



**US Army Corps
of Engineers**
Waterways Experiment
Station

Spatial Distribution of Mussels at a Bed in the Lower Ohio River Near Olmsted, Illinois

by *Barry S. Payne, Andrew C. Miller*

STATION NUMBER
PROJECT NUMBER
REPORT NUMBER
DATE
AUTHOR
TITLE
ABSTRACT
KEYWORDS
DISTRIBUTION STATEMENTS
AVAILABILITY STATEMENTS
NOTES
REFERENCES
SYNOPSIS
CONCLUSIONS
RECOMMENDATIONS
REFERENCES
SYNOPSIS
CONCLUSIONS
RECOMMENDATIONS

Approved For Public Release; Distribution Is Unlimited

19970305 055

DTIC QUALITY INSPECTED 8

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.



PRINTED ON RECYCLED PAPER

Technical Report EL-97-3
January 1997

Spatial Distribution of Mussels at a Bed in the Lower Ohio River Near Olmsted, Illinois

by Barry S. Payne, Andrew C. Miller

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

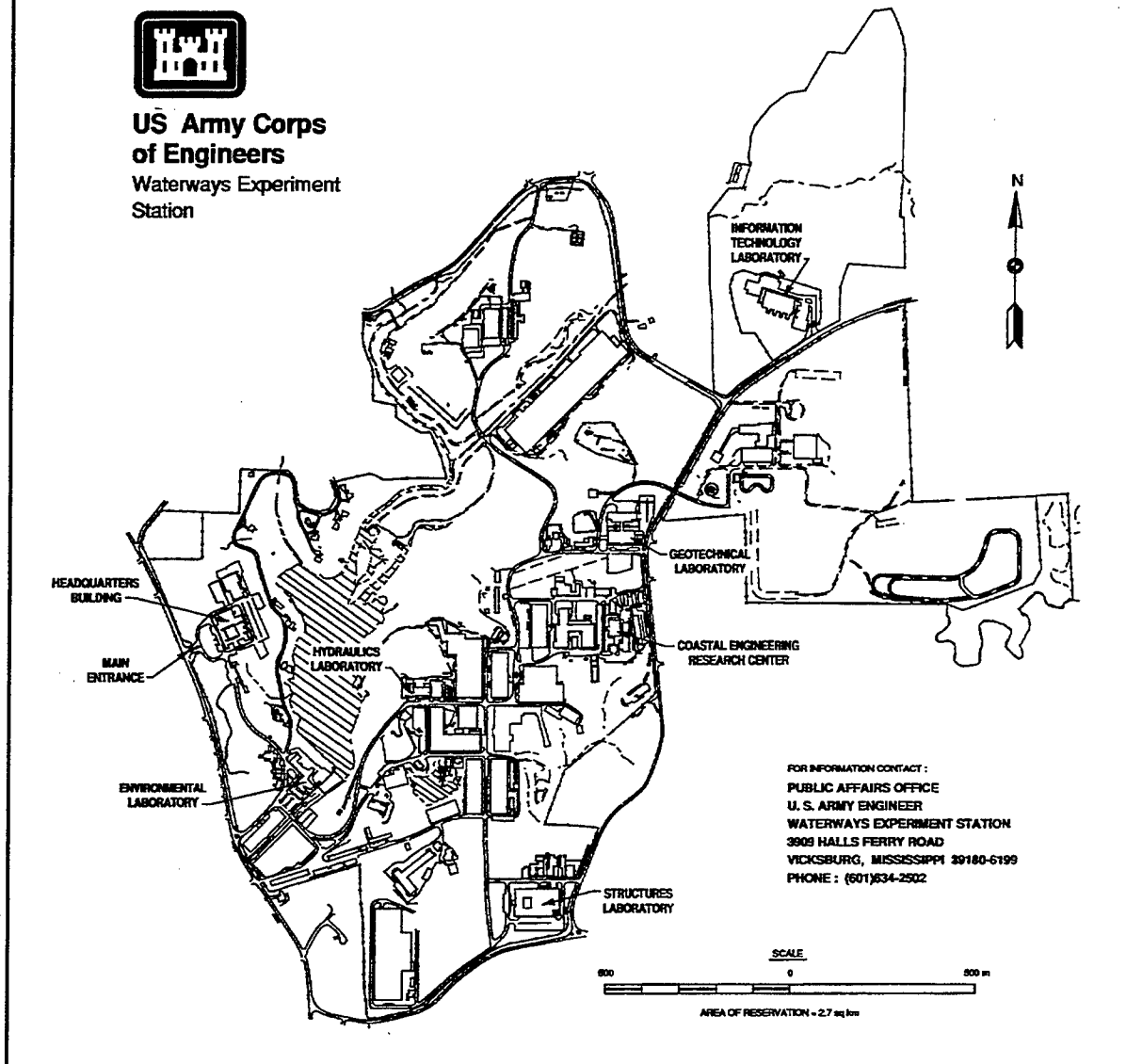
Approved for public release; distribution is unlimited

DTIC QUALITY INSPECTED 3

Prepared for U.S. Army Engineer District, Louisville
Louisville, KY 40201-0059



**US Army Corps
of Engineers**
Waterways Experiment
Station



FOR INFORMATION CONTACT :
PUBLIC AFFAIRS OFFICE
U. S. ARMY ENGINEER
WATERWAYS EXPERIMENT STATION
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199
PHONE : (601)634-2502

Waterways Experiment Station Cataloging-in-Publication Data

Payne, Barry S.

Spatial distribution of mussels at a bed in the lower Ohio River near Olmsted, Illinois / by Barry S. Payne, Andrew C. Miller ; prepared for U.S. Army Engineer District, Louisville.

61 p. : ill. ; 28 cm. — (Technical report ; EL-97-3)

Includes bibliographic references.

1. Zebra mussel — Ohio River. 2. *Corbicula fluminea* — Ohio River. 3. *Dreissena* — Ohio River. 4. Unionidae — Ohio River. I. Miller, Andrew C. II. United States. Army. Corps of Engineers. Louisville District. III. U.S. Army Engineer Waterways Experiment Station. IV. Environmental Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL-97-3. TA7 W34 no.EL-97-3

Contents

Preface	vii
Conversion Factors, Non-SI to SI Units of Measurement	viii
1—Introduction	1
Background	1
Purpose and Scope	2
2—Study Area and Methods	3
Study Area	3
Methods	3
3—Results	8
Dimensions of the Bed	8
Density Estimates	17
Community Composition	20
Demography of Abundant Populations	29
Substratum-Bivalve Relationships	34
Increasing Abundance of Zebra Mussels	36
4—Discussion	44
Spatial Characteristics of the Mussel Bed	44
Characteristics of the Mussel Community	45
Nonindigenous Species	46
Future Considerations	47
References	49
SF 298	

List of Figures

Figure 1. Map of 1993 sampling sites	5
Figure 2. Daily record of river stage, water year 1993, Cairo gauge	6
Figure 3. Daily record of river stage, water year 1994, Cairo gauge	7

Figure 4.	Upper section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples	8
Figure 5.	Upper middle section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples	9
Figure 6.	Lower middle section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples	10
Figure 7.	Lower section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples	11
Figure 8.	Shell length frequency histogram, <i>Fusconaia ebena</i> , 1993 and 1994	30
Figure 9.	Shell length frequency histogram, <i>Quadrula p. pustulosa</i> , 1993 and 1994	32
Figure 10.	Shell length frequency histogram, <i>Dreissena polymorpha</i> , 1993	33
Figure 11.	Shell length frequency histogram, <i>Dreissena polymorpha</i> from representative sites of low-population density, 1994	34
Figure 12.	Shell length frequency histogram, <i>Dreissena polymorpha</i> from representative sites of high-population density, 1994	35
Figure 13.	Mean length of young <i>Dreissena polymorpha</i> in relation to population density at sites quantitatively sampled in 1994	36
Figure 14.	Shell length frequency histograms indicating complex age structure of <i>Corbicula fluminea</i> assemblages at Sites 1, 5, and 6, 1993	37
Figure 15.	Shell length frequency histograms indicating complex age structure of <i>Corbicula fluminea</i> assemblages at Sites 7, 8, and 9, 1993	38
Figure 16.	Shell length frequency histograms indicating simple age structure of <i>Corbicula fluminea</i> assemblages at Sites 2, 3, and 4, 1993	39
Figure 17.	Shell length frequency histograms indicating simple age structure of <i>Corbicula fluminea</i> assemblages at Sites 10 and 11, 1993	40
Figure 18.	Sediment particle-size distribution, Sites 1-6, 1993	41
Figure 19.	Sediment particle-size distribution, Sites 7-11, 1993	42

List of Tables

Table 1.	Location and Number of Qualitative and Quantitative Samples Collected in Lower Ohio River, 8-10 September 1993	4
Table 2.	Summary of Data Gathered Along Transects Used to Map Mussel Bed in Lower Ohio River, 30 August - 2 September 1994	12
Table 3.	Summary of Native Mussel Density at Sites Sampled by Removing Substratum With Mussels From 0.25-m ² Quadrats, Lower Ohio River, 30 August - 2 September 1994	17
Table 4.	Summary of <i>Corbicula fluminea</i> Density at Sites Sampled by Removing Substratum With Mussels From 0.25-m ² Quadrats, Lower Ohio River, 30 August - 2 September 1994	18
Table 5.	Summary of Density Estimates of <i>Dreissena ploymorpha</i> Based on Core Samples Taken at Each Site During 1994 Transect-Based Mapping of Mussel Bed in Lower Ohio River	19
Table 6.	Summary Statistics for Quantitative Samples Collected in Lower Ohio River Near Olmsted, IL, September 1993	21
Table 7.	Percent Species Abundance at Four Sites in a Mussel Bed Near Olmsted, IL, August - September 1994	22
Table 8.	Percent Species Occurrence at Four Sites in a Mussel Bed Near Olmsted, IL, August - September 1994	23
Table 9.	Percent Abundance of Freshwater Mussels Collected at Lower Ohio River Near Olmsted, IL, September 1993, Using Quantitative Methods	24
Table 10.	Percent Occurrence of Freshwater Mussels Collected at Lower Ohio River Near Olmsted, IL, September 1993, Using Quantitative Methods	26
Table 11.	Percent Abundance Data on Freshwater Mussels Collected Using Semiquantitative Methods Along 13 Transects in Lower Ohio River, 1994	27
Table 12.	Percent Abundance and Percent Occurrence for Mussels Collected Using Qualitative Methods at Olmsted Bed in Lower Ohio River, September 1993	28
Table 13.	Species of Native Mussels Collected at Olmsted Mussel Bed, River Miles 966.2 to 969.3, 1983 to 1994	31

Table 14. Summary of Low River Stages, Lower Ohio River, Cairo
Gauge, 1975-1994 44

Preface

The study herein was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) in 1993 and 1994 for the U.S. Army Engineer District, Louisville, Louisville, KY. The purpose was to map the distribution of native and nonindigenous mussels in a prominent mussel bed in the lower Ohio River near Olmsted, IL, with special emphasis on delineating the boundaries of the native mussel bed. Data on density, size demography of dominant populations, species diversity, and community composition will be used to analyze the environmental effects of construction and operation of Olmsted Locks and Dam Project.

Divers for this study were Messrs. Larry Neill, Robert Warden, Robert James, Jeff Montgomery, and Johnny Buchanan from the Tennessee Valley Authority. Assistance in the field was provided by Messrs. David Armisted and David Morrow, Millsaps College. Mr. Van Shippley (1993) and Dr. Andrew Miller (1994) were diving inspectors for this work. Assistance in the laboratory was provided by Mr. Armisted, Mr. Morrow, Ms. Geralline Wilkerson, Hinds Community College, Ms. Monica Sanders, Jackson State University, and Ms. Fawn Burns, Rice University.

During the conduct of this study, Dr. John W. Keeley was Director, EL; Dr. Conrad J. Kirby was Chief, Ecological Resources Division (ERD), EL; and Dr. Alfred F. Cofrancesco was Chief, Aquatic Ecology Branch (AEB), ERD. Authors of this report were Drs. Barry S. Payne and Andrew C. Miller, AEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

Payne, B. S., and Miller, A. C. (1997). "Spatial distribution of mussels at a bed in the lower Ohio River near Olmsted, Illinois," Technical Report EL-97-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

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 (U.S. nautical)	1.852	kilometers
square miles	2.589998	square kilometers

1 Introduction

Background

The U.S. Army Engineer District, Louisville, is replacing Locks and Dams 52 and 53 on the lower Ohio River with a replacement structure located slightly downstream of existing Lock and Dam 53 (U.S. Army Corps of Engineers 1991). The replacement structure will consist of two 110- by 1,200-ft¹ locks, a 2,200-ft-wide navigable pass controlled by remotely operated hydraulic wickets, and a short section of fixed weir connecting the project to the Kentucky shore. During periods of normal and low flow, vessels will use the new locks to be located on the right descending bank (RDB) on the Illinois side of the river. During high flow, vessels will use the navigable pass located near the center of the channel. The new project, which is under construction, is at River Mile (RM) 964.4; Locks and Dams 52 and 53 are at RMs 938.9 and 962.8, respectively.

When completed, the Olmsted project will increase water levels by a maximum of 10 ft in the reach above the dam for approximately 42 percent of the year. This increased stage height will occur only during normal and low flow. During periods of high water (58 percent of the year), dam sections will be lowered to a horizontal position on the river bottom, and water levels will be similar to those during preproject conditions. In addition, the hydraulic regimen immediately downriver of the project will be altered, and existing commercial traffic patterns will be affected. Commercial vessels will have to pass close to the RDB when entering or exiting the lock. During high water, commercial vessels will operate in the thalweg as they have always done.

Potential alteration of the hydraulic regimen and commercial navigation traffic patterns immediately downriver of the Olmsted project are of special interest with respect to a dense and diverse bed of mussels that begins at approximately RM 966 and extends several miles downstream. In addition to the economic, ecological, and cultural value of this mussel bed, the endangered species *Plethobasus cooperianus* (U.S. Fish and Wildlife Service 1991) occurs at this location. Results of previous surveys and studies of this

¹ A table of factors for converting non-SI units of measurement to SI units is presented on page viii.

historically prominent mussel bed are included in publications by Williams (1969), Williams and Schuster (1982), Taylor (1989), Neff, Pearson, and Holdren (1981), Miller, Payne, and Siemsen (1986), Miller and Payne (1988), Payne and Miller (1989), Miller and Payne (1991), and Payne, Miller, and Shafer (1994).

Freshwater mussels can be affected by changes in water level, sedimentation and sediment erosion, sediment resuspension caused by dredging and disposal of dredged material, and movement of navigation vessels. Their sedentary lifestyle and reliance on suspended particulate organic material for food makes them particularly susceptible to fluctuating water levels, sediment scour, elevated suspended sediment, and turbulence. Biological consequences of these disturbances can be measured on organisms held in the laboratory (Holland 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller, and Conley 1987; Payne and Miller 1987; Payne, Miller, and Aldridge 1987; Payne, Killgore, and Miller 1990). However, caution must be taken when laboratory studies are used as the basis of predictions about natural populations (Payne and Miller 1987). Physiological responses that can be elicited in stylized laboratory studies often cannot be observed under more complex natural conditions.

Although laboratory studies are useful for identifying potential adverse effects and their probable causes, field studies are required to verify that physical disturbances that affect individuals in the laboratory result in measurable effects on naturally occurring individuals and populations. Planners and biologists evaluating ecological consequences of such physical disturbances should rely on field evaluations of natural populations. Field studies can be designed to evaluate physical effects of water resource development on individual growth and condition, population density, recruitment, and mortality, and community composition, including species richness, relative abundance, and diversity. These parameters provide the most useful measures of overall health and survival of a mussel community. A predetermined set of criteria can be evaluated annually to determine if man-made disturbances are negatively affecting native mussels.

Purpose and Scope

The objective of the present study is to delineate the boundaries and spatial distribution of density of mussels in the bed downstream of the Olmsted project. Additional objectives are to characterize patterns of mussel recruitment, community structure, and density of nonindigenous bivalves. These quantitative data can be used to assess environmental effects of alterations of hydraulic regimen, commercial navigation traffic patterns, and benthic scour and deposition associated with construction and operation of the Olmsted project. It is anticipated that studies will continue until the project has operated for at least several years.

2 Study Area and Methods

Study Area

The Ohio River originates in Pittsburgh, PA, at the confluence of the Allegheny and Monongahela rivers. It flows 981 miles to the northwest and then the southwest before joining the Mississippi River near Cairo, IL. The Ohio River drains 203,900 square miles and falls 450 ft from Pittsburgh to Cairo.

Studies were conducted from approximately RM 966 to RM 970 in the lower Ohio River (i.e., at the location of a historically prominent mussel bed along the RDB per previous reports by Williams (1969) and Williams and Schuster (1982)). Sampling in 1993 and 1994 was designed to describe spatial variation and identify boundaries of the bed, contribute to long-term monitoring of population and community demography, and provide information on the status of two nonindigenous species, the Asian clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena polymorpha*.

Methods

Methods of sampling were a modification of those described in Payne, Miller, and Shafer (1994) and references within. Mussel identification was based on taxonomic keys and descriptive information in Murray and Leonard (1962), Parmalee (1967), Starrett (1971), and Burch (1975). Taxonomy is consistent with Williams et al. (1993).

