm SL (recruits of 1989 or earlier). In contrast, all of the 28 individuals collected at the nearshore site (230-300 ft from the shore at a depth of 14-15 ft) were less than 12 mm SL. •

Cumberland River

Mussels were either absent or present in low densities at 10 sites in the lower Cumberland River or RDB of the Ohio River near Smithland Lock and Dam (Table 6 and Figure 12). Twelve species of unionids were found at Site 8; the assemblage was dominated by *Q. quadrula* (38.7 percent) and *F. ebena* (16.1 percent). Further downriver, 30 min of searching yielded four species and eight individuals. Eight species and thirty-five live mussels were collected in 30 min of searching on the dike. The fauna was dominated by *Q. quadrula* (51.4 percent) and *A. plicata* (20.0 percent).

Intensive searches in this reach of the river yielded no unusual or endangered species of mussels. Special effort was directed toward *Potamilus capax*, reported in the channel between Cumberland Island Towhead and the Kentucky shore. No specimens of *P. capax* were found in the lower Cumberland River or the reach of the Ohio River immediately below Smithland Lock and Dam.

4 Characterization of the Bivalve Community

The Unionid Assemblage

The mussel assemblage in the LOR and lower Cumberland River consisted almost entirely of thick-shelled species. The fauna was dominated by *F. ebena*, *A. plicata*, and *Quadrula* spp., with lesser numbers of *Elliptio* spp., *M. nervosa*, and *P. cordatum*. Thin- and moderately thick-shelled species (*L. fragilis*, *P. alatus*, and *Anodonta* spp.) were either uncommon or absent at sites sampled in both rivers. Within their range, these thin-shelled species are found in appropriate substrate in large rivers. Each species has multiple fish hosts (Fuller 1974) and would be more common at these sites if suitable conditions of substrate and water velocity existed. However, coarse gravel substrate and erosive flows at high discharge will stress thin-shelled species. If present, few are likely to reach adult size. This mussel assemblage would probably support more thin-shelled species if average water velocities were less and sediments contained a higher percentage of silt and sand.

The Presence of *C. fluminea*

Williams (1969) sampled the LOR with an 8-ft brail and a Petersen dredge. Based on quantitative samples, he estimated that *C. fluminea* comprised about 35 percent of the bivalve community, although no density estimates were provided. In the present survey, *C. fluminea* density ranged from 11.2 to 161.6 individuals/sq m (Table 5 and Figure 6). Based on these data it appears that *C. fluminea* densities are similar to those reported by Williams (1969). However, because this species does not require an intermediate fin-fish host and has a comparatively short life span, its densities and population structure can fluctuate extensively in response to physical disturbance.

Species Richness

Total species richness in the LOR is similar to that at other mussel beds in large rivers. In a survey of the upper Mississippi River conducted in 1989, Miller et al. (1990) collected over 15,000 bivalves in 667 qualitative samples at 58 locations and identified 34 species. However, total species richness at any one location was usually between 15 and 25. Smaller rivers usually support fewer species. Using quantitative techniques at dense beds in the Sunflower River and Big Black River in central Mississippi, 13 and 15 species were identified, respectively (Miller and Hartfield; Payne and Miller, unpublished information).

Species richness has not changed recently in this reach of the LOR. In 1988, Payne and Miller (1989) collected 23 species of freshwater mussels at sites along the RDB in the mussel bed below Lock and Dam 53.

Relative Species Abundance

The fauna in this mussel bed is characterized by moderate to low evenness. Evenness can range from near 0.0 to near 1.0; at these sites values ranged from 0.45 to 0.79. Low evenness was the result of the relatively high abundance of the dominant unionid *F. ebena* (21.1 to 70.2 percent, Table 3). Based on similar qualitative collections at six sites in a dense and diverse mussel bed in the Ohio River near Cincinnati, OH, evenness ranged from 0.756 to 0.817 (Miller and Payne 1991).

Density

In comparison with other large-river mussel beds, the range in unionid density (37.6 to 68.0 individuals/sq m) can be considered low to moderately high. At an inshore and offshore sites in the lower Tennessee River at RM 18.6 on the LDB (32 quantitative samples were collected at each site) total mussel density was 187.7 and 79.7 individuals/sq m, respectively (Way, Miller, and Payne 1989). In a survey of the upper Mississippi River, Miller et al. (1990) reported that total mussel density ranged from 5.2 to 333.2 individuals/sq m at 16 sites (10 quantitative samples were taken at each site). At half of the sites total density was greater than 50 individuals/sq m and at 4 sites it was greater than 100 individuals/sq m. In the Big Black River in central Mississippi, unionid density was 84.4 and 112.0 individuals/sq m at the upstream and downstream slopes of a gravel shoal, respectively (Payne and Miller, unpublished information).

The Presence of Endangered Species

Miller, Payne, and Siemsen (1986) collected *P. cooperianus* at this bed in the fall of 1983. In the present survey, 818 mussels were collected using qualitative techniques. After 400 individuals had been taken, 22 species had been identified; collecting an additional 200 individuals yielded 1 more species. The relationship between cumulative species and cumulative individuals (Figure 5), indicates that it would be unlikely to collect many more species. However, since two specimens of the endangered *P. cooperianus* were collected (using qualitative methods) in this survey, such additional sampling would not be required. It is apparent that *P. cooperianus* continues to exist in specific reaches of the LOR in densities high enough to be easily collected.

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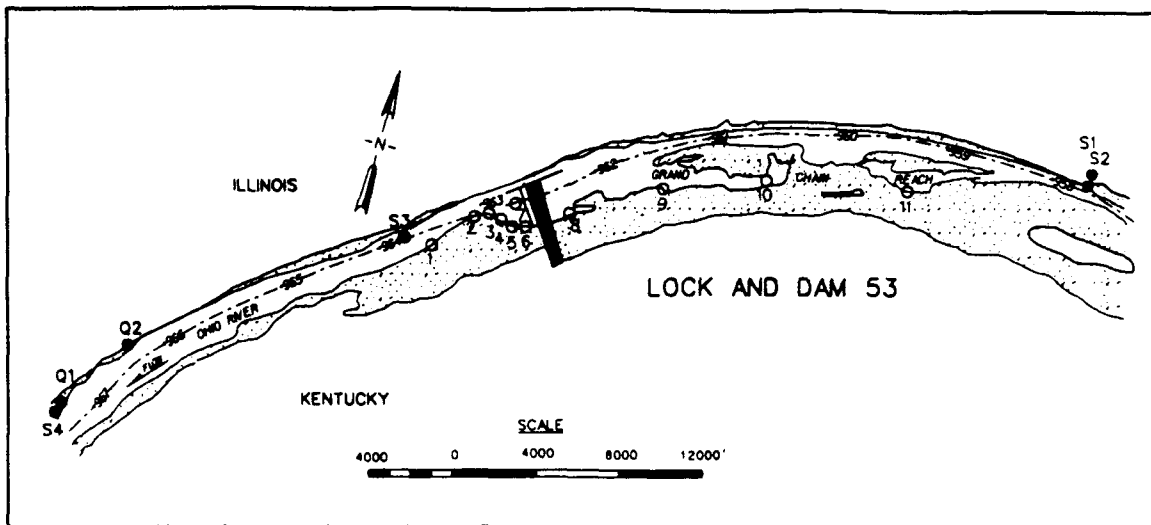


Figure 1. Sites surveyed for mussels in the lower Ohio River, September 1990. Q1 and Q2 were sampled using quantitative methods and S1-S4 were surveyed using qualitative methods. No mussels were found at Sites 1-11

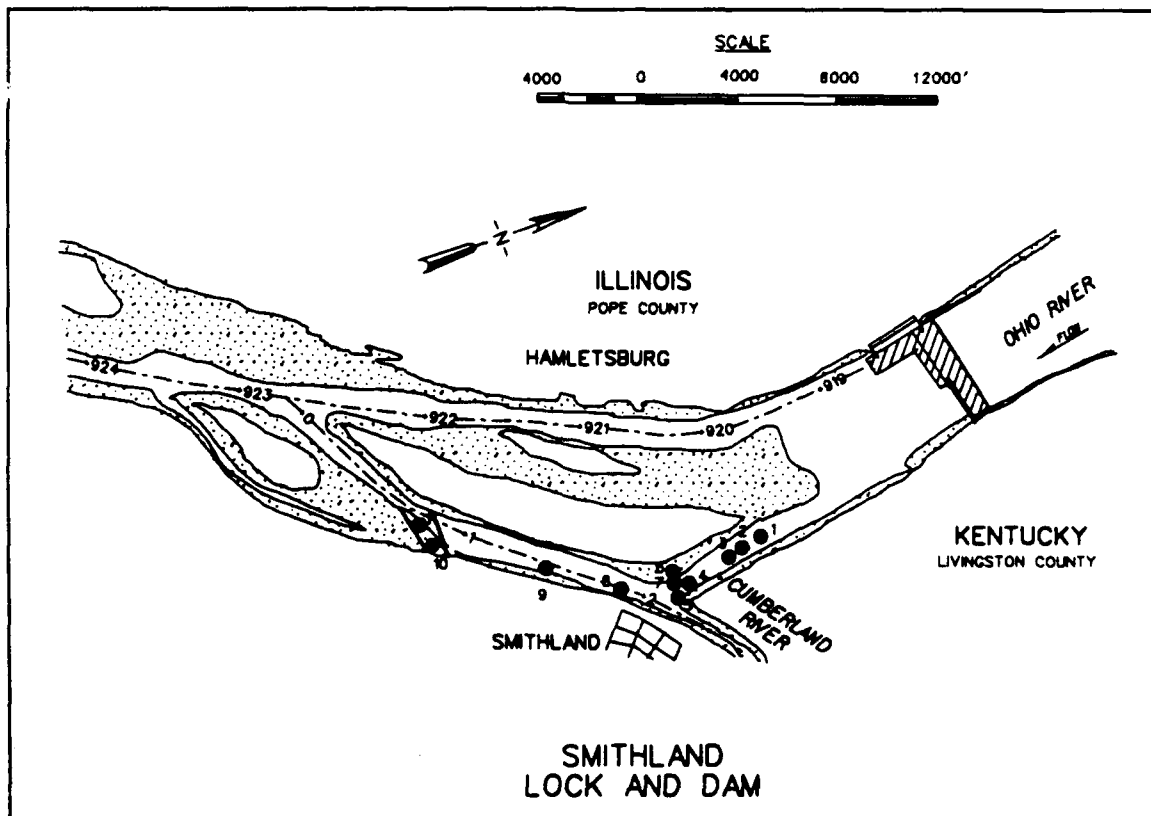


Figure 2. Sites surveyed for mussels in the lower Cumberland River, September 1990. Mussels were found at Sites 8 and 10

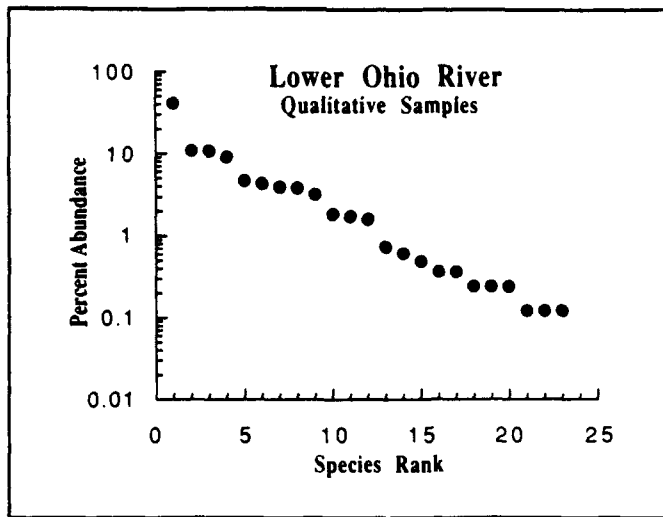


Figure 3. The relationship between percent abundance and species rank for mussels collected using qualitative methods in the lower Ohio River, September 1990

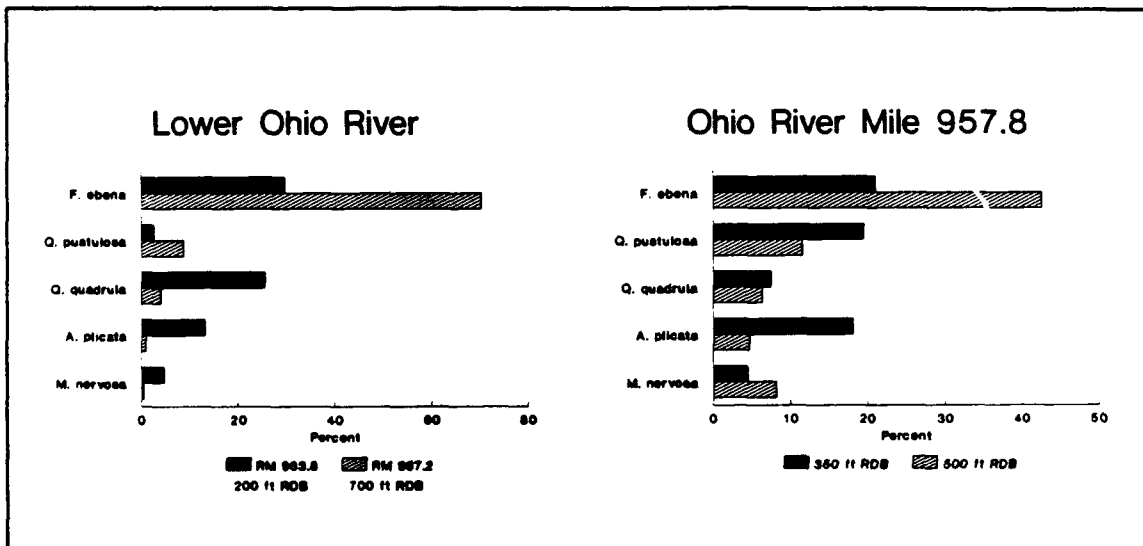


Figure 4. Results of qualitative freshwater mussel collections in the lower Ohio River, September 1990

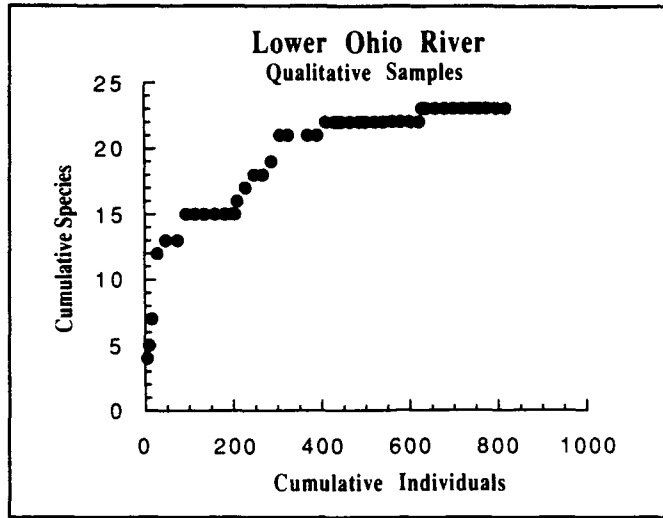


Figure 5. The relationship between cumulative species and cumulative individuals collected using qualitative methods in the lower Ohio River, September 1990