1993 survey

Samples were collected by a five-person dive crew from the Tennessee Valley Authority equipped with surface-supplied air and communications equipment. Divers collected both semiquantitative (search by feel) and quantitative (total substratum removal) at 11 sites in the mussel bed (Table 1; Figure 1). At all but one site, semiquantitative sampling consisted of divers searching either 1.00- or 0.25-m² aluminum quadrats ($n = 4$ at all sites) and collecting all native mussels encountered by touch. At one site (Site 3), such

Table 1
Location and Number of Qualitative and Quantitative Samples Collected in Lower Ohio River, 8-10 September 1993

Site	River Mile	Elevation, ft	Qualitative Samples		Number of 0.25-m ² Quantitative Samples
			Number	m ² per Quadrat	
1	966.1	261	4	1.0	4
2	966.1	267	4	1.0	4
3	966.8	261	4	1.0 ¹	6
4	967.3	272	4	1.0	4
5	968.3	276	4	1.0	4
6	968.8	270	4	0.25	4
7	968.8	275	4	0.25	4
8	969.3	272	4	0.25	4
9	966.9	272	4	0.25	4
10	967.5	272	4	0.25	4
11	966.9	272	4	0.25	4

¹ Semiquantitatively sampled per discussion in text.

an exceptionally high density of juvenile unionids was encountered that divers shoved substratum (mostly mussels) into a pile in the center of the quadrat, allowing more rapid collection of the juveniles.

Quantitative sampling included native unionids, *Corbicula fluminea*, and *Dreissena polymorpha* and was done by removing all substratum within 0.25-m² aluminum quadrats, sending the material in buckets to the surface, and sieving the substratum with bivalves through a series of wire screens. The finest screen had an aperture of 6.4 mm. All live bivalves were removed and placed in 4-ℓ zipper-lock bags. Each bivalve was subsequently identified and total shell length (SL) measured to the nearest 0.1 mm with calipers. Four 0.25-m² samples were collected at all sites except Site 3, where a total of six such samples were obtained.

High river stage during 1993 sampling required samples to be taken in moderately deep water. The mean depth of sites was 35.2 ft, ranging from 44 ft at Sites 1 and 3 to 30 ft at Site 8. River stage (Cairo Gauge) was 34.5, 34.1, and 34.0 ft on 8, 9, and 10 September, respectively (Figure 2). Recognition of the mussel bed was more difficult than usual because of the moderately high river stages. Sites were located with respect to buoys marking permanent monitoring stations at known river miles (see Figure 1), and sampling was conducted at depths corresponding to elevations that supported

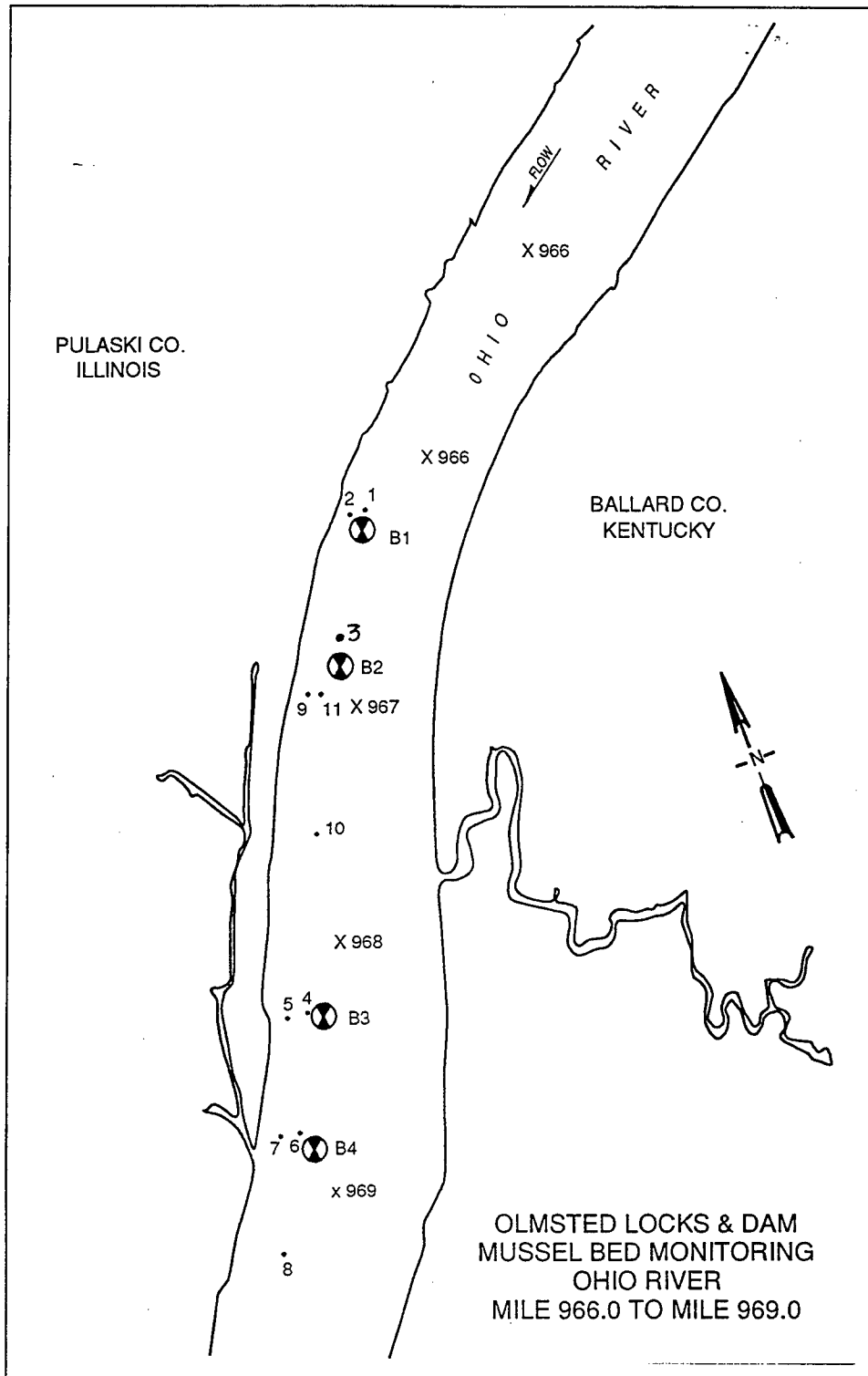


Figure 1. Map of 1993 sampling sites

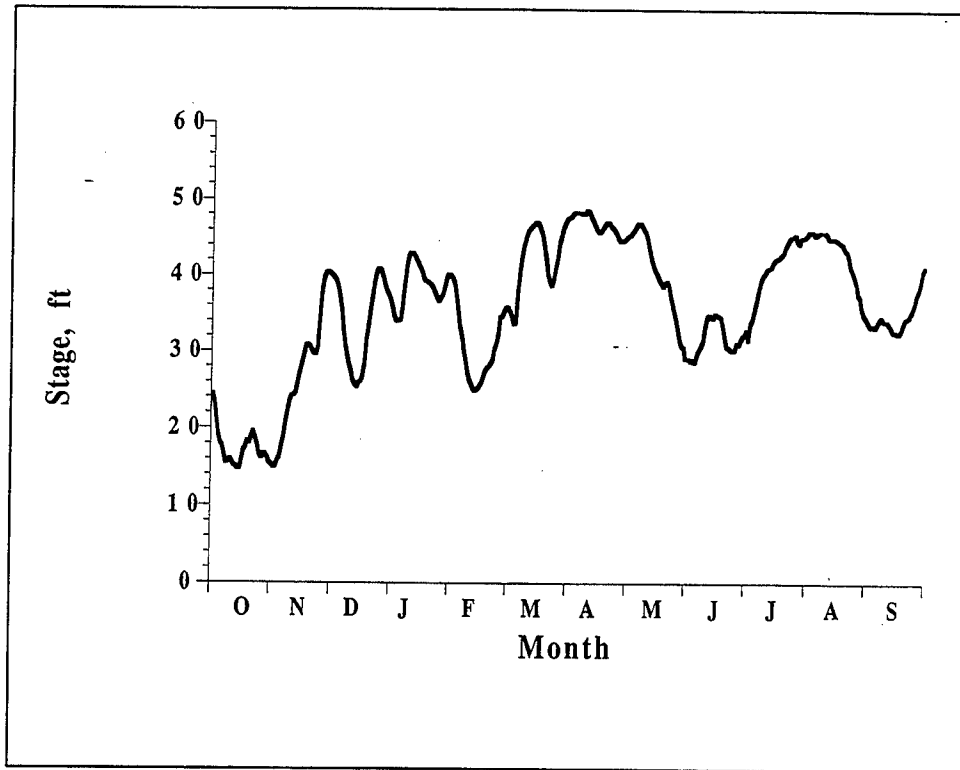


Figure 2. Daily record of river stage, water year 1993, Cairo gauge

moderately high densities of mussels in previous years. Exceptions were Sites 1 and 3, which were at elevations slightly lower than the typical elevations previously sampled.

1994 survey

Lower river stage made sampling more straightforward in 1994, as stage (Cairo Gauge) ranged from 18.3 to 18.7 ft during the August 30 to September 2 survey (Figure 3). Samples were collected by a five-person dive crew from the Tennessee Valley Authority. Divers were equipped with surface-supplied air and communications equipment, the latter allowing verbal description of substratum, native mussel density, and nonindigenous mussel density along 13 transects running perpendicular to shore. At each transect, samples were collected at four or more sites, separated by approximately 65 m (200 ft). At Transect 8, information was collected at six sites. Sites were numbered from 1 to 4 (or more for some transects) with Site 1 being that closest to shore and the highest numbered site being farthest from shore. The location of each site was identified with a Global Positioning System.

At each site on the transect, the divers relayed to the surface a description of substratum type as well as the presence and approximate density of unionids, zebra mussels, and Asian clams. Such information was provided by two divers, one working his way from the anchored dive boat toward shore

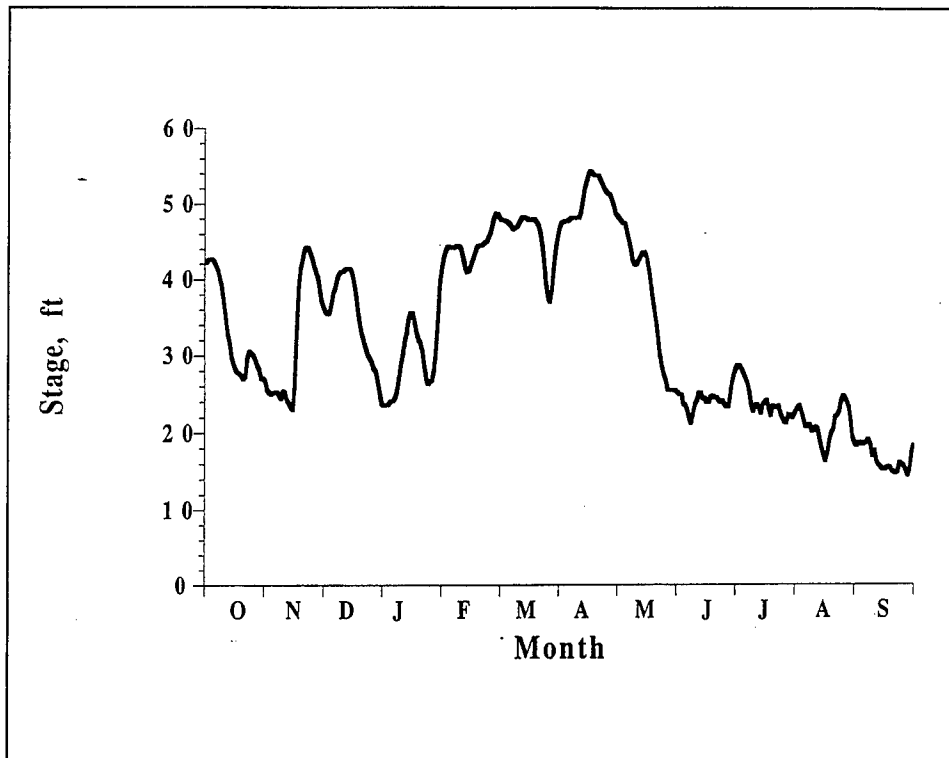


Figure 3. Daily record of river stage, water year 1994, Cairo gauge

and the other working away from shore. Each diver moved from the boat as far as allowed by water currents and their 150-ft umbilicals. A series of numerical codes were used to designate substratum conditions and density estimates. In addition, divers searched 0.25-m² aluminum quadrats when they reached their farthest distance from the boat. All native unionids encountered by touch were collected. Thus, these were semiquantitative, not quantitative, samples of unionid density. Native mussels were placed in nylon mesh bags, brought to the surface, identified, and total SL measured.

Divers collected ten 0.25-m² total substratum samples at each of four locations on the bed. These sites were located between Transects 4 and 7 at elevations ranging from 270.5 to 276.2 ft. As will be explained later, elevation is important in relation to the map of the mussel bed. These quantitative samples were used to provide accurate estimates of the size/age structure of the mussel community as well as more precise information on mussel density and community composition.

In addition, divers collected two core samples of substratum adjacent to the 0.25-m² quadrats searched by feel at each site. These samples were preserved in neutral formalin and returned to the laboratory for measurement of density and size demography of zebra mussels. Results of these samples provide a more accurate estimate of *D. polymorpha* densities than accounts made by divers. Accurate density estimates of *D. polymorpha* are not included on the mussel bed map, but are used in other analyses.

3 Results

Dimensions of the Bed

The transect surveys of 1994 allowed a relatively specific map of the mussel bed (Figures 4-7). The large circles surrounding 1994 mapping sites in Figures 4-7 define the sampling radius of divers. A contiguous area of high

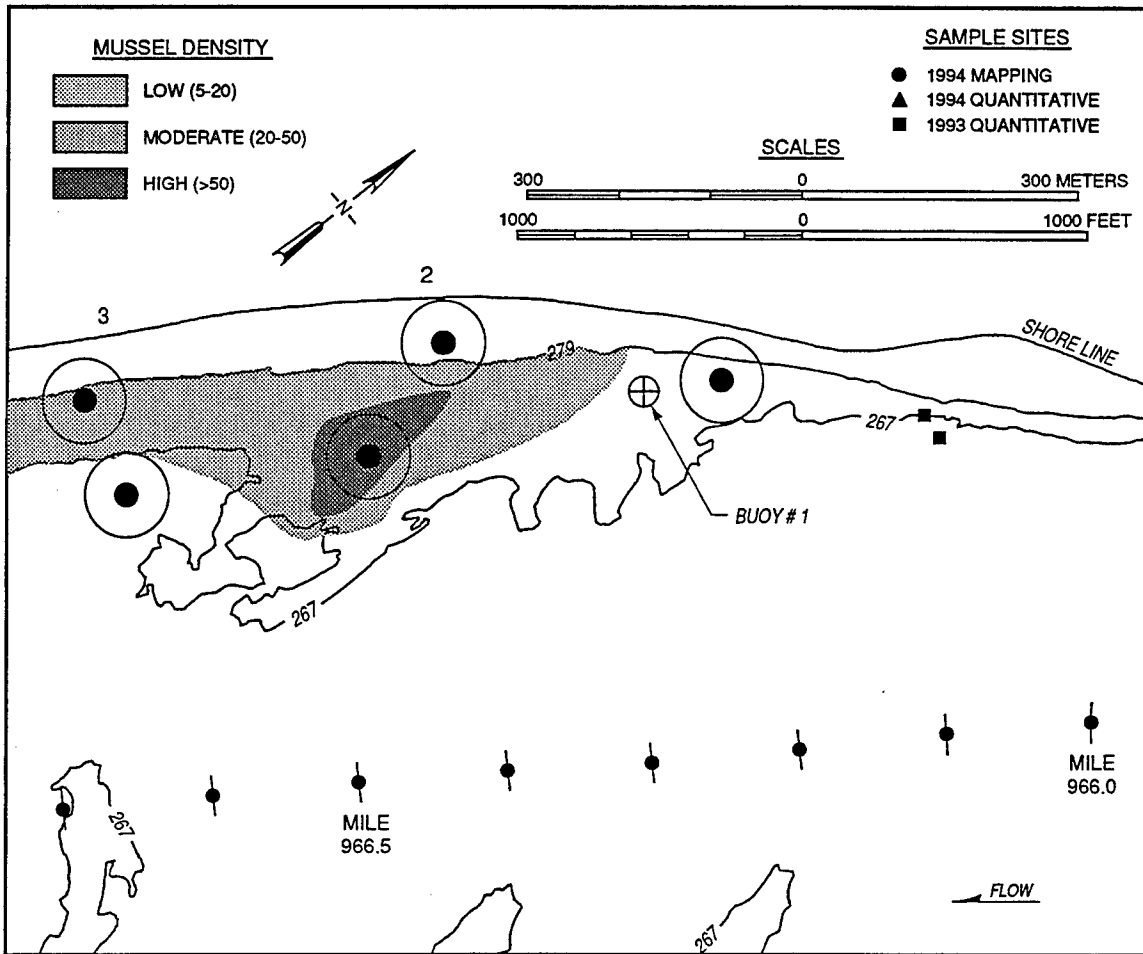


Figure 4. Upper section of mussel bed showing density estimates based on 1994 semi-quantitative samples and sites of 1993 and 1994 quantitative samples

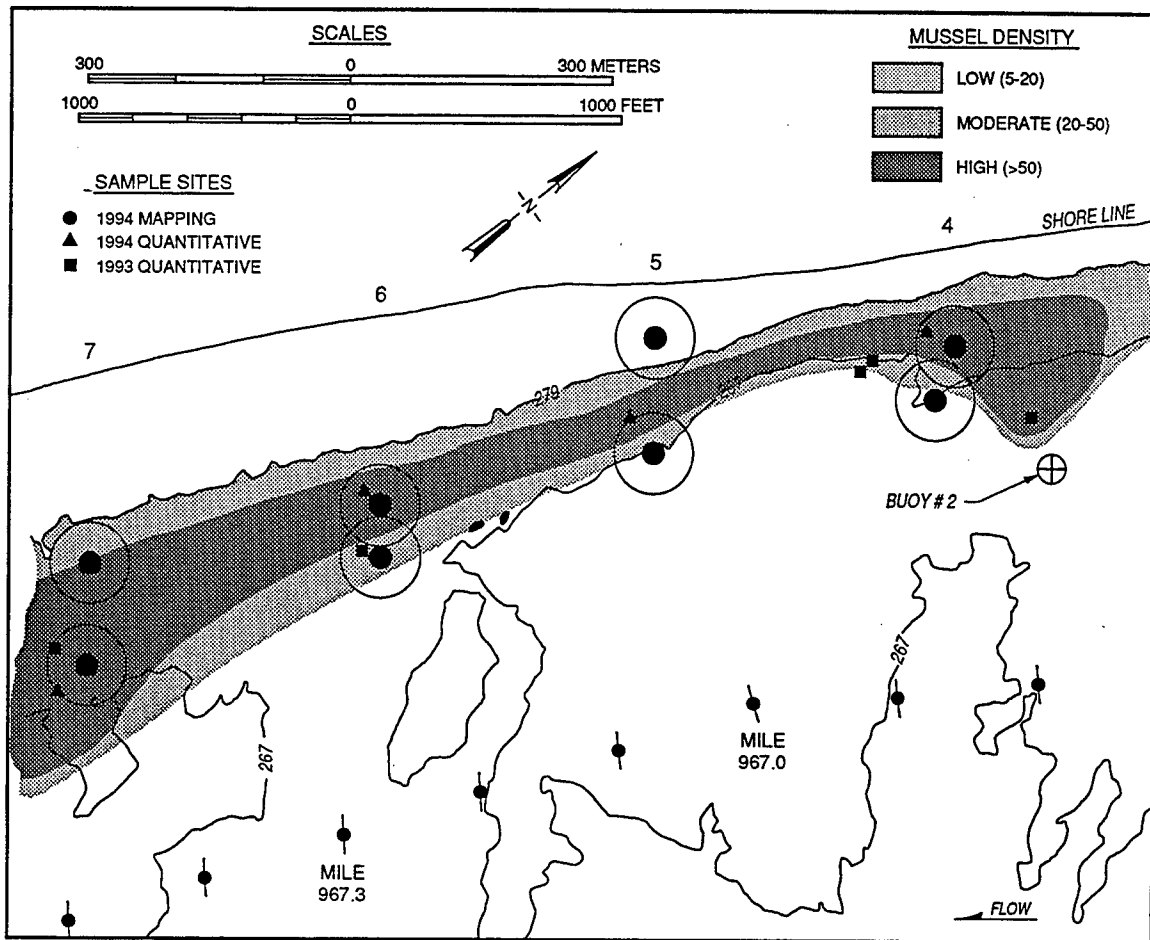


Figure 5. Upper middle section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples

mussel density (> 50 individuals per square meter) characterizes the mussel bed from RMs 966.8 to 967.9. This area of high mussel density is approximately 750 to 1,000 ft wide near the center of the bed (RMs 967.4 to 967.9), but tapers to <250 ft wide from RMs 967.1 to 966.8. A moderate density of mussels (20 to 50 individuals per square meter) characterizes the bed upstream of RM 966.8, although a patch of high density occurs near where the bed bulges in width to approximately 750 ft near RM 966.5. Nearshore and farshore limits are distinct along the upstream half of the bed and correspond approximately to the 279- and 267-ft elevation contours. These boundaries also apply, although less distinctly, to the center and downstream portions of the bed. The breadth and topographic irregularities of the shoal in the central portion and the low density of mussels in the downstream portion of the bed make the farshore boundary especially difficult to discern in those reaches. The RDB is relatively steeply sloped in the upstream portion, and the mussel bed is narrower and clearly defined in this reach.

Results obtained along the 13 transects sampled in 1994 are summarized in Table 2. The upstream limit of the mussel bed was identified on a steeply

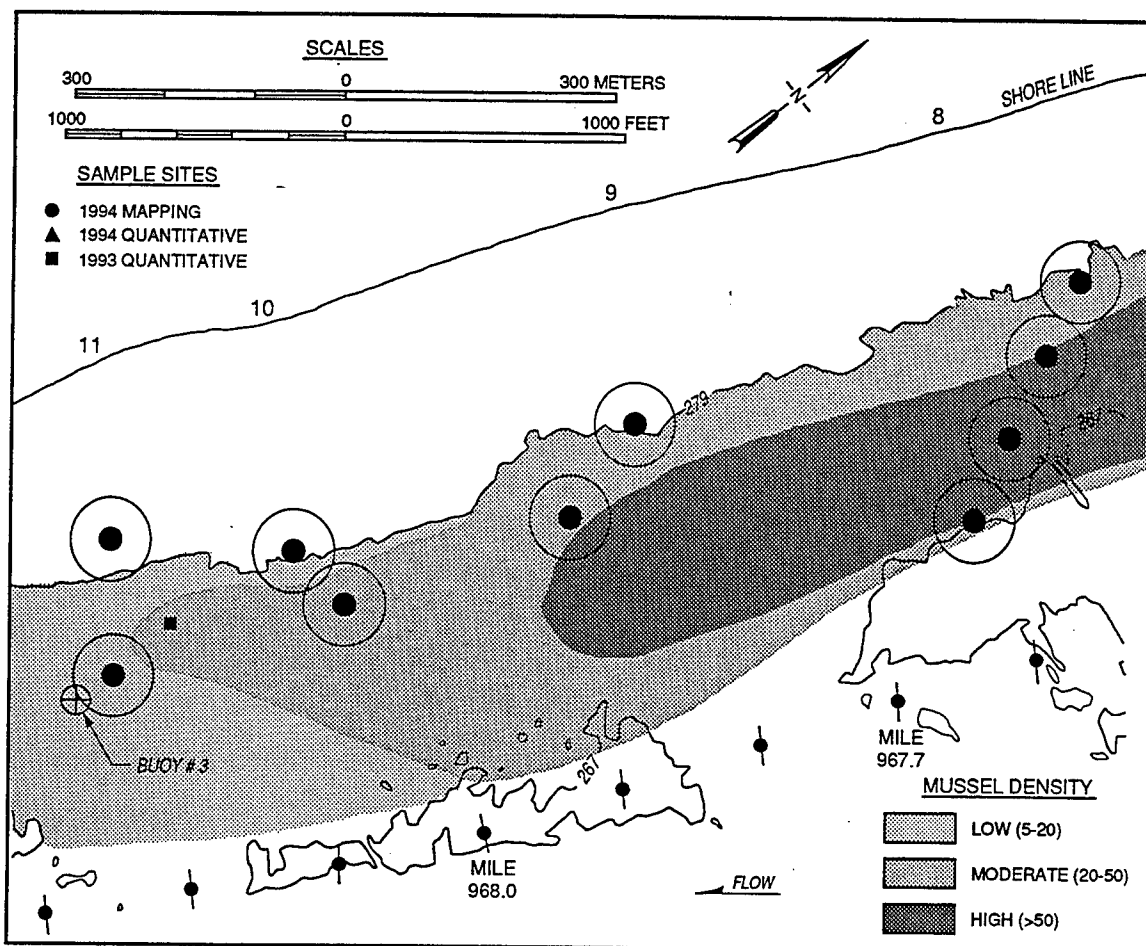


Figure 6. Lower middle section of mussel bed showing density estimates based on 1994 semiquantitative samples and sites of 1993 and 1994 quantitative samples

sloping portion of the RDB, between Transects 1 and 2 at RM 966.2 and RM 966.4, respectively. Unionid density averaged 0 and 4 individuals per square meter at Sites 1 and 2 along Transect 1. Although these sites were only 150 ft apart, elevation ranged from 278 to 268 ft. Substratum was coarser nearshore than farshore. Divers reported a 2- to 3-in. silt layer over the gravel and cobble nearshore. At the farshore end of the transect, substratum was heavily silted sand with gravel and cobble. River stage rapidly declined from 55 ft in mid April to 25 ft in late May, and remained low and gradually declined to less than 20 ft in June through September (Figure 3). This sequence of stage conditions may have enhanced siltation just prior to the late August-early September survey.

Transect 2 was also along a steeply sloping portion of the RDB, where substratum was finer with increasing farshore distance. Along Transect 2, the most upstream transect within the bed, unionid density equaled 32, 56, and 48 individuals per square meter at Sites 1-3, which ranged in elevation from 278 to 268 ft. All unionids were heavily infested by zebra mussels. Substratum was described as silt and cobble at Site 1, silt and sand over gravel

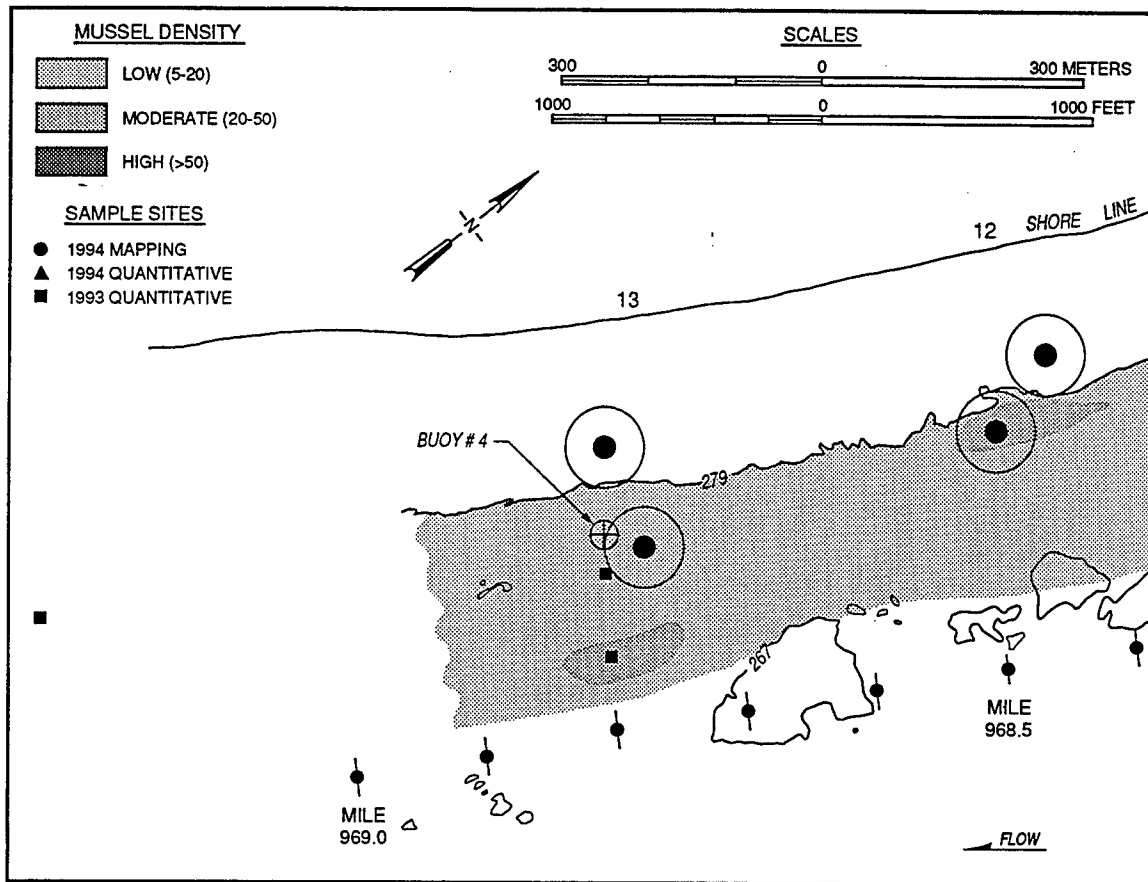


Figure 7. Lower section of mussel bed showing density estimates based on 1994 semi-quantitative samples and sites of 1993 and 1994 quantitative samples

at Site 2, grading into coarse sand at Site 4. Site 4, at an elevation of 265 ft, was beyond the farshore limit of the bed. Mussels declined rather abruptly in density once diver depth exceeded 22 ft (corresponding to an elevation of approximately 267 ft). At Site 4, mussel density was only four individuals per square meter.

Along Transect 3, sediments were finer grained, and depth increased steadily from nearshore to farshore. Site 1 (278-ft elevation) and Site 2 (269-ft elevation) consisted of very fine sand with some silt and gravel; unionid density equaled 44 and 28 individuals per square meter at these two sites. Site 3 (272-ft elevation) had a 1-in. layer of silt over sand and gravel and supported 40 unionids per square meter. Zebra mussels were extremely dense along the entire transect until the divers moved into coarse sand between Site 3 (272-ft elevation) at Site 4 (264-ft elevation); no zebra mussels occurred in the coarse sand at Site 4.

Sites along Transect 4 ranged in elevation from 274 to 263 ft, and depth steadily increased from nearshore to farshore. Substratum was silted sandy gravel. Divers clearly moved off the mussel bed between Site 2 (270-ft elevation) and Site 3 (266-ft elevation). Unionid density equaled 16, 72, 4,

Table 2
Summary of Data Gathered Along Transects Used To Map Mussel Bed in Lower Ohio River, 30 August - 2 September 1994

Transect and Site	Substratum Type	Elevation, ft	Density (Individuals per m ²)					Semi-quantitative Samples
			Divers' Estimates			Native Mussels		
			<i>Corbicula</i>	<i>Dreissena</i>				
1,1	C,G	278	0	> 400	0	0	0	
1,2	S,G	268	0	> 400	0	4		
2,1	S,G	278	0	> > 400	20-40	32		
2,2	G,S	271	0	> > 400	20-40	56		
2,3	C,G	268	0	> > 400	20-40	48		
2,4	coarse S	265	0	40-400	0	4		
3,1	fine S,G	278	0	> > 400	> 40	44		
3,2	fine S,G	269	0	> > 400	4-20	28		
3,3	S,G	272	0	> > 400	> 40	40		
3,4	coarse S	264	0	0	0	0		
4,1	G,S	274	4-40	> 400	4-20	16		
4,2	G,S	270	4-40	> 400	> 40	72		
4,3	G,S	266	0	4-40	0	4		
4,4	G,S	263	0	4-40	0	0		
5,1	C,G	283	4-40	> > 400	4-20	4		
5,2	G,S	273	40-400	> > 400	20-40	48		

(Sheet 1 of 3)

Note: Substratum codes are as follows: B = bedrock; C = cobble; G = gravel; S = sand.

Table 2 (Continued)									
Transect and Site	Substratum Type	Elevation, ft	Density (Individuals per m ²)						
			Divers' Estimates			Semiquantitative Samples			
			<i>Corbicula</i>	<i>Dreissena</i>	Native Mussels				
5,3	C,G	273	0	> > 400	20-40				32
5,4	S,G	266	0	> 400	0				0
6,1	C,G	276	0	> > 400	20-40				56
6,2	S,G	268	0	> > 400	4-20				20
6,3	coarse S	270	0	4-40	0				0
6,4	S,B	271	0	4-40	0				16
7,1	G,S	277	0	> 400	> 40				60
7,2	G,S	274	0	> 400	> 40				92
7,3	S,G	268	0	> 400	> 40				80
7,4	S	268	0	40-400	4-20				164
8,1	G,S	276	0	> > 400	> 40				48
8,2	S,G	274	0	> 400	20-40				80
8,3	S,G	272	0	> 400	> 40				172
8,4	S,G	272	0	> 400	20-40				200
8,5	S,C,G	271	0	> 400	20-40				184
8,6	S	271	0	40-400	4-20				44
8,7	B	265	0	0	0				0
9,1	G,S	278	0	> > 400	4-20				4
9,2	G,S	276	0	> > 400	4-20				48

(Sheet 2 of 3)

Table 2 (Concluded)

Transect and Site	Substratum Type	Elevation, ft	Density (Individuals per m ²)				
			Divers' Estimates			Native Mussels	Semiquantitative Samples
			<i>Corbicula</i>	<i>Dreissena</i>			
9,3	S,G	272	0	40-400	4-20	44	
9,4	S,G	272	0	40-400	4-20	84	
10,1	C,G	280	0	> > 400	4-20	0	
10,2	C,G	274	0	> > 400	4-20	12	
10,3	C,G,S	272	0	> > 400	4-20	12	
10,4	C,G,S	270	0	> > 400	20-40	28	
11,1	C,G	279	0	> 400	4-20	8	
11,2	C,G	276	0	> 400	4-20	16	
11,3	G,S	271	0	> 400	20-40	12	
11,4	C,G	271	0	> 400	4-20	16	
12,1	G,S	278	0	> > 400	0	28	
12,2	G,S	275	0	> > 400	4-20	12	
12,3	S,G	270	0	> > 400	4-20	8	
12,4	B,C,G	270	0	> > 400	20-40	4	
13,1	C,G,S	279	0	> > 400	4-20	20	
13,2	C,G,S	275	0	> > 400	4-20	0	
13,3	G,S	272	0	> > 400	4-20	12	
13,4	G,S	272	0	> > 400	4-20	20	

(Sheet 3 of 3)

and 0 at Sites 1-4, respectively. Unionids and substratum at Sites 1 and 2 were carpeted by a heavy infestation of zebra mussels; zebra mussels were much less dense at Sites 3 and 4.

Four sites were sampled along Transect 5. Site 1 (283-ft elevation) was nearshore, and Site 4 (266-ft elevation) was farshore of the limit of the mussel bed; Sites 2 and 3 were within the bed. Substratum was a mix of cobble, gravel, and sand (overlaid by silt) at Sites 1-3; gravelly sand occurred at Site 4. Thus, as along Transects 1-4, substratum became finer with farshore distance and increased depth. Zebra mussels were extremely dense at Sites 1-3 and noticeably less dense at Site 4.

Sites 1 (277-ft elevation) and 2 (268-ft elevation) along Transect 6 supported moderate-to-high densities of mussels; 56 individuals per square meter occurred at Site 1, and 20 individuals per square meter occurred at Site 2. Zebra mussels were extremely dense at both sites, and substratum ranged from cobble and gravel to gravelly sand. Sites 3 and 4, although farshore of Sites 1 and 2, were in shallower water; elevation at Sites 3 and 4 equaled 270 and 271 ft, respectively. Site 3 was comprised of coarse sand, with no unionids and zebra mussels restricted to shells and other debris. Site 4 supported a low density of unionids (16 individuals per square meter), substratum was sand over bedrock, and zebra mussels were dense on exposed rock but absent in sand. The low density of zebra mussels and unionids in sand at Sites 3 and 4 suggests the occurrence of a relatively unstable substratum.