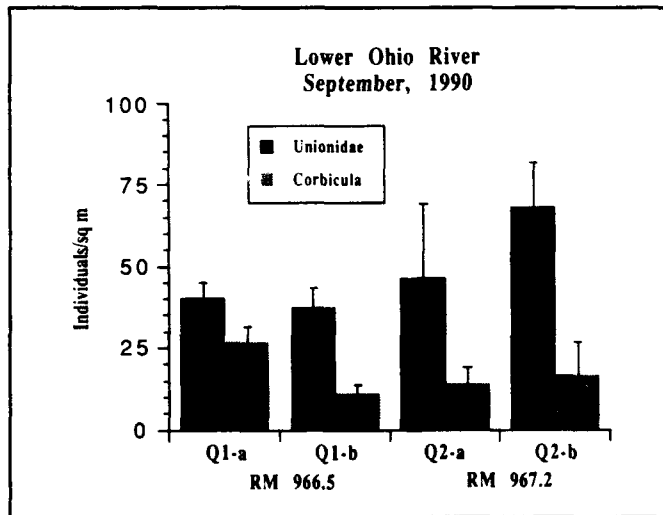
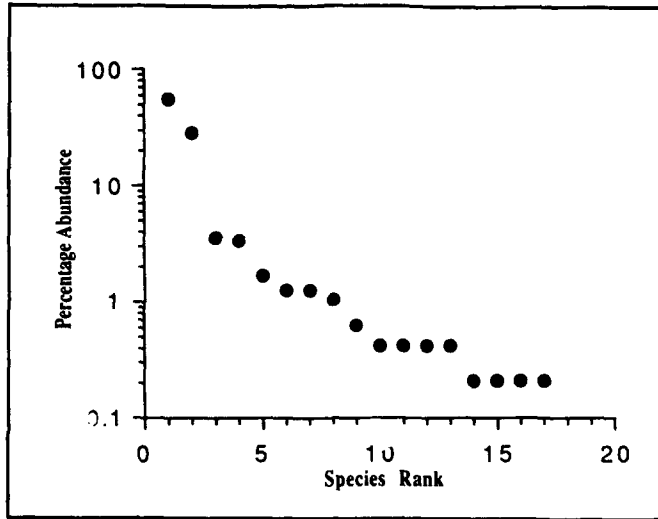
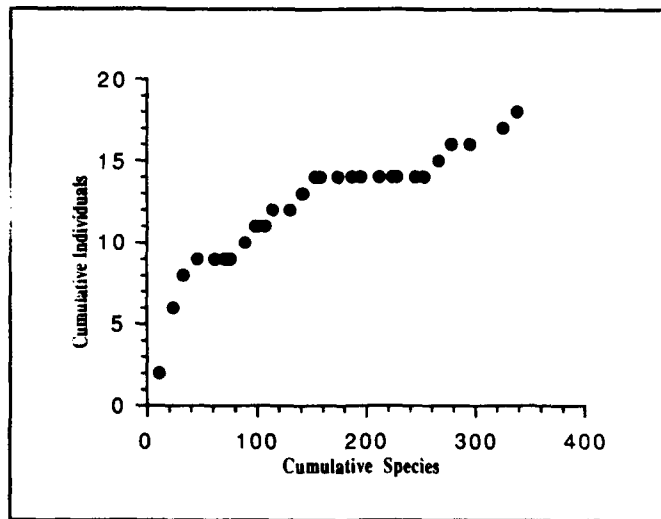


Figure 6. Total density (individuals/sq m) of unionids and *C. fluminea* collected in the lower Ohio River, September 1990

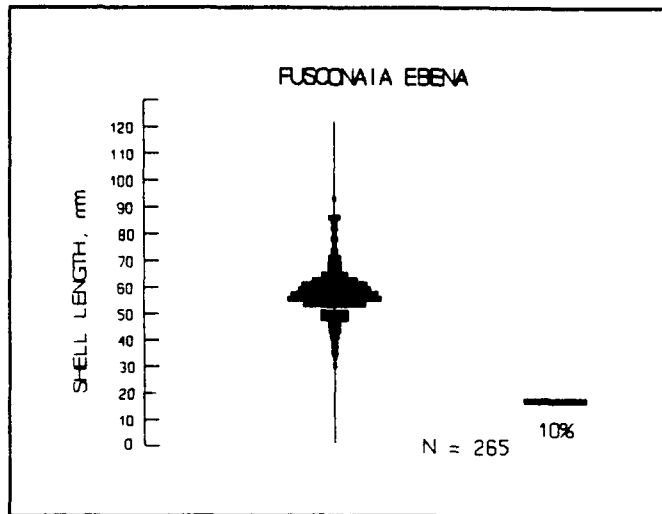


a. The relationship between percentage abundance and species rank

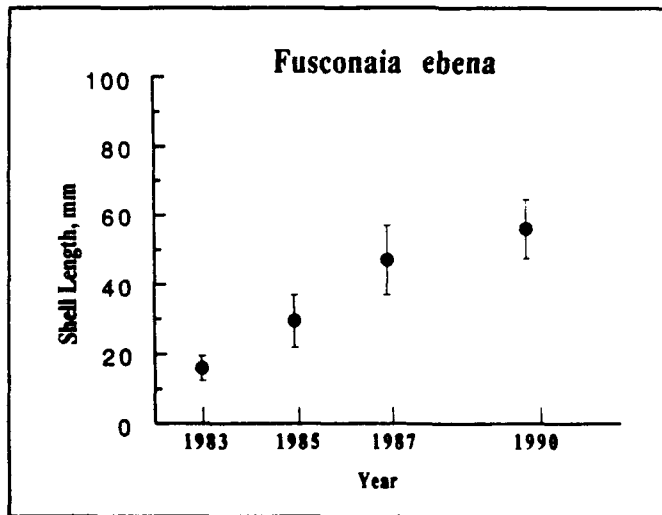


b. The relationship between cumulative individuals and cumulative species

Figure 7. Results of quantitative freshwater mussel collections in the lower Ohio River, September 1990

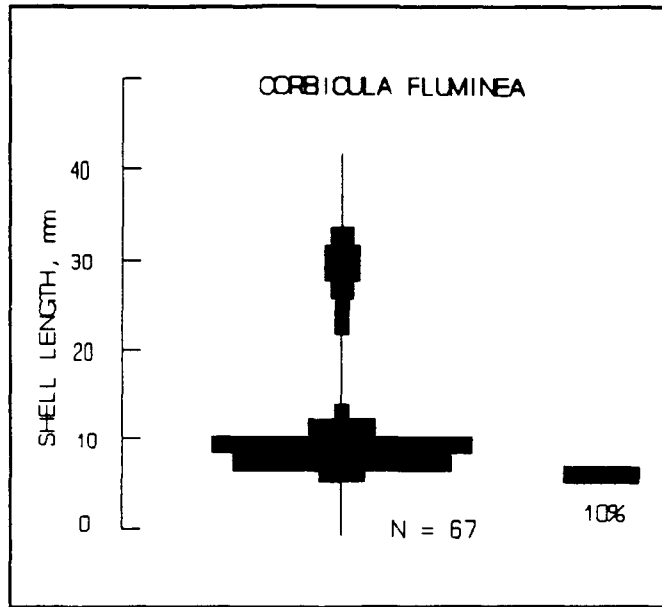


a. Length-frequency histogram

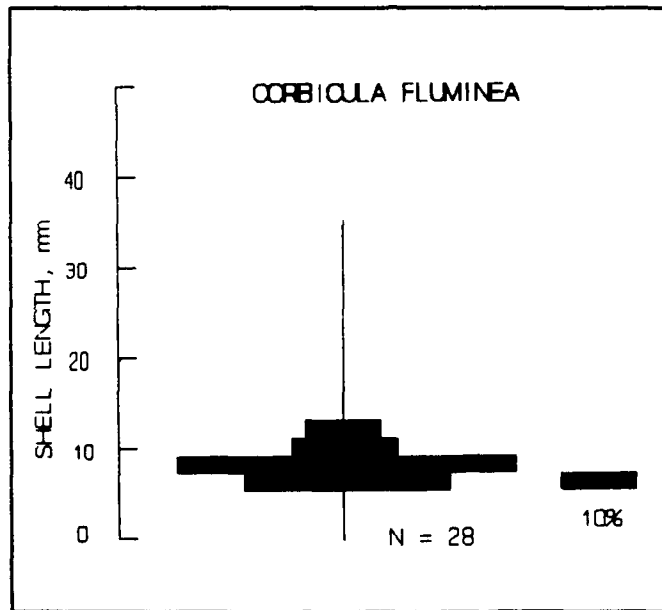


b. Mean and range shell length

Figure 8. Demographic analysis of *F. ebena*



a. Farshore site, 700 ft from RDB, RM 967.2



b. Nearshore site, 500 ft from RDB, RM 967.2

Figure 11. Length-frequency histograms for *Corbicula fluminea*

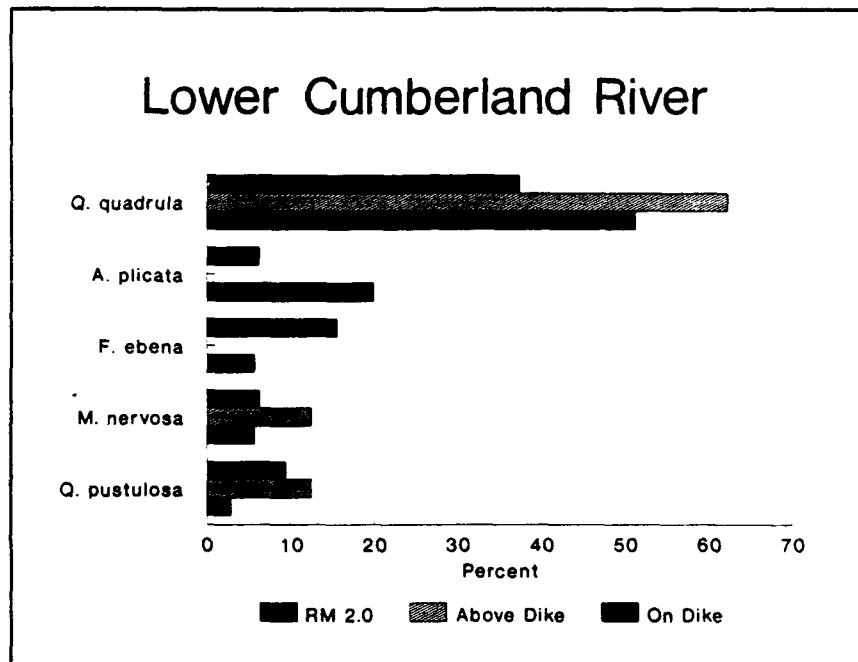


Figure 12. Relative abundance of five species of freshwater mussels at three sites in the lower Cumberland River, September 1990

Table 1
Areas Sampled for Freshwater Mussels in the Lower Ohio and Lower
Cumberland Rivers, September 1990 (Sites are depicted on Figures 1-2)

Study Area	Site No.	RM	Distance to Shore	Water Depth	No. of Samples
Lower Ohio River	Q1	967.2	500-700	14	20
	Q2	966.5	300	15	5
	Q2	966.5	230	14	5
	S1	957.8	350	15	12
	S2	957.8	500	14	12
	S3	963.8	200	14	12
	S4	967.2	700	15	12
Lower Cumberland River	8	2.0	125	12	1
	10 ¹	0.8	400	10	1
	10 ²	0.8	400	5-10	1

Notes: Q1-Q2: 0.25 sq m quantitative samples.
S1-S4: Qualitative samples.

¹ Upriver of dike.

² On dike.

Table 2
Summary of Relative Abundance and Frequency of Occurrence
for Freshwater Mussels Collected Using Qualitative Techniques
at Four Sites in the Lower Ohio River, 22-25 September 1990

Species	Total Mussels	Abundance	Total Sites	Frequency
<i>Fusconia ebena</i> (I. Lea 1831)	335	0.4095	46	0.9583
<i>Quadrula p. pustulosa</i> (I. Lea 1831)	88	0.1076	32	0.6667
<i>Quadrula quadrula</i> (Rafinesque 1820)	87	0.1064	32	0.6667
<i>Ambleria p. plicata</i> (Say 1817)	74	0.0905	29	0.6042
<i>Megaloniais nervosa</i> (Rafinesque 1820)	38	0.0465	21	0.4375
<i>Ellipsaria lineolata</i> (Rafinesque 1820)	35	0.0428	22	0.4583
<i>Obliquaria reflexa</i> (Rafinesque 1820)	32	0.0391	23	0.4792
<i>Quadrula metanevra</i> (Rafinesque 1820)	31	0.0379	24	0.5000
<i>Obovaria olivaria</i> (Rafinesque 1820)	26	0.0318	12	0.2500
<i>Tritogonia verrucosa</i> (Rafinesque 1820)	15	0.0183	11	0.2292
<i>Quadrula nodulata</i> (Rafinesque 1820)	14	0.0171	12	0.2500
<i>Potamilus alatus</i> (Say 1817)	13	0.0159	11	0.2292
<i>Elliptio crassidens</i> (Lamarck 1819)	6	0.0073	7	0.1458
<i>Pleurobema cordatum</i> (Rafinesque 1820)	5	0.0061	5	0.1042
<i>Cycloniais tuberculata</i> (Rafinesque 1820)	4	0.0049	4	0.0833
<i>Lampsilis ventricosa</i> (I. Lea 1858)	3	0.0037	2	0.0417
<i>Truncilla truncata</i> (Rafinesque 1820)	3	0.0037	3	0.0625
<i>Leptodea fragilis</i> (Rafinesque 1820)	2	0.0024	2	0.0417
<i>Lasmigona c. complanata</i> (Barnes 1823)	2	0.0024	2	0.0417
<i>Plethobasus cooperianus</i> (I. Lea 1834)	2	0.0024	2	0.0417
<i>Actinonaias ligamentina</i> (Lamarck 1819)	1	0.0012	1	0.0208
<i>Ligumia recta</i> (Lamarck 1819)	1	0.0012	1	0.0208
<i>Plethobasus cyphus</i> (Rafinesque 1820)	1	0.0012	1	0.0208
Total samples:	48			
Total mussels:	818			
Total species:	23			

Table 3
Relative Species Abundance for Freshwater Mussels Collected Using Qualitative Techniques
at Each of Four Sites in the Lower Ohio River, September 1990

Species	RM 957.8 350 ft RDB		RM 957.8 500 ft RDB		RM 963.8 200 ft RDB		RM 967.2 700 ft RDB	
	N	Abundance	N	Abundance	N	Abundance	N	Abundance
<i>F. ebena</i>	42	0.2111	99	0.4267	57	0.2969	137	0.7026
<i>Q. pustulosa</i>	39	0.1960	27	0.1164	5	0.0260	17	0.0872
<i>Q. quadrula</i>	15	0.0754	15	0.0647	49	0.2552	8	0.0410
<i>A. plicata</i>	36	0.1809	11	0.0474	25	0.1302	2	0.0103
<i>M. gigantea</i>	9	0.0452	19	0.0819	9	0.0469	1	0.0051
<i>E. lineolata</i>	6	0.0302	14	0.0603	0	0.0000	15	0.0769
<i>O. reflexa</i>	12	0.0603	10	0.0431	8	0.0417	2	0.0103
<i>Q. metanevra</i>	13	0.0653	11	0.0474	2	0.0104	5	0.0256
<i>O. olivaria</i>	2	0.0101	6	0.0259	18	0.0938	0	0.0000
<i>T. verrucosa</i>	8	0.0402	2	0.0086	5	0.0260	0	0.0000
<i>Q. nodulata</i>	4	0.0201	2	0.0086	8	0.0417	0	0.0000
<i>P. alatus</i>	5	0.0251	1	0.0043	5	0.0260	2	0.0103
<i>E. crassidens</i>	3	0.0151	0	0.0000	0	0.0000	3	0.0154
<i>P. cordatum</i>	1	0.0050	3	0.0129	0	0.0000	1	0.0051
<i>C. tuberculata</i>	2	0.0101	2	0.0086	0	0.0000	0	0.0000
<i>L. ventricosa</i>	0	0.0000	3	0.0129	0	0.0000	0	0.0000
<i>T. truncata</i>	0	0.0000	2	0.0086	1	0.0052	0	0.0000
<i>L. fragilis</i>	0	0.0000	2	0.0086	0	0.0000	0	0.0000
<i>L. complanata</i>	2	0.0101	0	0.0000	0	0.0000	0	0.0000
<i>P. cooperianus</i>	0	0.0000	1	0.0043	0	0.0000	1	0.0051
<i>A. ligamentina</i>	0	0.0000	1	0.0043	0	0.0000	0	0.0000
<i>L. recta</i>	0	0.0000	0	0.0000	0	0.0000	1	0.0051
<i>P. cyphyus</i>	0	0.0000	1	0.0043	0	0.0000	0	0.0000
Total species	16		20		12		13	
Total individuals	199		232		192		195	
Species diversity (H')	2.27		2.09		1.97		1.19	
Evenness (J)	0.62		0.67		0.79		0.45	