Sites along Transect 7 were all within the nearshore and farshore limits of the bed, ranging in elevation from 277 to 268 ft. Unionid density was high throughout the transect; density equaled 60, 92, 80, and 164 individuals per square meter at Sites 1, 2, 3, and 4, respectively. Zebra mussels were mainly restricted to unionids at Sites 1 and 2; far fewer zebra mussels occurred in the sandy gravel of these sites than at other such sites along Transects 1-6. Nonetheless, unionids were heavily infested. At Site 4, substratum was coarse sand with some gravel, and unionids, although dense, were almost exclusively relatively small *Fusconaia ebena* that were not at all or barely infested by zebra mussels.

A total of seven sites were sampled along Transect 8. Unionids were moderately to highly dense at all but the farshoremost site. Topography was flat to uneven (i.e., the bank did not steadily slope downward from nearshore to farshore). Substratum ranged from sandy gravel to sand with some gravel to sand, with no clear pattern of substratum change in a nearshore to farshore direction. Sites 1-4 (elevation range of 277 to 272 ft) supported high densities of unionids, with many unionids having heavy infestations of zebra mussels. The carpet of zebra mussels along this transect was not consistently heavy like at more upstream transects. Sites 5 and 6 consisted of coarse sand with occasional cobble. Although unionids were dense (184 and 44 individuals per square meter), most were relatively small *F. ebena* that were relatively free of zebra mussels. At both of these sites, sand was coarse and seemingly unstable—zebra mussels were restricted to the pieces of cobble and

occasionally occurred in high density on a unionid. Site 7 was at an elevation of 265 ft; substratum was exposed bedrock, and water velocity was high. No unionids were obtained at Site 7, and zebra mussels were restricted to crevices in the bedrock.

Similar to Transect 8, Sites along Transect 9 were sandy. Zebra mussels tended to be restricted to rocks and unionids. Divers described interspersed patches of sand between sites; substratum was generally less imbricated than the cobble, gravel, and sand mixture along Transects 2-6. Site 1 (elevation 278 ft) was approximately at the nearshore limit of the bed and supported only four unionids per square meter. Sites 2, 3, and 4 ranged in elevation from 276 to 272 ft and supported 44 to 84 unionids per square meter. Zebra mussel density was very high at Sites 1 and 2, but markedly lower at Sites 3 and 4.

The nearshoremost sites along Transect 10 were clearly nearshore of the limit of the bed. The diver moved from a uniformly low-to-moderate density of unionids to virtually no unionids as he went from Site 2 (elevation 274 ft) to Site 1 (elevation 280 ft). Substratum was coarser along Transect 10 than along Transect 9, ranging from cobble and gravel nearshore to gravel and sand farshore. Zebra mussel infestation of unionids and substratum was heavy. Unionid density at the farshore site (Site 4 at an elevation of 270 ft) equaled 28 individuals per square meter. Farshore of and slightly deeper than Site 4, the diver moved into sand and fine gravel.

Unionid density was low along Transect 11, ranging from 8 individuals per square meter near the nearshore limit at Site 1 to 16 individuals per square meter at Site 4. Beyond Site 4 (at an elevation of 271 ft), the diver moved into coarse sand, with no zebra mussels. Zebra mussels were dense at Sites 1-4. Substratum was a mix of cobble, gravel, and sand.

Moderate-to-low density of mussels continued to characterize the bed along Transect 12. Site 1 (278-ft elevation) supported 28 individuals per square meter, but density ranged only from 12 to 4 individuals at Sites 2-4. Substratum was relatively coarse (cobble, gravel, and sand) at all sites.

The downstreammost transect (13) also supported a low density of unionids, ranging from 0 individuals per square meter at Site 2 (275-ft elevation) to 20 individuals per square meter at Site 4 (272-ft elevation). As along Transect 12, zebra mussel density was very high. Substratum was a mix of gravel and sand.

In summary, the highest densities of mussels were observed along Transects 7 and 8, where the bed was also very wide. Density ranged from 44 to 200 individuals between elevations of 277 and 268 ft along these two transects. The site furthest from shore along Transect 8, at an elevation of 265 ft was off the mussel bed. Substratum at that site was bedrock, indicating that increasingly erosional conditions limit the bed in the farshore direction. Nonetheless, divers could still locate a few small mussels only in sand and

gravel deposited among cracks in the bedrock near that site. Sites 5 and 6 along Transect 8, as well as the farshore site along Transect 7, had a substratum consisting of sand over bedrock. However, mussels were still dense at these sites. Sites nearer shore were more depositional, with substratum of sandy gravel or gravelly sand.

Sites along transects across the downstream portion of the bed (Transects 10-13) supported low densities of mussels (mostly < 20 individuals per square meter) compared with Transects 2-9. The relatively consistent low density of unionids downstream of RM 968 made it difficult to clearly discern nearshore, farshore, and downstream limits of the bed. Substratum along Transects 10-13 tended toward a mix of cobble, gravel, and sand, with gravelly sand or sandy gravel being less prevalent than at upstream sites.

Density Estimates

Ten 0.25-m² samples of substratum with mussels were taken at each of four sites in the high density, upstream half of the bed in 1994. Average mussel density was higher when estimated from these quantitative samples (Table 3) than when based on the search-by-feel methods used during semi-quantitative sampling along transects (Table 2). Average unionid density based on substratum removal and sieving ranged from 90 to 198 individuals per square meter; search-by-feel sampling of quadrats at the same locations during transect sampling yielded density estimates ranging from 16 to 60 individuals per square meter. Semiquantitative samples were collected in response to a resource agency recommendation that emphasis should be on extensive spatial coverage of the mussel bed; this rapid and repeatable method of mussel density estimation obviously is less accurate than the more labor-intensive quantitative samples that require total substratum removal.

Location		No. of Samples	Individuals per m ²		
Transect	Site		Mean	S.D.	Range
4	1	10	90 ^c	26	48-15
5	3	10	133 ^b	37	60-180
6	1	10	129 ^b	32	68-184
7	1	10	198 ^a	33	156-260
Total		40	137	50	48-260

Note: Superscript letters indicate significant differences among means ($p < 0.05$) per Duncan's Multiple Range Test.

Replicated quantitative sampling allows estimation of variance-to-mean ratios of density estimates (i.e., estimation of degree of mussel aggregation). Variance-to-mean ratios ranged from 5.4 to 10.5 at the four sites sampled in 1994. Values greater than unity are indicative of an aggregated (versus a regular (< 1) or random ($= 1$)) distribution of individuals. Thus, native unionids in this mussel bed are highly aggregated within the rectangular area of approximately 2 by 10 m from which each set of ten 0.25-m² samples were collected.

Average density of *Corbicula fluminea* ranged from 2 to 73 individuals per square meter and equaled 36 individuals per square meter for all sites (Table 4). Variance-to-mean ratios of this species' density ranged from 5.3 to 143.1, indicative of a high degree of spatial aggregation of *C. fluminea* within the mussel bed.

Table 4
Summary of *Corbicula fluminea* Density at Sites Sampled by Removing Substratum With Mussels From 0.25-m² Quadrats, Lower Ohio River, 30 August - 2 September 1994

Location		No. of Samples	Individuals per m ²		
Transect	Site		Mean	S.D.	Range
4	1	10	3.2 ^b	4.1	0-12
5	3	10	66.4 ^a	60.8	0-188
6	1	10	72.8 ^a	102.3	4-284
7	1	10	2.0 ^b	3.4	0-8
Total		40	36.1	66.5	0-284

Note: Superscript letters indicate significant differences among means ($p < 0.05$) per Duncan's Multiple Range Test.

Density of *D. polymorpha* was so high that estimation from 0.25-m² quadrat-based samples of substratum was impractical. Therefore, *D. polymorpha* density estimates in 1994 were based on the core samples taken in association with the transect sampling effort (Table 5). Thus estimated, *D. polymorpha* density in 1994 ranged from 0 to 332,800 individuals per square meter. The average density equaled 39,194 individuals per square meter. Core samples with no or few zebra mussels often, but not always, represented relatively erosional locations farshore of the unionid bed.

In 1993, average density of native mussels ranged from 6.0 to 571 individuals per square meter among the nine sites sampled in 1993 within the confines of the bed (Sites 1 and 2 were upstream of the bed) (Table 6). Two sites (3 and 9) were characterized by extremely high density. That these two sites supported markedly higher mussel densities than the others reflects the high

Table 5
Summary of Density Estimates of *Dreissena polymorpha* Based on
Core Samples Taken at Each Site During 1994 Transect-Based
Mapping of Mussel Bed in Lower Ohio River

Transect and Site	Individuals per m ²		
	Sample 1	Sample 2	Mean
1,1	6,633	3,551	5,092
1,2	11,993	7,035	9,514
2,1	36,180	54,940	45,560
2,2	56,280	89,512	72,896
2,3	78,792	82,008	80,400
2,4	4,154	4,958	4,556
3,1	124,400	263,200	193,800
3,2	66,400	127,200	96,800
3,3	223,200	332,800	278,000
3,4	600	500	550
5,3	85,600	149,600	117,600
5,4	10,900	18,600	14,750
6,1	64,800	50,800	57,800
6,2	88,800	95,200	92,000
6,3	3,500	1,300	2,400
6,4	3,000	2,800	2,900
7,1	25,800	13,500	19,650
7,2	5,300	3,900	4,600
7,3	500	6,800	3,650
7,4	0	0	0
8,1	74,800	no sample	74,800
8,2	20,000	no sample	20,000
8,3	1,800	no sample	1,800
8,4	6,000	no sample	6,000
8,5	23,450	7,504	15,477
8,6	804	134	469
9,1	196,712	0	98,356
9,2	63,248	18,090	40,669
9,3	17,152	68,608	42,880
9,4	0	134	67
10,1	10,988	13,065	11,987
10,2	155,440	59,496	107,468
10,3	33,500	43,592	38,546
10,4	15,812	2,077	8,945
11,1	43,148	82,544	62,846
11,2	7,839	47,436	27,638
11,3	1,608	2,211	1,910
11,4	1,608	0	804
12,1	35,912	60,032	47,972
12,2	22,646	0	11,323
12,3	31,892	29,480	30,686

(Continued)

Table 5 (Concluded)			
Transect and Site	Individuals per m ²		
	Sample 1	Sample 2	Mean
12,4	31,356	14,740	23,048
13,1	41,808	59,228	50,518
13,2	32,160	29,480	30,820
13,3	54,672	63,248	58,960
13,4	4,087	7,571	5,829

degree of patchiness of mussel density within the bed. Patchiness in 1993 was probably greater than previous years because of the heavy dominance of very small, recently recruited juvenile mussels (see discussion below). Variance-to-mean ratios of density estimates averaged 7.8 for the 11 sites quantitatively sampled in 1993.

Average density of *Corbicula fluminea* ranged from 6.0 to 1,073 individuals per square meter (Table 6). Averaged for all sites, *C. fluminea* density equaled 511 individuals per square meter. There was no apparent relationship between native mussel and *C. fluminea* density. Like the native mussels, *C. fluminea*, showed a highly aggregated distribution; variance-to-mean ratios of density estimates averaged 30. However, three sites had ratios close to unity that suggested random rather than aggregated distributions, including Site 2 (1.9), Site 8 (1.0), and Site 10 (1.0).

Density of *D. polymorpha* was low enough in 1993 that estimates were made from 0.25-m² substratum samples. Average density ranged from 0 to 154.0 individuals per square meter (Table 6). Averaged for all 11 sites, density equaled 39.3 individuals per square meter (approximately 1,000 less than in 1994). Like native unionids and *Corbicula*, variance-to-mean ratios of *D. polymorpha* indicated an aggregated rather than random or regular distribution of individuals within sites. The ratios averaged 9.0 for the 10 sites at which *D. polymorpha* was present (ranging from 1.5 to 19.4).

Community Composition

Twenty-one species of native unionids were represented among 1,375 individuals included in quantitative samples of substratum taken in 1994 (Table 7). Relative abundance was extremely uneven; *Fusconaia ebena* comprised 84 percent of the community, ranging from 70 to 89 percent. The second most abundant species, *Quadrula p. pustulosa*, only comprised 3 percent of the community. Percent species occurrence was more equitable than abundance (Table 8). Four species (*F. ebena*, *Q. p. pustulosa*, *Obliquaria reflexa*, and *Ellipsaria lineolata*) occurred in more than half the samples. Despite high species richness and moderately high equitability of species occurrence, evenness (0.32) and species diversity (0.8) were very low. Evidence of recent

Table 6
Summary Statistics for Quantitative Samples Collected in Lower Ohio River Near
Olmsted, IL, September 1993

Site	Parameter	<i>Unionidae</i>		<i>D. polymorpha</i>		<i>C. fluminea</i>	
		Density	Biomass	Density	Biomass	Density	Biomass
1	Mean	5.0 ^c	35.2 ^c	13.0 ^{fe}	11.8 ^{ef}	1,056.0 ^a	5,191.7 ^a
	SE	1.9	12.8	3.4	2.5	145.6	761.0
2	Mean	3.0 ^c	10.8 ^c	1.0 ^f	0.9 ^f	330.0 ^d	332.5 ^d
	SE	1.0	9.5	1.0	0.9	12.5	15.1
3	Mean	571.3 ^a	6,143.2 ^a	59.33 ^{cb}	44.3 ^c	62.0 ^e	82.2 ^d
	SE	37.2	12,116.9	13.5	9.1	17.9	23.5
4	Mean	9.0 ^c	459.0 ^c	18.0 ^{efd}	12.3 ^{ef}	37.0 ^e	44.2 ^d
	SE	3.4	261.0	7.4	4.2	16.4	15.5
5	Mean	39.0 ^c	830.6 ^c	38.0 ^{ced}	39.2 ^{cd}	751.0 ^{bc}	4,616.0 ^{ab}
	SE	15.3	268.1	3.8	5.1	122.4	766.3
6	Mean	28.0 ^c	284.6 ^c	154.0 ^a	147.5 ^a	611.0 ^c	2,575.4 ^c
	SE	4.9	128.27	18.5	15.1	21.8	158.5
7	Mean	19.0 ^c	516.5 ^c	17.0 ^{edf}	16.6 ^{def}	882.0 ^{ab}	4,894.2 ^{ab}
	SE	5.5	286.9	3.8	3.9	91.7	450.0
8	Mean	16.0 ^c	234.9 ^c	45.0 ^{bcd}	39.2 ^{cd}	655.0 ^c	3,571.8 ^{cb}
	SE	3.6	129.8	9.4	8.7	12.6	224.0
9	Mean	234.0 ^b	2,436.0 ^b	68.0 ^b	69.3 ^b	1,073.0 ^a	5,422.8 ^a
	SE	23.6	516.5	13.7	14.7	144.7	981.2
10	Mean	11.0 ^c	439.7 ^c	9.0 ^{ef}	6.8 ^f	6.0 ^e	4.2 ^d
	SE	4.4	261.0	6.6	4.6	1.2	1.4
11	Mean	6.0 ^c	29.7 ^c	0.0 ^f	0.0 ^f	383.0 ^d	434.5 ^d
	SE	3.5	22.7	0.0	0.0	26.9	34.9
All sites	Mean	106.7	1,260.2	39.3	35.4	511.0	2,366.1
	SE	97.3	1,104.5	22.8	21.5	204.0	1,194.1
F		151.1	17.6	22.2	29.11	28.72	27.57
Pr > F		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Note: Means within each taxonomic grouping with the same superscripts are not significantly different ($p > 0.05$) based on Duncan's Multiple Range Test. Pr = Probability; F = F statistic.

recruitment was strong. Seventy-four percent of all mussels collected were less than 30 mm long; 11 of the 25 species obtained included individuals less than 30 mm long. Semiquantitative sampling (search-by-feel) of quadrats yielded an additional 520 individuals, but only one additional species, *Actinonaias ligamentina*, not obtained in quantitative samples. Twenty-two species were represented among 1,895 individuals collected by quantitative and semiquantitative methods.

Similar results were obtained in 1993, when twenty-one species were included among 1,227 individuals obtained from quantitative samples

Table 7
Percent Species Abundance at Four Sites in a Mussel Bed Near
Olmsted, IL, August - September 1994

Species	Transect 4 Site 1	Transect 5 Site 3	Transect 6 Site 1	Transect 7 Site 1	Total
<i>Fusconaia ebena</i>	69.91	90.66	80.12	88.89	84.15
<i>Quadrula p. pustulosa</i>	4.87	1.51	4.04	2.63	3.05
<i>Obliquaria reflexa</i>	2.65	1.20	5.90	2.42	2.98
<i>Ellipsaria lineolata</i>	4.42	2.41	3.73	1.82	2.84
<i>Truncilla truncata</i>	3.98	1.51	1.24	0.61	1.53
<i>Quadrula quadrula</i>	5.31	0.30	1.55	0.20	1.38
<i>Obovaria olivaria</i>	1.33	1.51	0.31	0.40	0.80
<i>Quadrula metanevra</i>	0.44	0.30	0.93	1.01	0.73
<i>Amblema p. plicata</i>	1.33	0.00	0.62	0.81	0.65
<i>Elliptio crassidens</i>	1.33	0.30	0.62	0.00	0.44
<i>Megalonaias nervosa</i>	1.33	0.00	0.31	0.00	0.29
<i>Quadrula nodulata</i>	0.88	0.00	0.31	0.20	0.29
<i>Truncilla donaciformis</i>	0.44	0.00	0.31	0.20	0.22
<i>Leptodea fragilis</i>	0.00	0.30	0.00	0.20	0.15
<i>Tritogonia verrucosa</i>	0.44	0.00	0.00	0.00	0.07
<i>Ligumia recta</i>	0.00	0.00	0.00	0.20	0.07
<i>Plethobasus cyphus</i>	0.00	0.00	0.00	0.20	0.07
<i>Potamilus alatus</i>	0.44	0.00	0.00	0.00	0.07
<i>Lampsilis teres</i>	0.44	0.00	0.00	0.00	0.07
<i>Cyclonaias tuberculata</i>	0.44	0.00	0.00	0.00	0.07
<i>Pleurobema coccineum</i>	0.00	0.00	0.00	0.20	0.07
Total individuals	226	332	322	495	1,375
Total species	17	10	13	15	21
Percent Individuals < 30 mm	56.19	83.74	75.78	75.35	74.33
Percent Species < 30 mm	41.18	50	69.23	40	52.38
Menhinick's Index	1.13	0.55	0.72	0.67	0.57
Species diversity (H')	1.33	0.49	0.89	0.59	0.8
Evenness	0.36	0.34	0.38	0.33	0.32

Note: See Figure 5 for location of transects and sites.