Table 4
Frequency of Occurrence for Freshwater Mussels Collected Using Qualitative Techniques at Each
of Four Sites in the Lower Ohio River, September 1990

Species	RM 957.8 350 ft RDB		RM 957.8 500 ft RDB		RM 963.6 200 ft RDB		RM 967.2 700 ft RDB	
	N	Abundance	N	Frequency	N	Frequency	N	Frequency
<i>F. ebena</i>	12	1.0000	12	1.0000	10	0.8333	12	1.0000
<i>Q. pustulosa</i>	11	0.9167	10	0.8333	4	0.3333	7	0.5833
<i>Q. quadrata</i>	7	0.5833	8	0.6667	11	0.9167	6	0.5000
<i>A. plicata</i>	11	0.9167	7	0.5833	9	0.7500	2	0.1667
<i>M. gigantea</i>	7	0.5833	8	0.6667	5	0.4167	1	0.0833
<i>E. lineolata</i>	5	0.4167	8	0.6667	0	0.0000	9	0.7500
<i>O. reflexa</i>	7	0.5833	8	0.6667	6	0.5000	2	0.1667
<i>Q. metanavra</i>	9	0.7500	9	0.7500	1	0.0833	5	0.4167
<i>O. olivaria</i>	1	0.0833	3	0.2500	8	0.6667	0	0.0000
<i>T. verrucosa</i>	5	0.4167	2	0.1667	4	0.3333	0	0.0000
<i>Q. nodulata</i>	4	0.3333	1	0.0833	7	0.5833	0	0.0000
<i>P. alatus</i>	4	0.3333	1	0.0833	4	0.3333	2	0.1667
<i>E. crassidens</i>	4	0.3333	0	0.0000	0	0.0000	3	0.2500
<i>P. cordatum</i>	1	0.0833	3	0.2500	0	0.0000	1	0.0833
<i>C. tuberculata</i>	2	0.1667	2	0.1667	0	0.0000	0	0.0000
<i>L. ventricosa</i>	0	0.0000	2	0.1667	0	0.0000	0	0.0000
<i>T. truncata</i>	0	0.0000	2	0.1667	1	0.0833	0	0.0000
<i>L. fragilis</i>	0	0.0000	2	0.1667	0	0.0000	0	0.0000
<i>L. complanata</i>	2	0.1667	0	0.0000	0	0.0000	0	0.0000
<i>P. cooperianus</i>	0	0.0000	1	0.0833	0	0.0000	1	0.0833
<i>A. ligamentina</i>	0	0.0000	1	0.0833	0	0.0000	0	0.0000
<i>L. recta</i>	0	0.0000	0	0.0000	0	0.0000	1	0.0833
<i>P. cyphus</i>	0	0.0000	1	0.0833	0	0.0000	0	0.0000
Total samples	12		12		12		12	

Table 5
Relative Species Abundance and Summary Statistics for Quantitative
Samples Collected in the Lower Ohio River, September 1990

Species	RM 966.5		RM 967.2	
	Q1-a	Q1-b	Q2-a	Q2-b
<i>F. ebena</i>	0.4821	0.05820	0.6282	0.6038
<i>C. fluminea</i>	0.3988	0.2295	0.2564	0.1981
<i>Q. pustulosa</i>	0.0119	0.0492	0.0385	0.0566
<i>E. lineolata</i>	0.0357	0.0574	0.0128	0.0189
<i>A. plicata</i>	0.0000	0.0082	0.0128	0.0377
<i>Q. metanevra</i>	0.0060	0.0410	0.0000	0.0000
<i>O. reflexa</i>	0.0179	0.0082	0.0128	0.0283
<i>T. truncata</i>	0.0060	0.0082	0.0000	0.0000
<i>Q. quadrula</i>	0.0119	0.0000	0.0128	0.0189
<i>F. flava</i>	0.0000	0.0000	0.0000	0.0000
<i>Q. nodulata</i>	0.0000	0.0000	0.0000	0.0000
<i>P. cordatum</i>	0.0060	0.0000	0.0128	0.0000
<i>P. alatus</i>	0.0000	0.0164	0.0128	0.0000
<i>E. crassidens</i>	0.0000	0.0000	0.0000	0.0094
<i>M. nervosa</i>	0.0000	0.0000	0.0000	0.0189
<i>P. cyphus</i>	0.0000	0.0000	0.0000	0.0000
<i>P. cooperianus</i>	0.0119	0.0000	0.0000	0.0000
<i>C. tuberculata</i>	0.0000	0.0000	0.0000	0.0000
<i>S. undulatus</i>	0.0000	0.0000	0.0000	0.0000
<i>L. teres</i>	0.0060	0.0000	0.0000	0.0000
<i>L. fragile</i>	0.0060	0.0000	0.0000	0.0000
<i>E. dilatata</i>	0.0000	0.0000	0.0000	0.0094
<i>A. ligamentina</i>	0.0000	0.0000	0.0000	0.0000
Total bivalves	168	122	78	106
Total species	12	9	9	10
Unionid density (No./sq m)	40.4	37.6	46.4	68.0
<i>C. fluminea</i> density (No./sq m)	26.8	11.2	16.0	16.8
Total samples	10	10	5	5

Table 6
Relative Abundance of Freshwater Mussels Collected in the Lower Cumberland River, 23 September 1990

Species	Site 8		Site 10, Upriver of Dike		Site 10, On Dike	
	No.	Abundance	No.	Abundance	No.	Abundance
<i>Q. quachula</i>	12	0.3871	5	0.6250	18	0.5143
<i>A. plicata</i>	1	0.0323	0	0.0000	7	0.2000
<i>F. ebena</i>	5	0.1613	0	0.0000	2	0.0571
<i>Q. pustulosa</i>	3	0.0968	1	0.1250	1	0.0286
<i>M. nervosa</i>	2	0.0645	1	0.1250	2	0.0571
<i>Q. nodulata</i>	1	0.0323	1	0.1250	2	0.0571
<i>F. flava</i>	1	0.0323	0	0.0000	2	0.0571
<i>Q. metanevra</i>	2	0.0645	0	0.0000	0	0.0000
<i>O. reflexa</i>	1	0.0323	0	0.0000	1	0.0286
<i>P. alatus</i>	1	0.0323	0	0.0000	0	0.0000
<i>L. fragilis</i>	1	0.0323	0	0.0000	0	0.0000
<i>E. crassidens</i>	1	0.0323	0	0.0000	0	0.0000
Total mussels	31		8		35	
Total species	12		4		8	

Appendix A

Freshwater Mussels of the Lower Ohio River

The following is a list of freshwater mussels (and *C. fluminea*) of the lower Ohio River collected in September 1990. Photographs of all species are provided on pages A2-A9. Species marked with an asterisk (*) were not collected alive using quantitative or qualitative methods. The orange-footed pimpleback (*Plethobasus cooperianus*) was photographed alive. Photographs were taken by Dr. Bill Pearson, Water Resources Laboratory, University of Louisville