Table 8
Percent Species Occurrence at Four Sites in a Mussel Bed Near
Olmsted, IL, August - September 1994

Species	Transect 4 Site 1	Transect 5 Site 3	Transect 6 Site 1	Transect 7 Site 3	Total
<i>F. ebena</i>	100.00	100.00	100.00	100.00	100.00
<i>Quadrula pustulosa</i>	80.00	50.00	70.00	80.00	70.00
<i>Obliquaria reflexa</i>	40.00	40.00	100.00	70.00	62.50
<i>Ellipsaria lineolata</i>	50.00	50.00	70.00	50.00	55.00
<i>Truncilla truncata</i>	70.00	40.00	40.00	30.00	45.00
<i>Quadrula quadrula</i>	90.00	10.00	50.00	10.00	40.00
<i>Obovaria olivaria</i>	20.00	30.00	10.00	20.00	20.00
<i>Quadrula metanevra</i>	10.00	10.00	30.00	40.00	22.50
<i>Amblema plicata</i>	20.00	0.00	20.00	40.00	20.00
<i>Elliptio crassidens</i>	20.00	10.00	20.00	0.00	12.50
<i>Megaloniaias nervosa</i>	30.00	0.00	10.00	0.00	10.00
<i>Quadrula nodulata</i>	20.00	0.00	10.00	10.00	10.00
<i>Truncilla donaciformis</i>	10.00	0.00	10.00	10.00	7.50
<i>Leptodea fragilis</i>	0.00	10.00	0.00	10.00	5.00
<i>Tritogonia verrucosa</i>	10.00	0.00	0.00	0.00	2.50
<i>Ligumia recta</i>	0.00	0.00	0.00	10.00	2.50
<i>Plethobasus cyphus</i>	0.00	0.00	0.00	10.00	2.50
<i>Potamilus alatus</i>	10.00	0.00	0.00	0.00	2.50
<i>Lampsilis teres</i>	10.00	0.00	0.00	0.00	2.50
<i>Cycloniaias tuberculata</i>	10.00	0.00	0.00	0.00	2.50
<i>Pleurobema coccineum</i>	0.00	0.00	0.00	10.00	2.50
Total samples	10	10	10	10	40

Note: See Figure 5 for location of transects and sites.

(Table 9). *Fusconaia ebena* was heavily dominant, comprising 79 percent of the community; no other species comprised more than 7 percent of the community. Percent occurrence of species was more equitable, with seven species occurring in more than 25 percent of the samples (Table 10). Semi-quantitative samples added 520 individuals but no additional species (Table 11). An additional three species (*Cycloniaias tuberculata*, *Lampsilis teres*, and *Plethobasus cyphus*) were obtained from just 152 individuals collected qualitatively (Table 12). Thus, a total of 24 species were represented

Table 9
Percent Abundance of Freshwater Mussels Collected at Lower Ohio River Near Olmsted, IL, September 1993, Using
Quantitative Methods

Species	1	2	3	4	5	6	7	8	9	10	11	Total
<i>F. ebena</i>	0.00	0.00	84.83	33.33	41.03	60.71	31.58	37.50	82.48	45.45	0.00	79.30
<i>T. donaciformis</i>	20.00	33.33	6.42	0.00	10.26	7.14	15.79	18.75	3.42	27.27	83.33	6.93
<i>L. fragilis</i>	40.00	33.33	1.87	55.56	2.56	14.29	0.00	0.00	0.43	0.00	0.00	2.44
<i>T. truncata</i>	20.00	0.00	1.63	0.00	5.13	0.00	5.26	0.00	3.85	0.00	0.00	2.20
<i>O. reflexa</i>	0.00	33.33	1.28	0.00	15.38	10.71	0.00	6.25	1.71	9.09	0.00	2.20
<i>Q. p. pustulosa</i>	0.00	0.00	0.82	0.00	10.26	0.00	21.05	12.50	2.99	0.00	0.00	1.96
<i>E. lineolata</i>	0.00	0.00	0.70	0.00	5.13	0.00	15.79	6.25	1.28	9.09	0.00	1.30
<i>Q. metanevra</i>	0.00	0.00	1.05	0.00	2.56	3.57	0.00	6.25	0.43	0.00	0.00	1.06
<i>Q. quadrula</i>	0.00	0.00	0.58	0.00	5.13	0.00	5.26	6.25	0.85	0.00	0.00	0.90
<i>E. crassidens</i>	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.41
<i>Q. nodulata</i>	0.00	0.00	0.23	0.00	2.56	0.00	0.00	0.00	0.43	0.00	0.00	0.33
<i>A. p. plicata</i>	0.00	0.00	0.00	0.00	0.00	0.00	5.26	6.25	0.00	0.00	0.00	0.16
<i>M. nervosa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.16
<i>P. cordatum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.09	0.00	0.08
<i>F. flava</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.08
<i>L. recta</i>	0.00	0.00	0.00	11.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
<i>A. ligamentina</i>	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
<i>P. alatus</i>	0.00	0.00	0.00	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.08

(Continued)

Table 9 (Concluded)

Species	1	2	3	4	5	6	7	8	9	10	11	Total
<i>T. verrucosa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.08
<i>O. olivaria</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67	0.08
<i>A. confragosus</i>	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Total individuals	5	3	857	9	39	28	19	16	234	11	6	1,227
Total species	4	3	12	3	10	6	7	8	14	5	2	21
% Individuals < 30 mm	40.00	66.67	94.16	77.78	64.10	82.14	57.89	75.00	91.45	72.73	83.33	90.95
% Species < 30	50.00	66.67	75.00	66.67	80.00	66.67	71.43	62.50	57.14	60.00	50.00	57.14
Menhinck's Index	1.79	1.73	0.41	1.00	1.60	1.13	1.61	2.00	0.92	1.51	0.82	0.60
Simpson's dominance	0.10	0.00	0.70	0.36	0.20	0.39	0.16	0.16	0.68	0.24	0.67	0.64
Species diversity (H')	1.33	1.10	0.71	0.94	1.86	1.25	1.74	1.81	0.85	1.37	0.45	0.96
Evenness	3.23	8.51	0.36	1.14	0.73	0.64	1.14	1.04	0.34	1.11	0.88	0.36

Table 10
Percent Occurrence of Freshwater Mussels Collected at Lower Ohio River Near Olmsted, IL, September 1993, Using
Quantitative Methods

Species	1	2	3	4	5	6	7	8	9	10	11	Total
<i>F. ebena</i>	0.00	0.00	100.00	50.00	75.00	100.00	75.00	100.00	100.00	75.00	0.00	63.04
<i>T. donaciformis</i>	25.00	25.00	100.00	0.00	75.00	50.00	75.00	50.00	100.00	25.00	50.00	54.35
<i>L. fragilis</i>	50.00	25.00	100.00	75.00	25.00	75.00	0.00	0.00	25.00	0.00	0.00	36.96
<i>T. truncata</i>	25.00	0.00	100.00	0.00	25.00	0.00	25.00	0.00	75.00	0.00	0.00	26.09
<i>O. reflexa</i>	0.00	25.00	100.00	0.00	100.00	75.00	0.00	25.00	75.00	25.00	0.00	41.30
<i>Q. p. pustulosa</i>	0.00	0.00	66.67	0.00	50.00	0.00	75.00	25.00	50.00	0.00	0.00	26.09
<i>E. lineolata</i>	0.00	0.00	66.67	0.00	50.00	0.00	50.00	25.00	75.00	25.00	0.00	28.26
<i>Q. metanevra</i>	0.00	0.00	66.67	0.00	25.00	25.00	0.00	25.00	25.00	0.00	0.00	17.39
<i>Q. quadrula</i>	0.00	0.00	66.67	0.00	50.00	0.00	25.00	25.00	50.00	0.00	0.00	21.74
<i>E. crassidens</i>	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	8.70
<i>Q. nodulata</i>	0.00	0.00	33.33	0.00	25.00	0.00	0.00	0.00	25.00	0.00	0.00	8.70
<i>A. p. plicata</i>	0.00	0.00	0.00	0.00	0.00	0.00	25.00	25.00	0.00	0.00	0.00	4.35
<i>M. nervosa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	2.17
<i>P. cordatum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	2.17
<i>F. flava</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	2.17
<i>L. recta</i>	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17
<i>A. ligamentina</i>	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17
<i>P. alatus</i>	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	2.17
<i>T. verrucosa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	2.17
<i>O. olivaria</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	2.17
<i>A. confragosus</i>	0.00	0.00	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17
Total samples	4	4	6	4	4	4	4	4	4	4	4	46

**Table 11
Percent Abundance Data on Freshwater Mussels Collected Using Semiquantitative Methods Along 13 Transects in
Lower Ohio River, 1994**

Species	Transect Number													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	
<i>F. ebena</i>	0.00	77.14	60.71	79.41	38.10	60.87	86.87	87.78	85.11	90.91	46.15	50.00	57.14	78.46
<i>Q. p. pustulosa</i>	0.00	0.00	7.14	0.00	0.00	8.70	3.03	5.56	4.26	9.09	23.08	7.14	14.29	5.00
<i>E. lineolata</i>	0.00	2.86	7.14	0.00	14.29	13.04	0.00	1.67	2.13	0.00	0.00	14.29	14.29	3.27
<i>Q. quadrula</i>	0.00	5.71	0.00	2.94	14.29	4.35	1.01	1.11	4.26	0.00	15.38	7.14	7.14	3.08
<i>P. alatus</i>	0.00	5.71	3.57	5.88	4.76	4.35	0.00	0.56	0.00	0.00	0.00	0.00	0.00	1.54
<i>O. reflexa</i>	0.00	0.00	0.00	0.00	4.76	0.00	2.02	1.11	0.00	0.00	15.38	0.00	0.00	1.35
<i>Q. metanevra</i>	0.00	0.00	0.00	0.00	0.00	4.35	1.01	1.11	2.13	0.00	0.00	7.14	7.14	1.35
<i>T. truncata</i>	0.00	5.71	3.57	2.94	0.00	0.00	1.01	0.00	2.13	0.00	0.00	0.00	0.00	1.15
<i>E. crassidens</i>	0.00	0.00	10.71	2.94	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96
<i>L. recta</i>	0.00	0.00	0.00	2.94	4.76	0.00	0.00	0.00	0.00	0.00	0.00	14.29	0.00	0.77
<i>Q. nodulata</i>	0.00	0.00	0.00	2.94	0.00	0.00	3.03	0.00	0.00	0.00	0.00	0.00	0.00	0.77
<i>O. olivaria</i>	0.00	0.00	0.00	0.00	9.52	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.58
<i>A. p. plicata</i>	100.00	0.00	0.00	0.00	4.76	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.58
<i>A. ligamentina</i>	0.00	0.00	0.00	0.00	0.00	4.35	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.38
<i>L. fragilis</i>	0.00	0.00	3.57	0.00	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.38
<i>T. donaciformis</i>	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
<i>T. verrucosa</i>	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Total Individuals	1	35	28	34	21	23	99	180	47	11	13	14	14	520
Total Species	1	6	8	7	9	7	9	9	6	2	4	6	5	17

Table 12
Percent Abundance and Percent Occurrence for Mussels Collected
Using Qualitative Methods at Olmsted Bed in Lower Ohio River,
September 1993

Species	No. of Individuals	% Abundance	No. of Samples	% Occurrence
<i>F. ebena</i>	68	44.74	24	60.00
<i>L. fragilis</i>	13	8.55	12	30.00
<i>E. lineolata</i>	12	7.89	6	15.00
<i>Q. p. pustulosa</i>	10	6.58	8	20.00
<i>Q. metanevra</i>	9	5.92	8	20.00
<i>O. olivaria</i>	5	3.29	4	10.00
<i>Q. quadrula</i>	5	3.29	5	12.50
<i>T. truncata</i>	5	3.29	4	10.00
<i>T. donaciformis</i>	4	2.63	4	10.00
<i>C. tuberculata</i>	4	2.63	2	5.00
<i>P. alatus</i>	3	1.97	3	7.50
<i>O. reflexa</i>	3	1.97	3	7.50
<i>L. teres</i>	2	1.32	2	5.00
<i>P. cordatum</i>	2	1.32	2	5.00
<i>A. p. plicata</i>	2	1.32	2	5.00
<i>Q. nodulata</i>	1	0.66	1	2.50
<i>A. grandis</i>	1	0.66	1	2.50
<i>P. cyphus</i>	1	0.66	1	2.50
<i>M. nervosa</i>	1	0.66	1	2.50
<i>E. crassidens</i>	1	0.66	1	2.50
Total individuals	152			
Total samples	40			
Total species	20			
% Individuals < 30 mm	25.66			
% Species < 30 mm	40.00			
Menhinick's Index	1.62			
Simpson's dominance	0.22			
Species diversity (H')	2.14			
Evenness	0.47			

Note: Site 3 was not included. See text for details.

among 1,899 individuals collected by both methods in 1993. Species evenness (0.36) and diversity (0.96) were very low. Evidence of recent recruitment was very strong. Approximately 91 percent of all individuals obtained in 1993 were less than 30 mm long; 12 of 21 species from quantitative samples included some individuals less than 30 mm long.

Quantitative and qualitative sampling of this mussel bed since 1983 has yielded a total sample of 12,786 individuals and 32 species of native unionids (Table 13). Over half this total (7,008) has come from quantitative sampling that is more likely than qualitative sampling to obtain species that grow to small adult size. Sampling in any particular year (involving the collection and identification 1,000 to 2,000 individuals) typically yields a richness estimate of 20 to 25 species. Clearly, many of the 32 species collected from this bed occur at low enough density that they are not likely to be encountered in each year's sampling.

Demography of Abundant Populations

Unionids

The dominant unionid, *Fusconaia ebena*, in this mussel bed showed enormously successful recent recruitment. A single-year class (probably 1990) with an average length of 20 mm (range approximately 14 to 30 mm) heavily dominated the population in 1993 (Figure 8). By 1994, the cohort had not grown much; its average length in 1994 was 25 mm (Figure 8). Although still heavily dominant, the relative abundance of the 1990 year class was slightly reduced in 1994.

The prevalence of very small unionids in 1993 and 1994 was most striking in the *F. ebena* population, but was not restricted to this species. For example, in 1993 the *Q. p. pustulosa* population, like *F. ebena*, was dominated by individuals ranging from 12 to 28 mm long (Figure 9). These probably represented 1990 recruits to both populations. The extent of dominance of this cohort in the *Q. p. pustulosa* was less than in the *F. ebena* population. In 1994, this young cohort of recent recruits still comprised the majority of the *Q. p. pustulosa* population (Figure 9).

Zebra mussels

The *D. polymorpha* population in 1993 was dominated by a cohort that ranged in length from 15 to 24 mm (mean = 19 mm) (Figure 10). Although individuals ranged downward in length to as small as 5 mm, 5- to 15-mm-long zebra mussels were not sufficiently abundant to detect cohort structure among smaller individuals. It is likely that the 19-mm-long cohort represents 1992 recruits, and the relatively rare smaller individuals represent 1993 recruits.

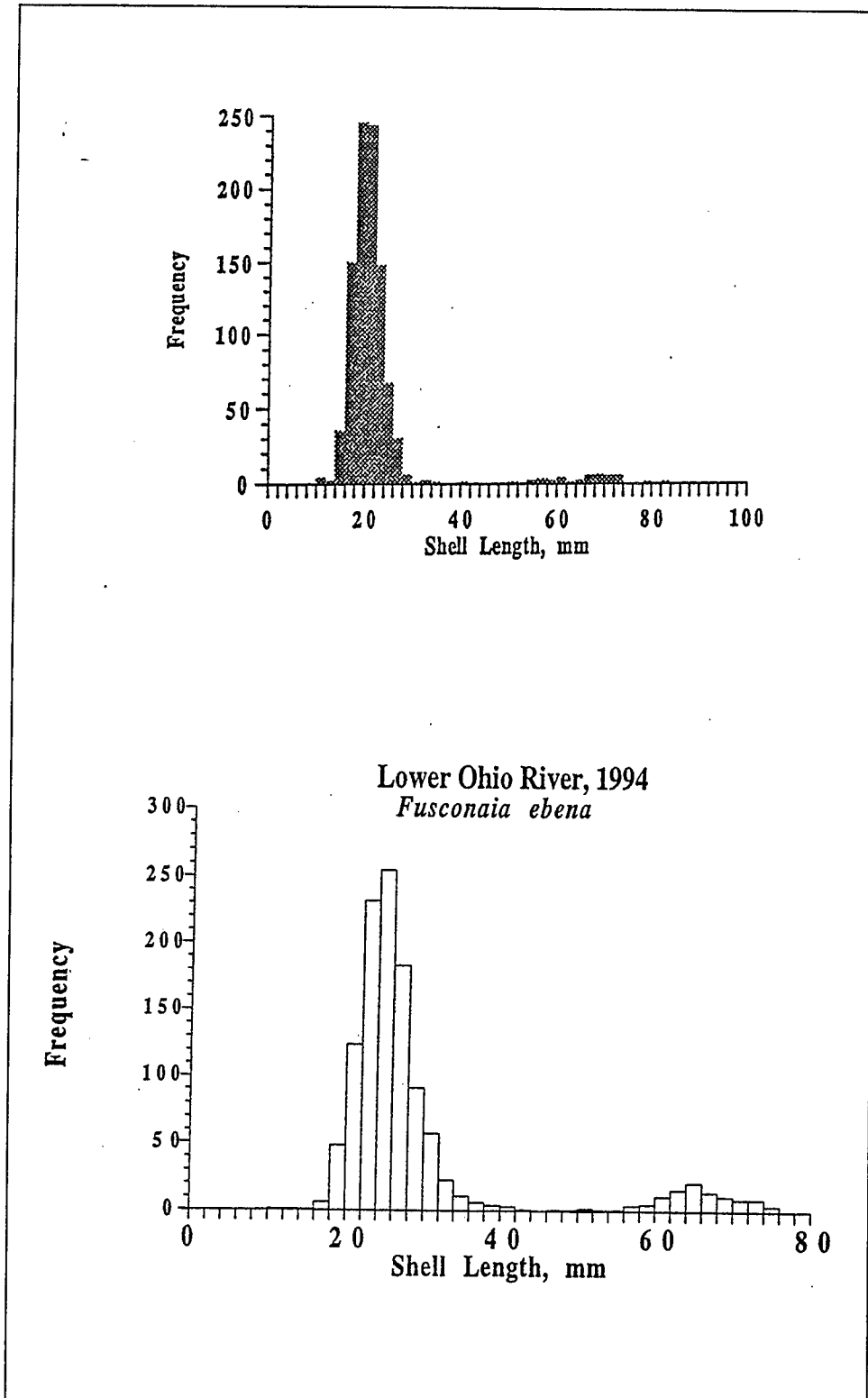


Figure 8. Shell length frequency histogram, *Fusconaia ebena*, 1993 and 1994

Table 13
Species of Native Mussels Collected at Olmsted Mussel Bed, River
Miles 966.2 to 969.3, 1983 to 1994

Scientific Name
<i>Fusconaia ebena</i>
<i>Quadrula quadrula</i>
<i>Quadrula pustulosa pustulosa</i>
<i>Ellipsaria lineolata</i>
<i>Quadrula metanevra</i>
<i>Amblema plicata plicata</i>
<i>Potamilus alatus</i>
<i>Megaloniaias nervosa</i>
<i>Quadrula metanevra</i>
<i>Cycloniaias tuberculata</i>
<i>Obliquaria reflexa</i>
<i>Truncilla truncata</i>
<i>Truncilla donaciformis</i>
<i>Tritogonia verrucosa</i>
<i>Lampsilis teres</i>
<i>Elliptio crassidens</i>
<i>Quadrula nodulata</i>
<i>Leptodea fragilis</i>
<i>Ligumia recta</i>
<i>Obovaria olivaria</i>
<i>Pleurobema cordatum</i>
<i>Lampsilis ventricosa</i>
<i>Plethobasus cyphus</i>
<i>Lasmigona complanata</i>
<i>Plethobasus cooperianus</i>
<i>Actinoniaias ligamentina</i>
<i>Fusconaia flava</i>
<i>Arcidens confragosus</i>
<i>Potamilus purpuratus</i>
<i>Potamilus ohioensis</i>
<i>Pleurobema coccineum</i>
<i>Anodonta imbecillis</i>
Total Number of Species Collected = 32
Total Number of Individuals Collected = 12,786
Total Number of Individuals Collected Qualitatively = 5,778
Total Number of Individuals Collected Quantitatively = 7,008

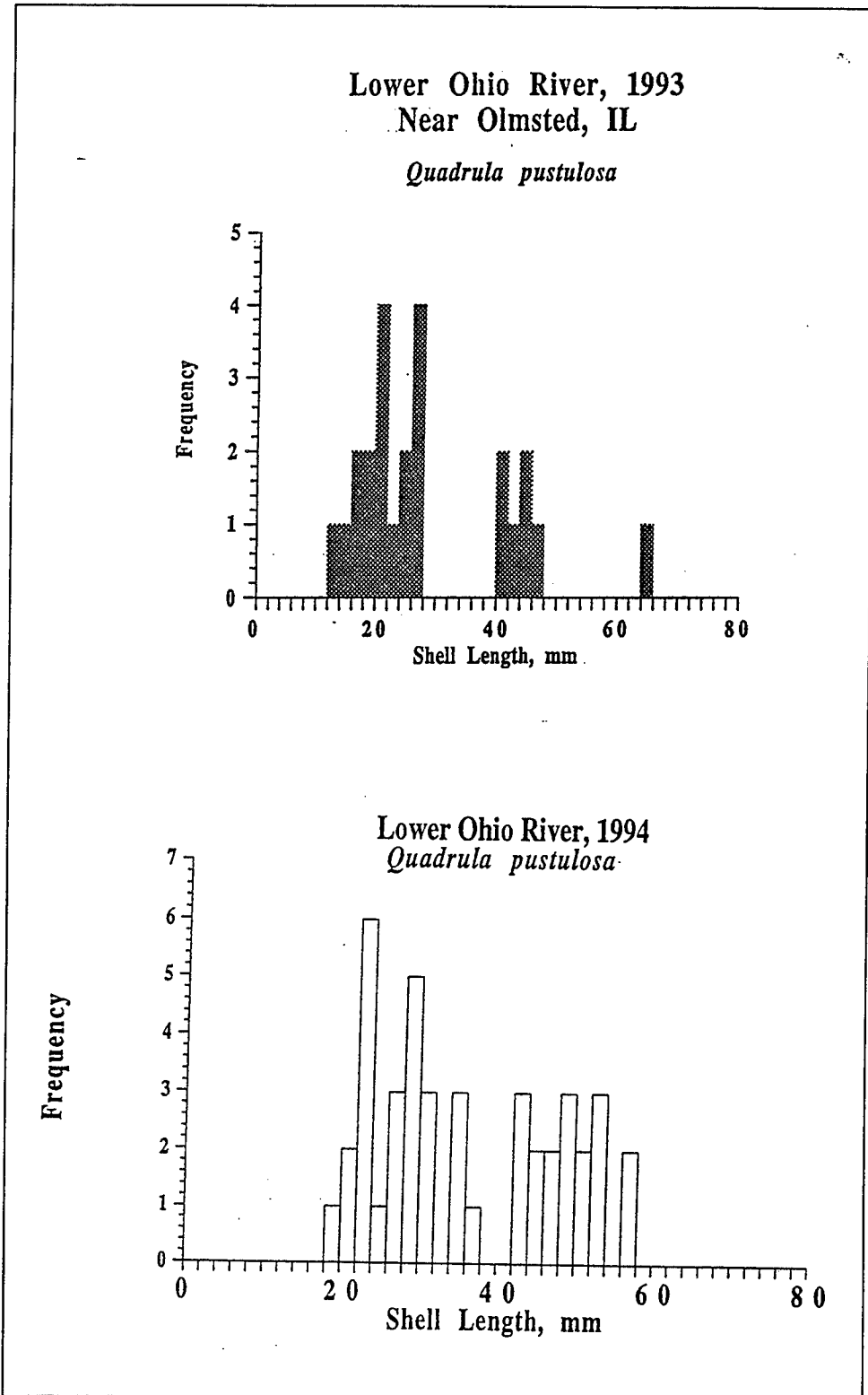


Figure 9. Shell length frequency histogram, *Quadrula p. pustulosa*, 1993 and 1994

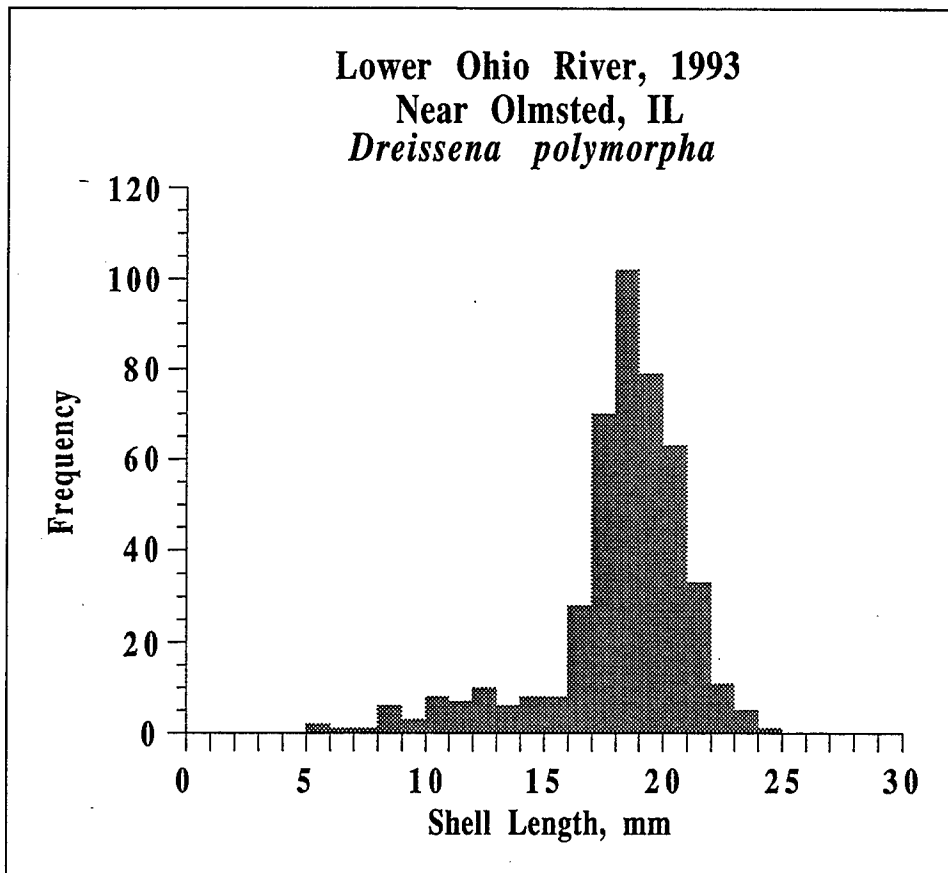


Figure 10. Shell length frequency histogram, *Dreissena polymorpha*, 1993

In 1994, the zebra mussel population was comprised almost entirely of individuals apparently representing a single recruitment cohort (probably 1994 recruitment) (Figures 11 and 12). These individuals ranged from 2 to 16 mm long; only a single mussel fell outside this range from thousands measured from the 81 quantitative samples of *Dreissena polymorpha* collected in 1994. This individual measured 24.5 mm long and was collected along Transect 7. The average length of the recruitment cohort varied inversely with the density of zebra mussels at particular locations within the bed. Shell length frequency histograms in Figure 11 are representative of low-density sites, at which mean length varied from 8 to 10 mm, depending on site. Shell length frequency histograms in Figure 12 are representative of high-density locations, at which mean length ranged from 6 to 7.5 mm, depending on site. The relationship of mean length to population density for all sites is shown in Figure 13. The representation of several high-density assemblages (> 100,000 individuals per square meter) among the 81 samples taken to estimate zebra mussel density allowed the negative exponential relationship of length to density to be clearly discerned.

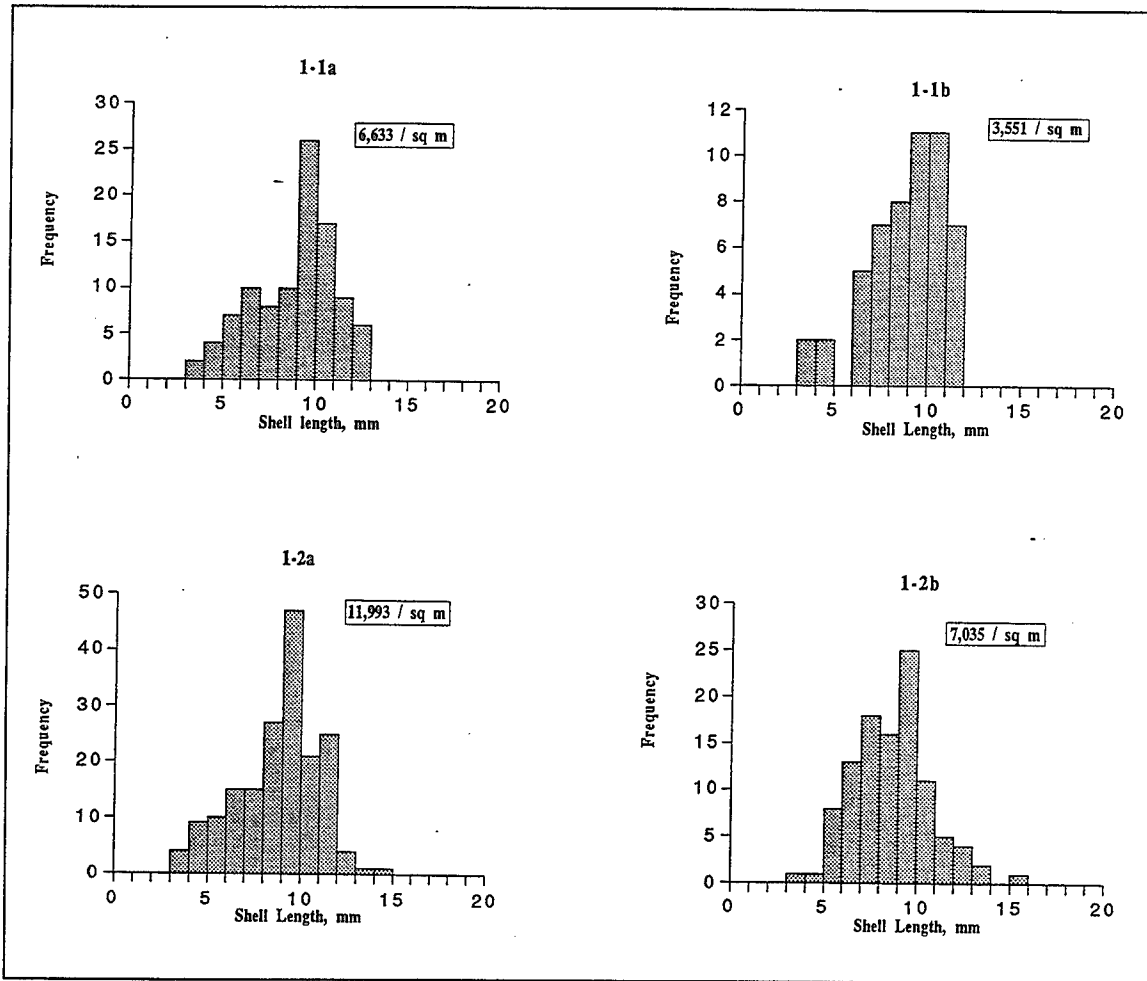


Figure 11. Shell length frequency histogram, *Dreissena polymorpha* from representative sites of low-population density, 1994

Asian clams

The size structure of samples from this population fell into one of two categories, depending on the site of collection. Population samples either showed complex or simple size/age structure. Sites 1, 5, 6, 7, 8, and 9 all had complex structure (Figures 14 and 15). Most or all of four cohorts (centered at approximately 14, 18, 23, and 26 mm) were present at these sites. Conversely, Sites 2, 3, 4, 10, and 11 all showed simple structure, with only the smallest cohort being represented (Figures 16 and 17).

Substratum-Bivalve Relationships

Sites 1 and 5-9, with complex age/size structure of *C. fluminea* populations in 1993, tended to have relatively heterogenous substratum that included a substantial amount of gravel and cobble in addition to sand (Figures 18

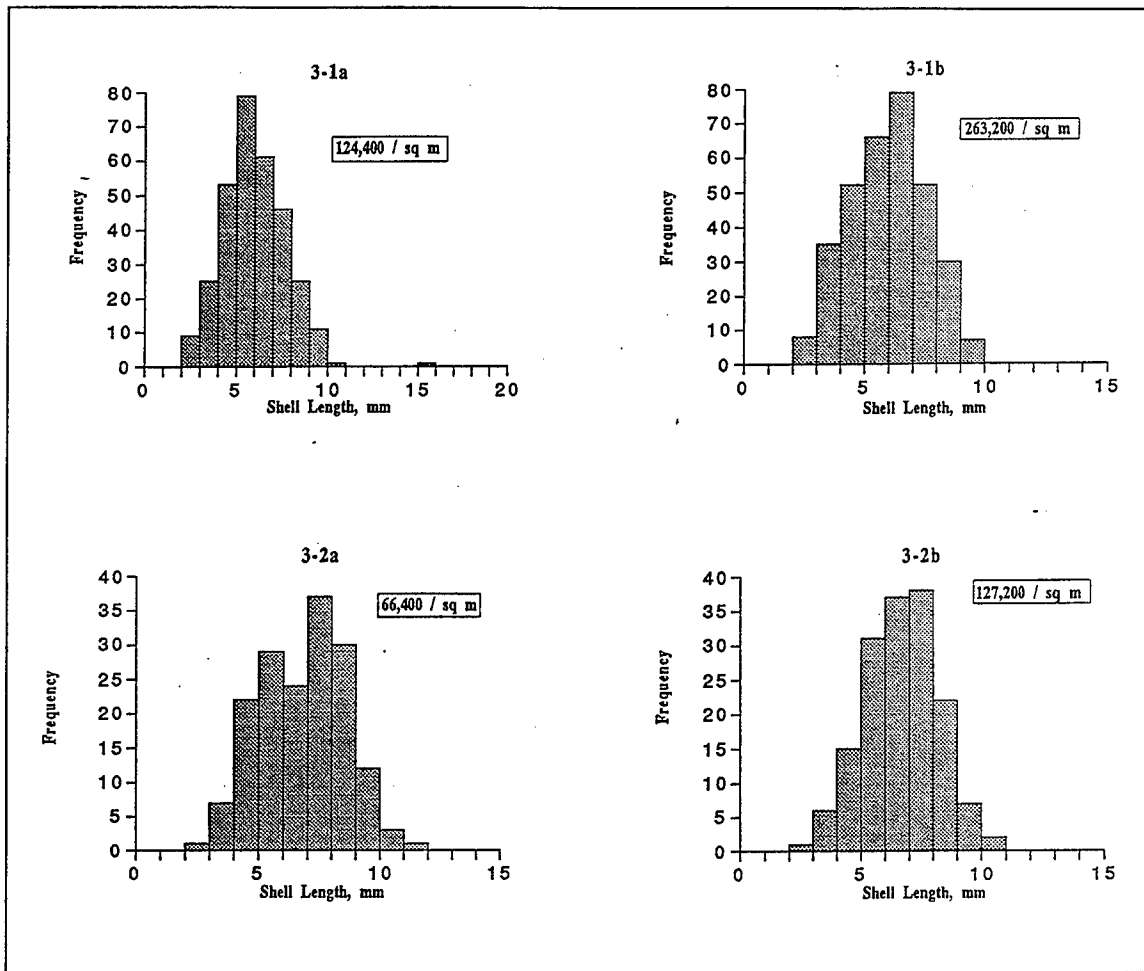


Figure 12. Shell length frequency histogram, *Dreissena polymorpha* from representative sites of high-population density, 1994

and 19). Of these sites, only Site 1 had substratum with more than 50-percent particles finer than 6.35 mm. Sites at which *C. fluminea* had simple size structure (Sites 2-4 and 10 and 11) mostly had substratum that was >75-percent finer than 6.35 mm (Figures 18 and 19). An exception was Site 4, where substratum was heterogeneous. Although in-field processing of substratum samples did not provide categories finer than <6.35 mm, field observations were that Sites 2, 3, and 10 were exclusively medium sand. The association of armored and heterogenous substratums with complex *C. fluminea* size demography and nearly pure sand with simple demography suggests that substratum instability may prevent highly age-structured populations from developing.