<i>Actinonaias ligamentina</i>	<i>Obliquaria reflexa</i>
<i>Amblema p. plicata</i>	<i>Obovaria olivaria</i>
<i>Corbicula fluminea</i>	<i>Plethobasus cooperianus</i>
<i>Cyclonaias tuberculata</i>	<i>Plethobasus cyphus</i>
<i>Ellipsaria lineolata</i>	<i>Pleurobema cordatum</i>
<i>Elliptio crassidens</i>	<i>Potamilus alatus</i>
* <i>Elliptio dilatata</i>	* <i>Quadrula cylindrica cylindrica</i>
<i>Fusconaia ebena</i>	<i>Quadrula metanevra</i>
* <i>Fusconaia flava</i>	<i>Quadrula nodulata</i>
<i>Lampsilis ovata</i>	<i>Quadrula p. pustulosa</i>
* <i>Lampsilis teres</i>	<i>Quadrula quadrula</i>
<i>Lasmigona c. complanata</i>	<i>Tritogonia verrucosa</i>
<i>Leptodea fragilis</i>	<i>Truncilla truncata</i>
<i>Ligumia recta</i>	
<i>Megalonaias nervosa</i>	
(= <i>gigantea</i>)	

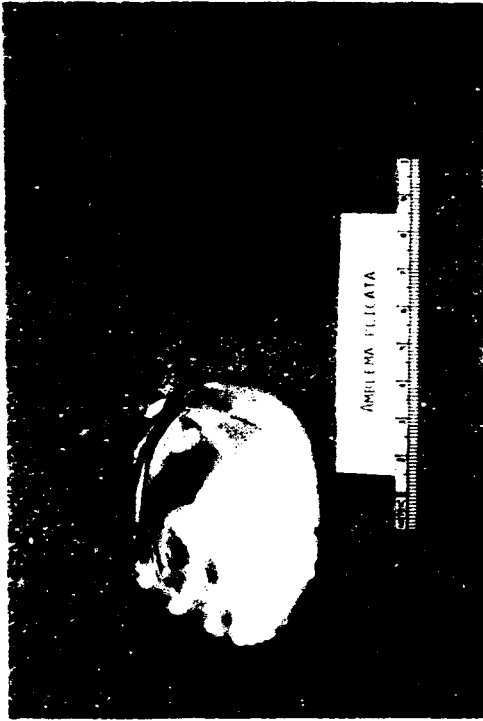


Figure A2



Figure A4

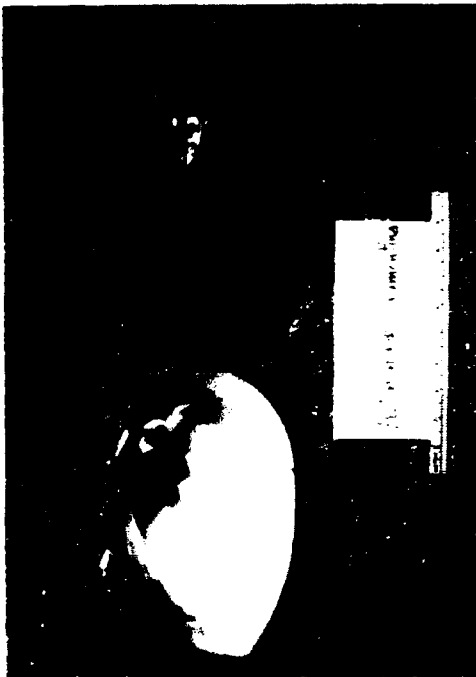


Figure A1



Figure A3



Figure A6



Figure A8

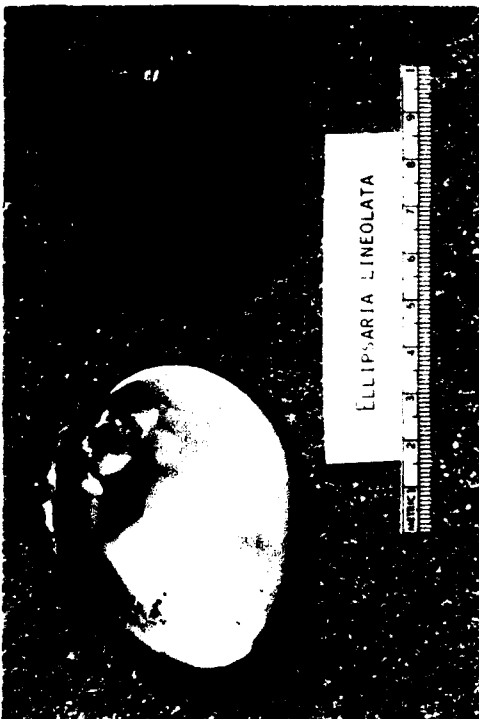


Figure A5

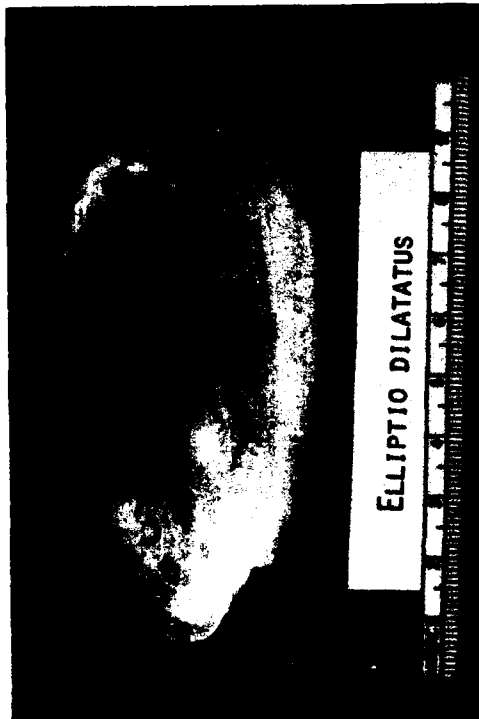


Figure A7



Figure A10



Figure A12

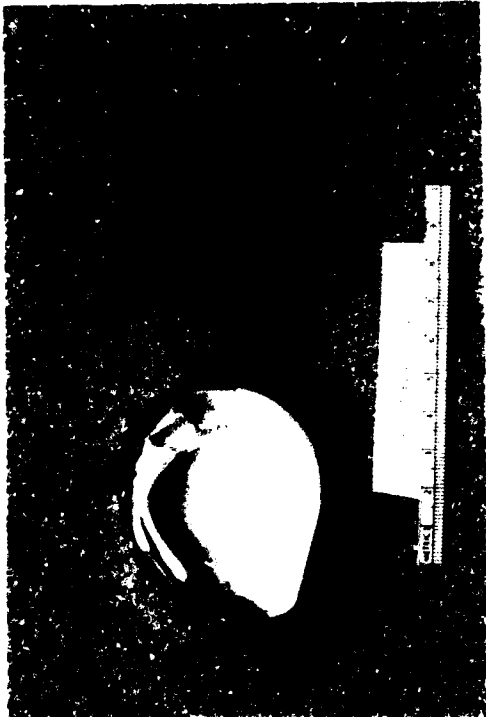


Figure A9

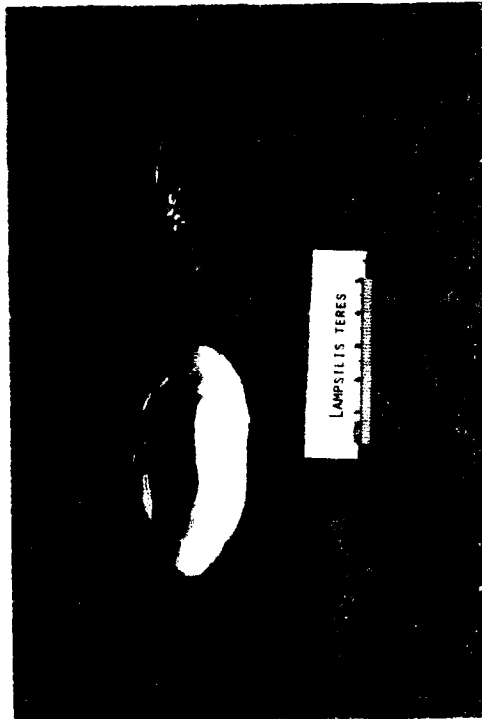


Figure A11



Figure A14

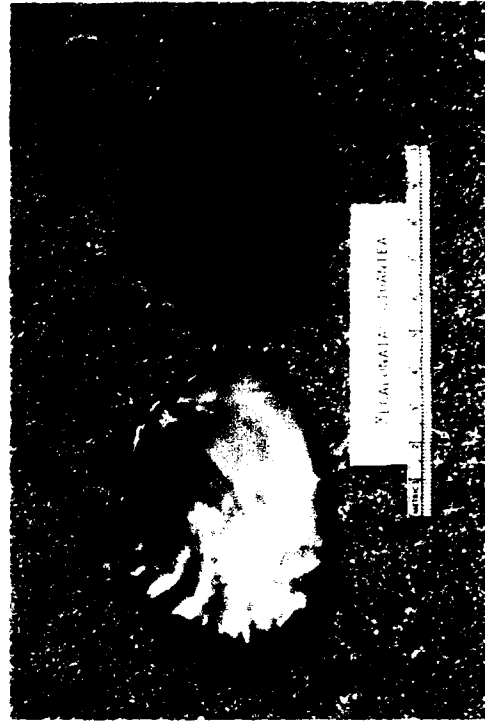


Figure A16

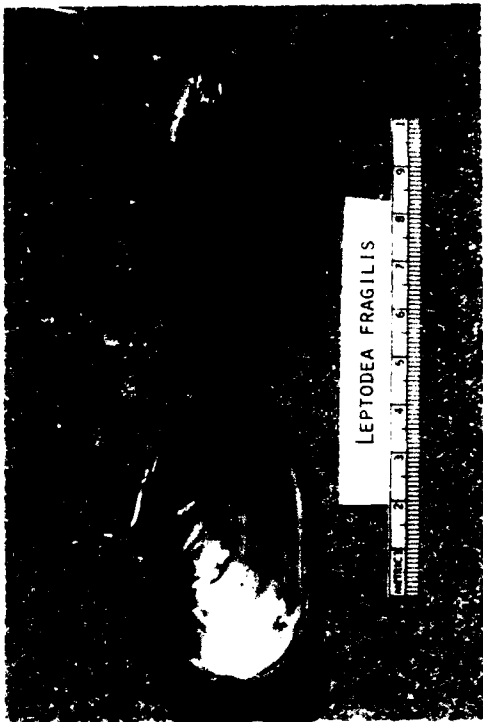


Figure A13