Substratum at sites with a moderate and high density of unionids in 1994 yielded a similar assessment of the stable, central portion of the mussel bed. For example, sites along Transects 4, 5, 6, and 7 in the high-density portion of the mussel bed (Figures 4-7) had substratum that was a heterogenous mix of particle sizes (Table 2). High-density communities of unionids require

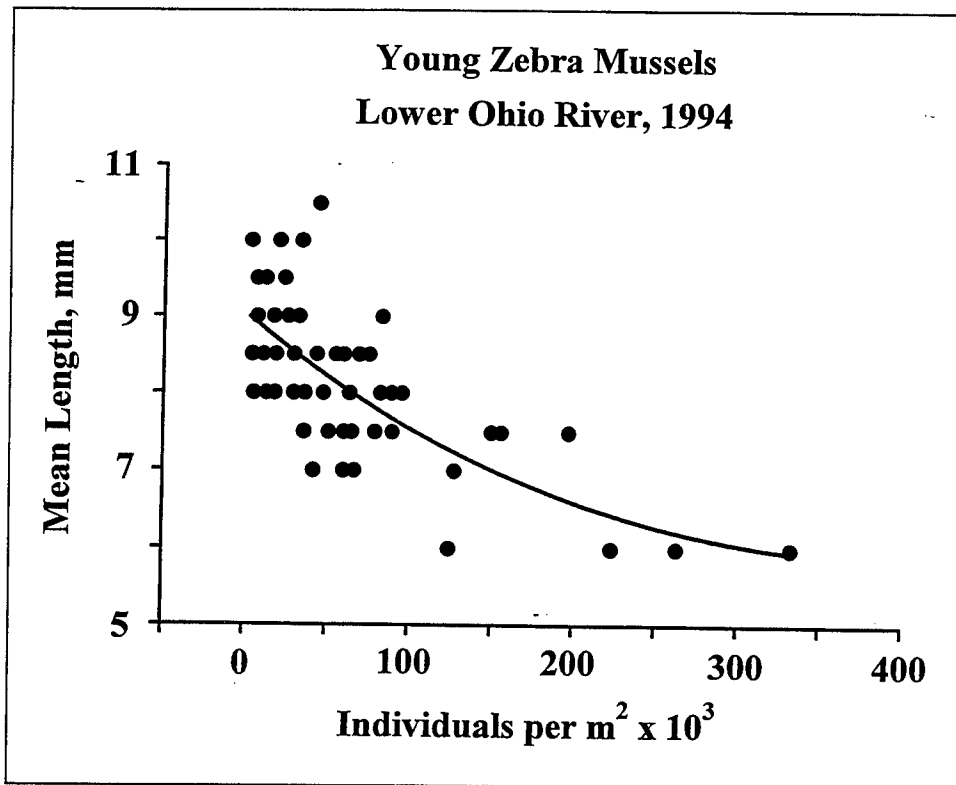


Figure 13. Mean length of young *Dreissena polymorpha* in relation to population density at sites quantitatively sampled in 1994

even more years than *C. fluminea* to develop highly age structure assemblages at a single location. Therefore, it is not surprising that high-density sites of unionids were associated with heterogeneous substratum.

Increasing Abundance of Zebra Mussels

Density of zebra mussels increased by a factor of 1,000 from 1993 to 1994, marking the latter year as the first year of serious infestation of the mussel bed by this nonindigenous species. In 1993, the average density of zebra mussels ranged from 0 to 160 individuals per square meter at the 11 sites quantitatively sampled in and around the mussel bed (Table 6). Zebra mussels were so sparse that they could be counted from gravel, cobble, and unionids sieved during routine processing of quantitative samples of sediment and unionids. In 1994, zebra mussels were so dense that quantification of their density was practical only by taking small core samples from within the mussel bed (Table 5). Density ranged up to 330,000 individuals per square meter and averaged 39,000 individuals per square meter. Virtually all unionids (as well as several species of pleurocerid snails) were very heavily infested by *D. polymorpha*. Most unionids had between several hundred and a few



Figure 14. Shell length frequency histograms indicating complex age structure of *Corbicula fluminea* assemblages at Sites 1, 5, and 6, 1993

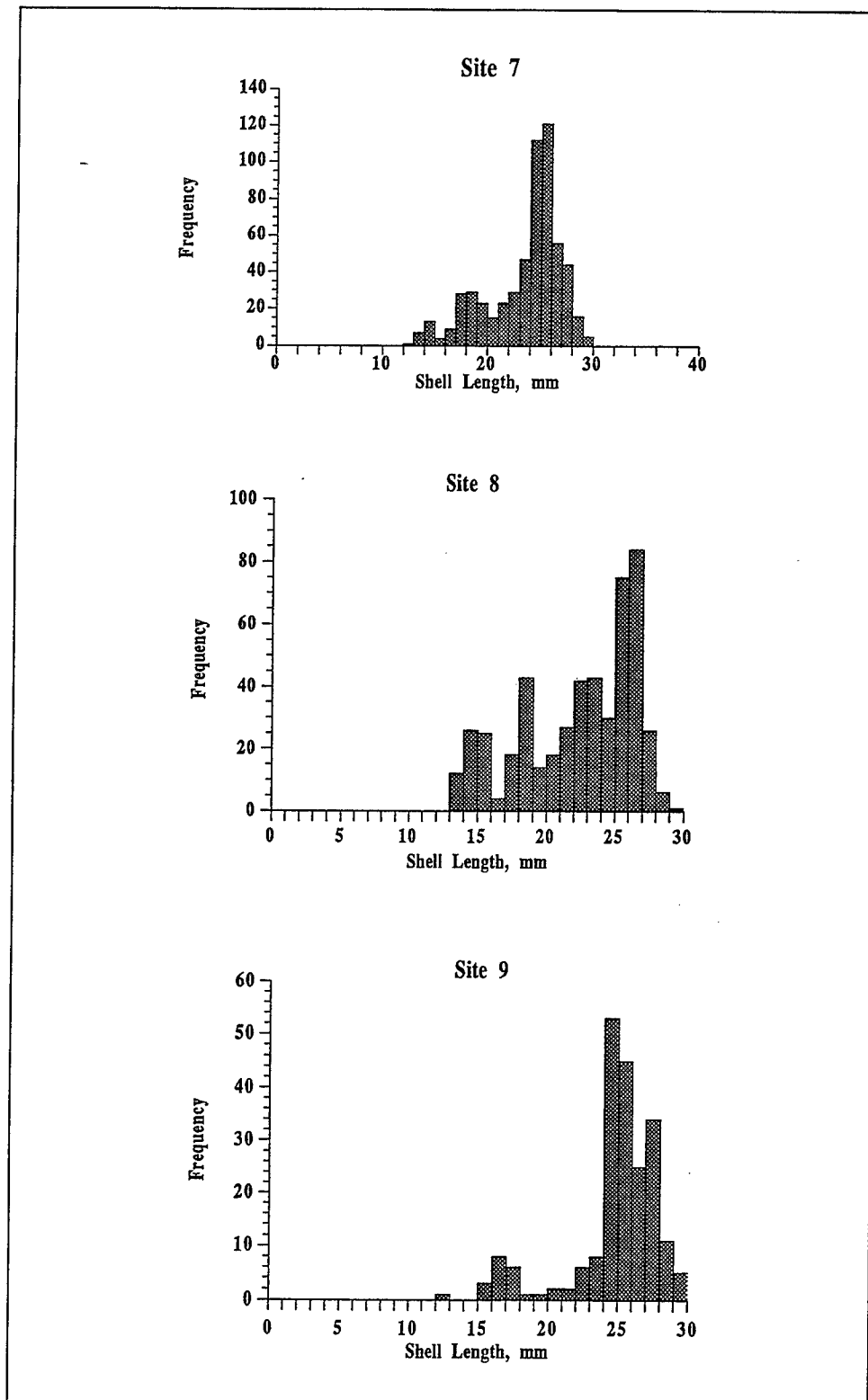


Figure 15. Shell length frequency histograms indicating complex age structure of *Corbicula fluminea* assemblages at Sites 7, 8, and 9, 1993

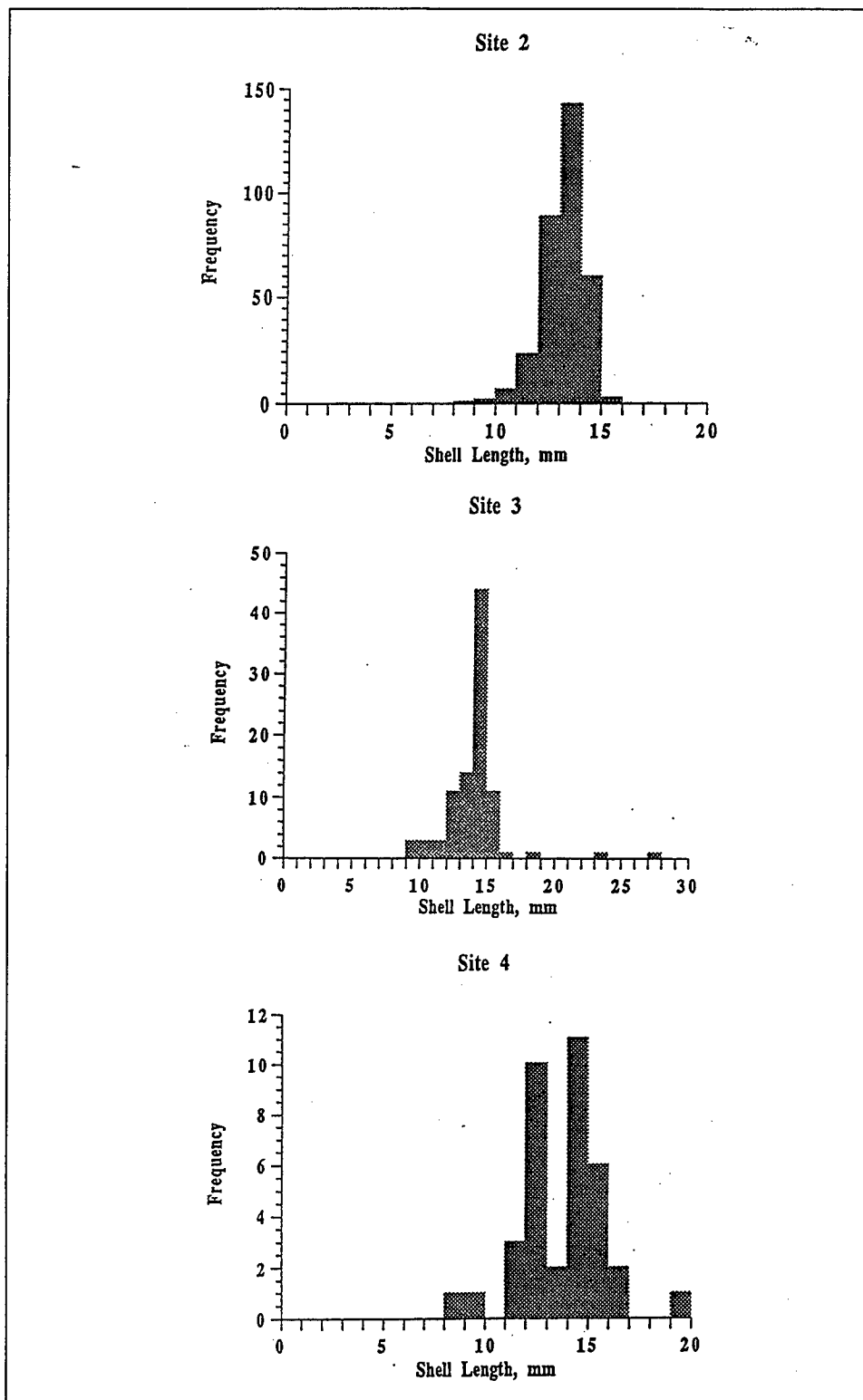


Figure 16. Shell length frequency histograms indicating simple age structure of *Corbicula fluminea* assemblages at Sites 2, 3, and 4, 1993

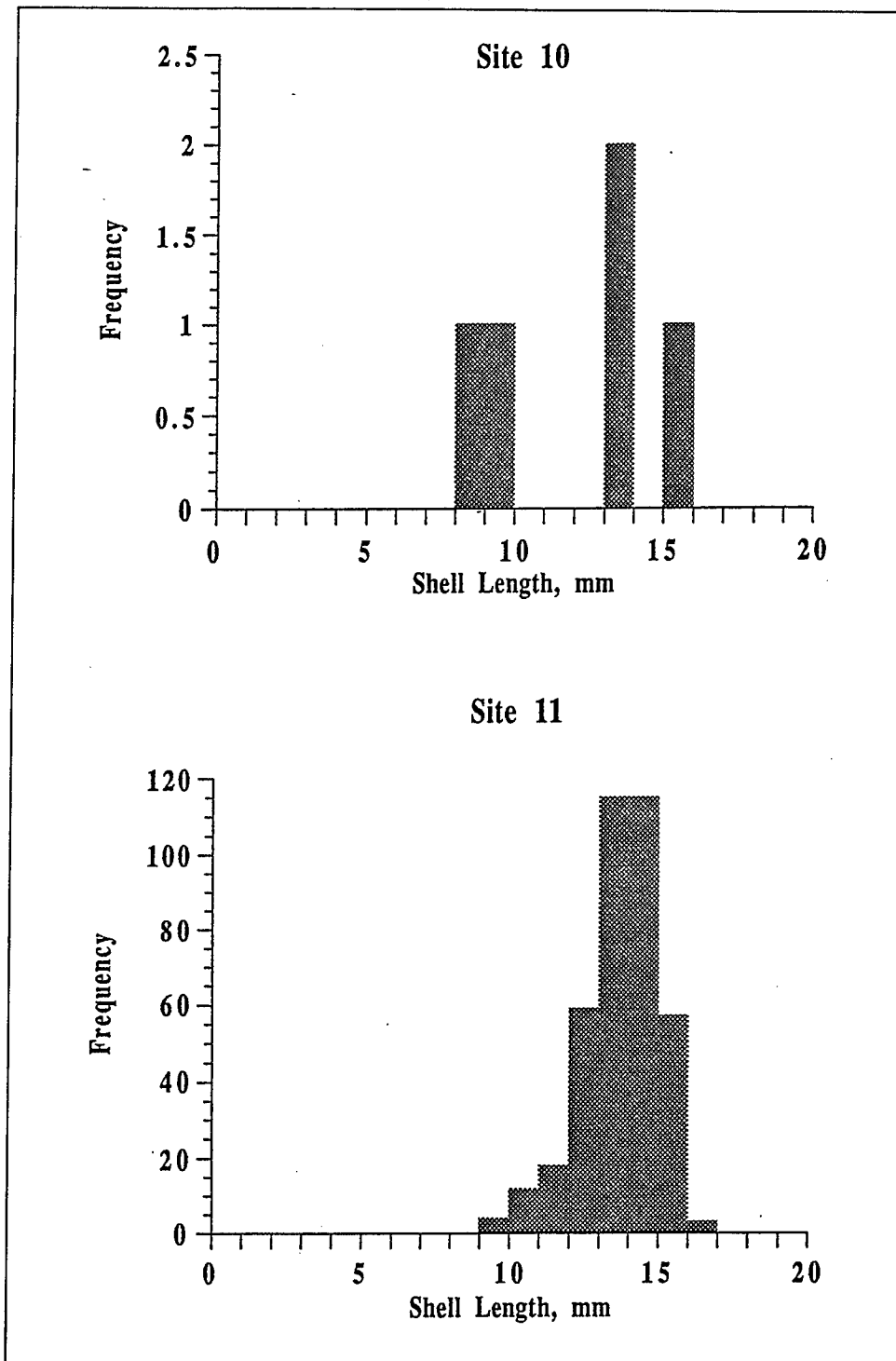


Figure 17. Shell length frequency histograms indicating simple age structure of *Corbicula fluminea* assemblages at Sites 10 and 11, 1993