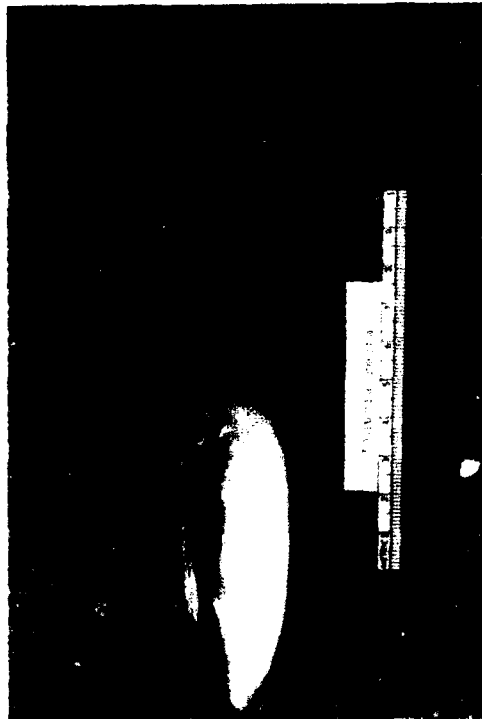


Figure A15

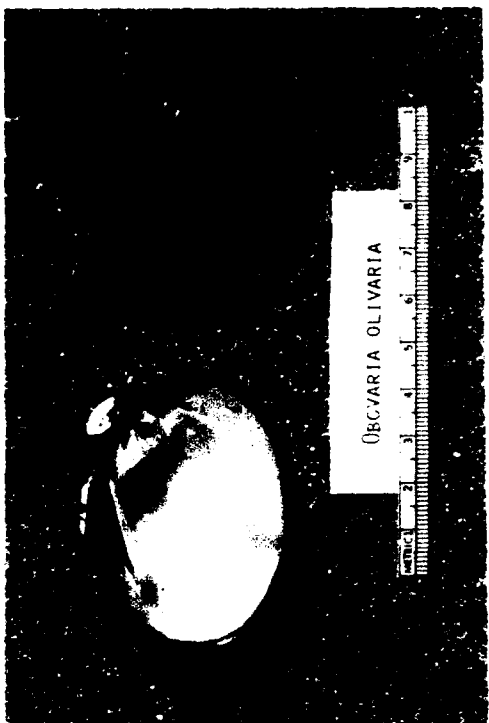


Figure A18

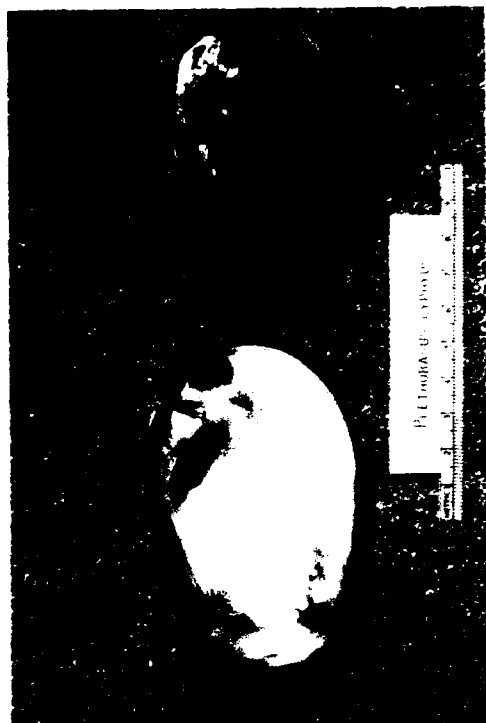


Figure A20

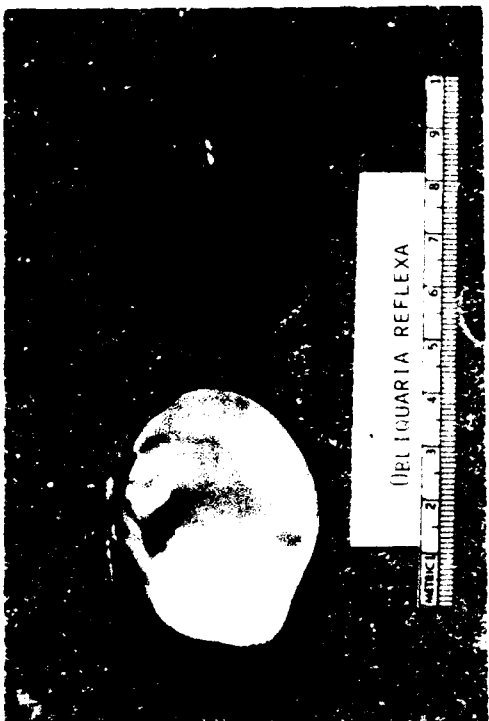


Figure A17

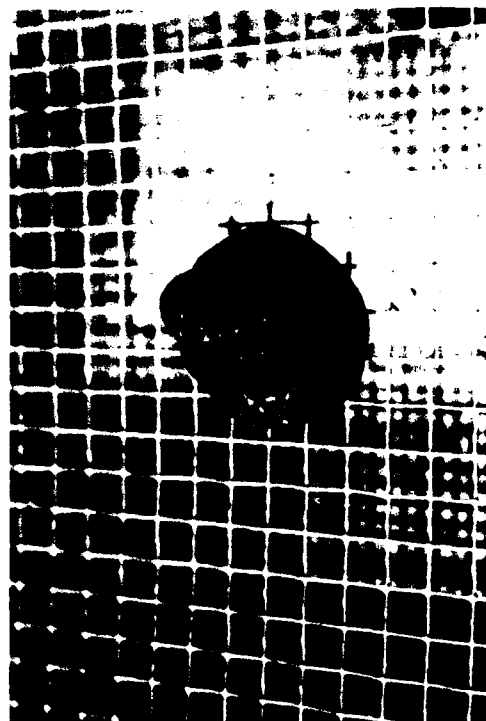


Figure A19



Figure A22

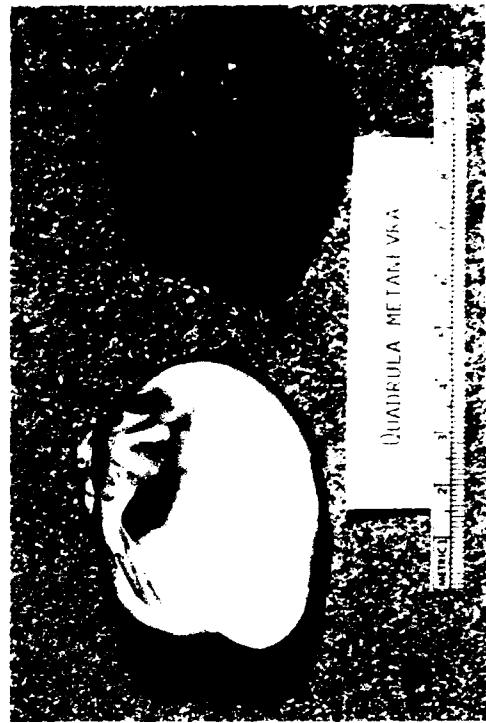


Figure A24



Figure A21

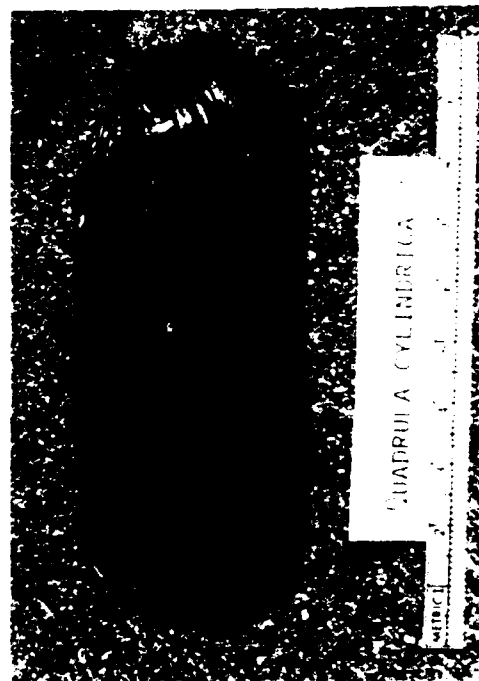


Figure A23

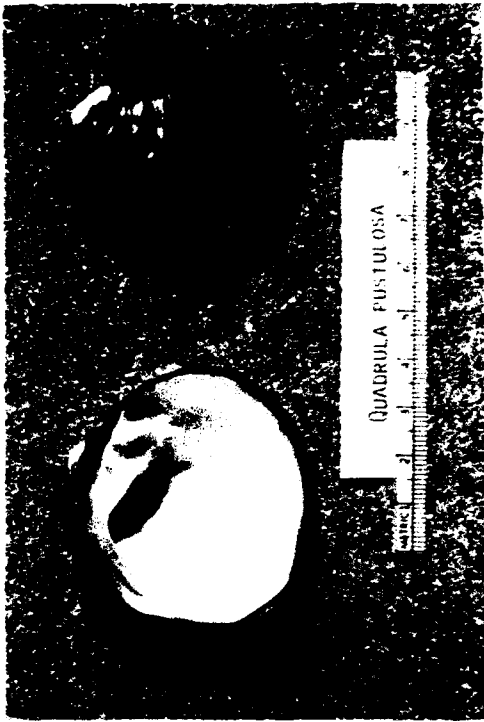


Figure A26



Figure A28

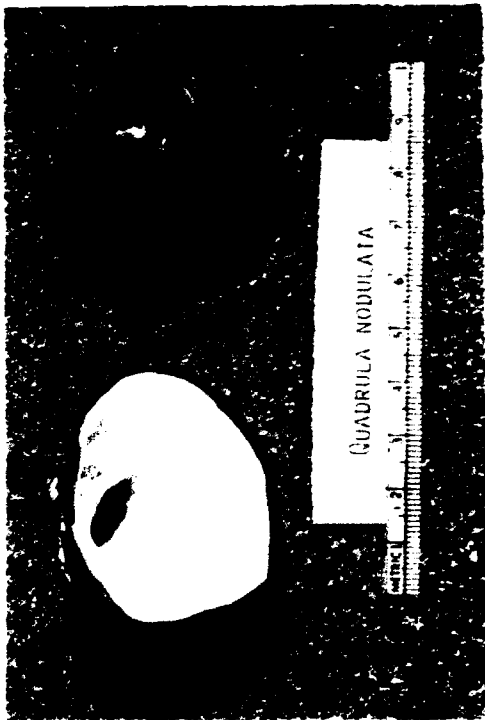


Figure A25

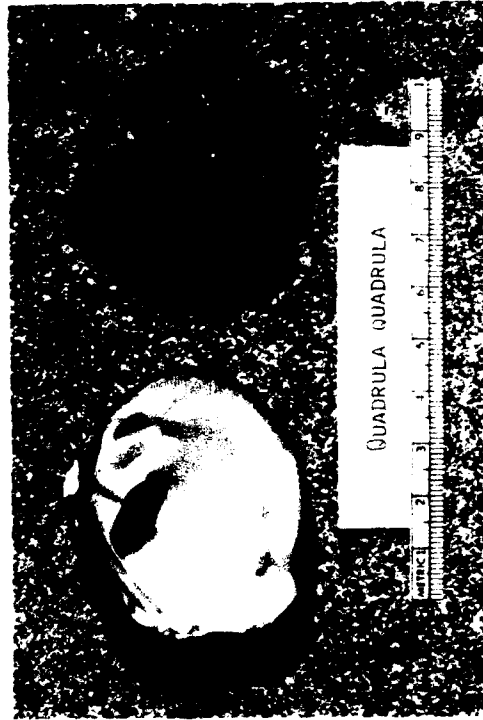


Figure A27

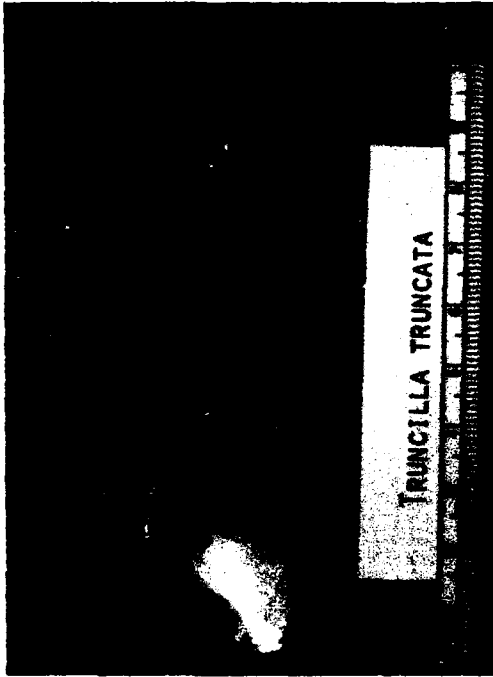


Figure A29