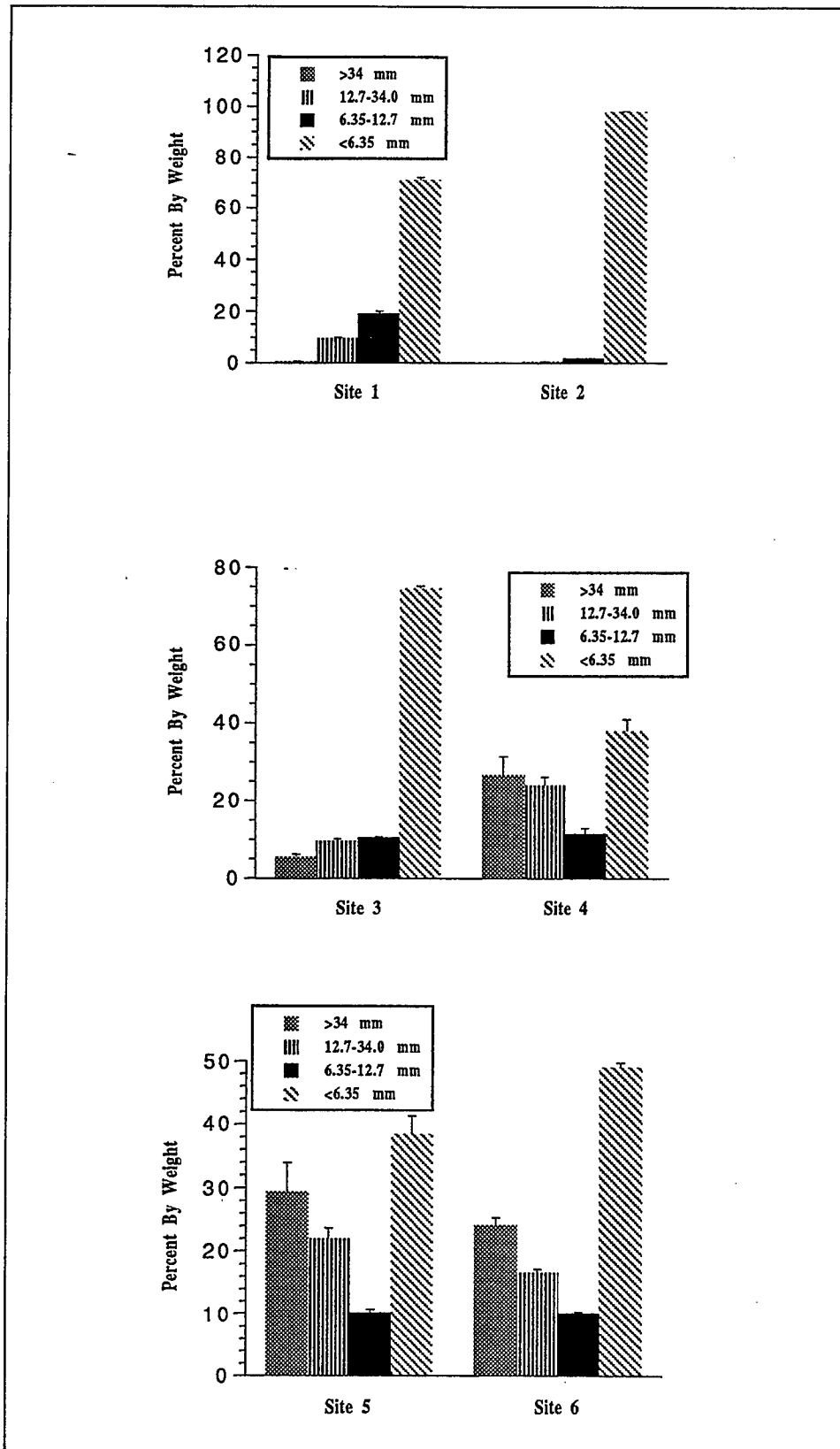


Figure 18. Sediment particle-size distribution, Sites 1-6, 1993

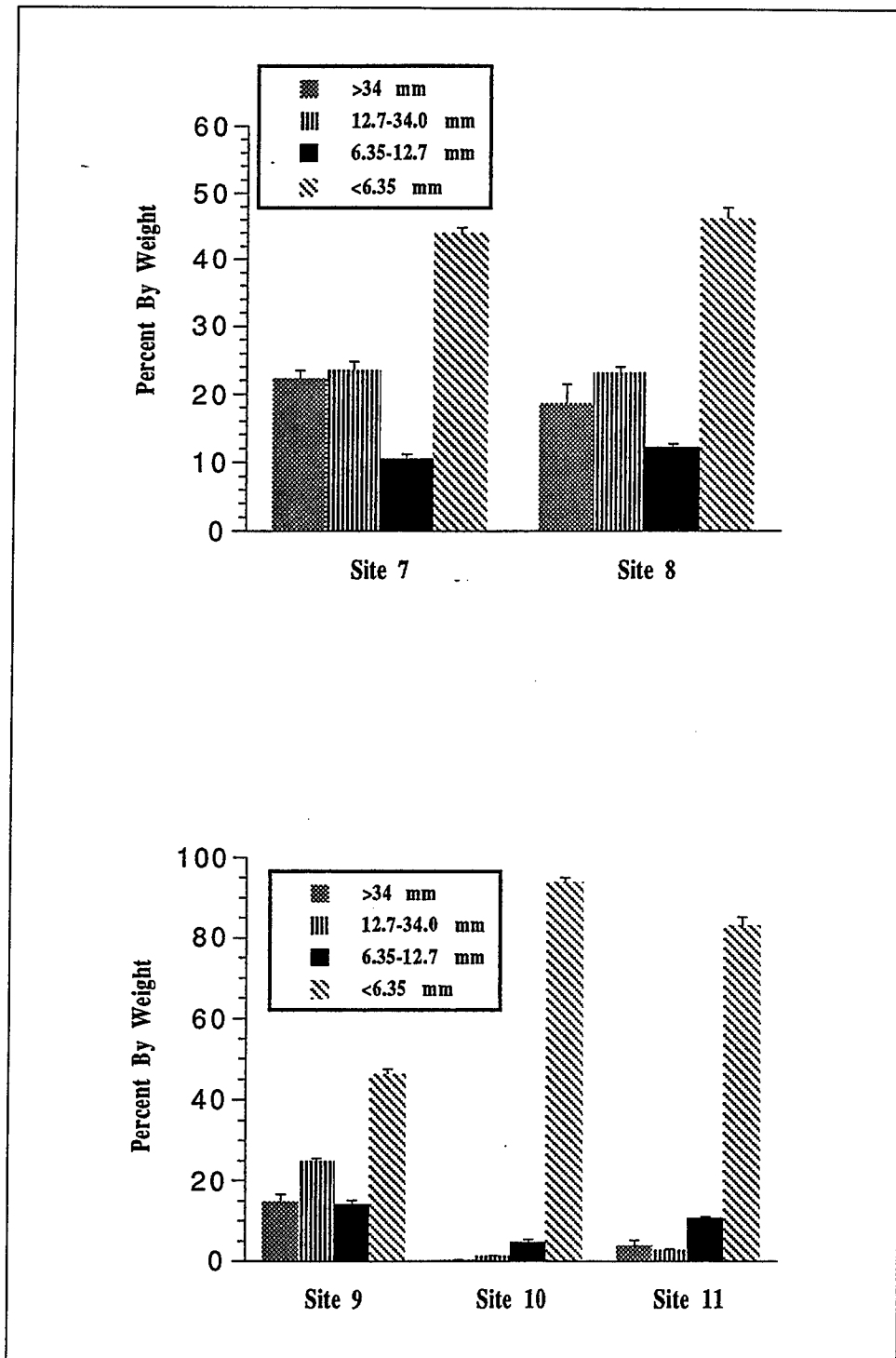


Figure 19. Sediment particle-size distribution, Sites 7-11, 1993

thousand attached zebra mussels, although no mortality of unionids was apparent in association with these heavy infestations of zebra mussels.

4 Discussion

Spatial Characteristics of the Mussel Bed

The boundaries of the moderate-to-high-density (i.e., >20 individuals per square meter) portion of the bed were identified by both the 1993 and 1994 surveys. The upstream and downstream edges of the bed occur at approximately RMs 966.3 and 968.0, respectively. The nearshore edge of the bed approximately corresponds to the 279-ft elevation contour. The farshore edge of the bed approximately corresponds to the 267-ft elevation contour. In turn, that farshore elevation appears to approximately correspond to the farshore distance at which near-bottom water velocity increases to a point that conditions are too erosional for suitably stable substratum for mussels.

The nearshore limit of the mussel bed relates to mussels' intolerance to sustained aerial exposure. As indicated in Table 14, the 279-ft contour has been exposed by low river stage for 14 or more consecutive days three times since 1975. The major drought of 1988 even exposed elevations as high as 277 ft for at least 24 consecutive days. Personal observations made of the mussel bed during that 24-day period confirmed that all exposed unionids within 1 to 2 vertical ft of the shoreline elevation were dead. These unionids died of sustained aerial exposure buried in their normal position in the sediment or slightly deeper. Only a few mussel "trails" were seen. The

Table 14
Summary of Low River Stages, Lower Ohio River, Cairo Gauge, 1975-1994

Date	Consecutive Days Exposing Elevations of		
	281 ft	279 ft	277 ft
9/76	25	1	0
12/80 to 1/81	35	14	0
6/88 to 7/88	44	37	24
7/88 to 9/88	59	16	4
10/88 to 11/88	35	6	0

compacted nature of the substratum probably prevented much movement—or many mussels from burying deeply. Thus, the 279-ft elevation contour provides a reasonable estimate of the bed's nearshore limit based on recent low water patterns.

Results of quantitative samples taken at RMs 967.4 and 967.5 at nearshore (at an elevation of approximately 278 ft), midshore (275 ft), and farshore (272 ft) in 1992 are reasonably concordant with the present estimate that the 279-ft elevation approximates the nearshore limit of the bed. Densities at the nearshore, midshore, and farshore sites in 1992 averaged 15, 82, and 105 individuals per square meter (Payne, Miller, and Shafer 1994).

Assuming that the moderate-to-high-density region of the mussel bed extends from RMs 966.3 to 968 and that the nearshore-to-farshore limits are approximately from the 279- to 267-ft contours, as slightly modified by survey results, then the total area of this region of the bed is readily estimated. Approximately $4.357 \times 10^5 \text{ m}^2$ is the total area of the moderate-to-high-density assemblage of unionids. The average density of unionids, based on the 26 sites semiquantitatively sampled along Transects 2-9 within this region of the bed, is 71 individuals per square meter. Forty quantitative samples taken from sites along Transects 4-7 in 1994 yielded an average density of 138 individuals per square meter. Multiplication of these density estimates by the total area of the bed from RMs 966.3 to 968 yields a total of 31 to 60 million unionids.

Characteristics of the Mussel Community

Quantitative and qualitative samples for estimates of community composition of this bed since 1983 have yielded 12,786 individuals and 32 species of native unionids (Table 13). Only a single *Plethobasus cooperianus* has been obtained among these 12,786 individuals. In addition, three other specimens were collected in 1983 during specialized qualitative searches for "large pustulose species"; however, these biased collections were not included in the totals summarized in Table 13. Thus, the relative abundance of this endangered species is estimated to equal 0.0078 percent. Applying this value to an estimate of 31 to 60 million unionids, an estimated 2,425 to 4,693 *P. cooperianus* occur on the bed from RM 966.3 to RM 968.

Within the middle of the bed, unionid density is not closely correlated with substratum conditions. However, unsuitable substratum (scoured sand and bedrock) becomes prevalent beyond the farshore limit of the bed, reflecting the overall importance of substratum conditions and the general tendency of unionids in the lower Ohio River to be most dense where a stable, heterogeneous mix of cobble, gravel, and sand occurs.

Nonindigenous Species

Density of unionids is not closely associated with the density of the non-indigenous bivalve, *C. fluminea*, which has been abundant in the lower Ohio River since the late 1950s (McMahon 1983). Prior to the appearance of zebra mussels, density of *C. fluminea* generally was not correlated to native mussel density. Indeed, most significant correlations (and they were generally weak) were positive (Miller and Payne 1994). In addition, density of Asian clams has declined greatly since 1983, but unionid density has remained relatively constant (Payne, Miller, and Shafer 1994).

In 1991, the zebra mussel was first observed in the lower Ohio River during a qualitative mussel survey that was conducted of the location of the replacement lock and dam at Olmsted. During quantitative studies of the mussel bed in 1992, no zebra mussels were obtained among seventy 0.25-m² samples of substratum (Payne, Miller, and Shafer 1994). In 1993, zebra mussel density in such quantitative samples averaged 39 individuals per square meter, with the population being comprised almost entirely of 1992 recruits. By 1994, density had increased exponentially to over 39,000 individuals per square meter. However, size demography in 1994 still reflected a potentially "unstable" population; the population was comprised of only 1994 recruits.

An increase in zebra mussel density from < 1 to 4,500 individuals per square meter in Lake St. Clair from 1988 to 1989 was associated with subsequent declines in native unionid populations (Nalepa 1994). Hunter and Bailey (1992) found an inverse relationship between zebra mussel and unionid density in Lake St. Clair in 1990. Gillis and Mackie (1994) reported major reductions of native unionids in Lake St. Clair from 1990 to 1992, with no live unionids at some sites where they previously occurred.

The present level of infestation of unionids in the lower Ohio River mussel bed is sufficient to cause high mortality of unionids. Nalepa (1994) reviews available data that suggest densities of greater than 5,000 individuals per square meter appear to cause unionid infestation intensities of 150 to 200 zebra mussels per unionid that are usually lethal. It is noteworthy that not all core samples from within or near the mussel bed in 1994 had high zebra mussel density. Six of eighty-eight samples contained no zebra mussels, four indicated densities of < 1,000 individuals per square meter, and six others yielded density estimates of 1,000 to 5,000 individuals per square meter. Despite the overall high density of zebra mussels on this bed, patchiness in zebra mussel densities may prevent lethal levels of infestation of all unionids. Although most unionids sampled in 1994 were heavily infested, some individuals were obtained that had few or no attached zebra mussels.

Annual length increase of a 1981 cohort of *F. ebena* in the lower Ohio River averaged 8 mm from 1983 to 1987 (Payne and Miller 1989). The 1990 cohort of *F. ebena* grew in average length from 13 to 22 mm from 1992 to 1993, an increase in close agreement with previous observations of growth of

the 1981 cohort. However, from 1993 to 1994, the 1990 cohort grew only from 22 to 25 mm. It is noteworthy that this very low annual growth from 1993 to 1994 corresponded to the year in which zebra mussel density increased from 39 to 39,000 individuals per square meter.

If zebra mussels are responsible for reduced unionid growth, the likely mechanism is reduced ability of heavily infested unionids to feed. Experimental studies have demonstrated that unionids heavily infested by zebra mussels have lower tissue glycogen reserves than noninfested controls (Haag et al. 1993). However, expected negative correlations between infestation level and glycogen reserves did not occur in naturally occurring mussels (Haag et al. 1993). Similarly, Gillis and Mackie (1994) did not observe significant growth reduction in naturally occurring *Potamilus alatus* before and after the arrival of zebra mussels in Lake St. Clair (from 1986-1990). In contrast, Lewandowski (1976) observed that infested unionids in the Mazurian Lakes of Poland had smaller shell lengths than uninfested unionids.

Native unionids have coexisted since the late 1950s with the Asian clam with no apparent difficulty. Recent decline in the density of the Asian clam has roughly coincided with the appearance of the zebra mussel in the lower Ohio River. A causal relationship is not indicated. The demographic simplicity of the zebra mussel population does not yet indicate a highly age-structured population typical of equilibrium populations. Thus, it is likely that zebra mussels in the lower Ohio River will vary substantially in density until a more stable age structure is achieved.

Future Considerations

Personnel of the U.S. Army Engineer Waterways Experiment Station have used qualitative and quantitative methods to collect bivalves at this mussel bed since 1983. Throughout this period, the native unionid community has been stable, characterized by high density, high species richness, and moderate-to-low diversity. Recruitment is strong, although marked by annual inconsistency such as seen in the dominant *F. ebena* that is heavily dominated by 1981 and 1990 year classes. The shoal consists mainly of stable, firmly packed gravel and gravelly sand. However, areas of bedrock and unstable sand do occur, typically on the thalweg side of the bed. Although the bed is free of excessive sedimentation, during low-water periods, 1 to 3 cm of silt accumulate in some areas. Comparatively high-density populations of *C. fluminea*, which characterized the shoal in the 1980s, have had no effects on native mussels. Although densities of *D. polymorpha* have exceeded 10,000 individuals per square meter, little mortality of native mussels can be attributed to this species.

Continued monitoring, using qualitative and quantitative methods, will provide data that can be used to determine if construction and operation of the Olmsted Locks and Dam Project has negative effects on freshwater mussels.

The detailed database developed since 1983 will be invaluable for interpreting causes and significance of fluctuations in physical and biotic parameters and population demographics of nonindigenous species.

References

- Aldridge, D., Payne, B. S., and Miller, A. C. (1987). "The effects of intermittent exposure to suspended solids and turbulence on three species of freshwater mussels," *Environmental Pollution* 45, 17-28.
- Burch, J. B. (1975). *Freshwater Unionacean clams (Mollusca: Pelecypoda) of North America*. Malacological Publications, Hamburg, MI.
- Gillis, P. L., and Mackie, G. L. (1994). "Impact of the zebra mussel, *Dreissena polymorpha*, on populations of unionidae (Bivalvia) in Lake St. Clair," *Canadian Journal of Zoology* 72, 1260-1271.
- Haag, W. R., Berg, D. J., Garton, D. W., and Farris, J. L. (1993). "Reduced survival and fitness in native bivalves in response to fouling by the introduced zebra mussel (*Dreissena polymorpha*) in western Lake Erie," *Canadian Journal of Fisheries and Aquatic Sciences* 50, 13-19.
- Holland, L. E. (1986). "Effects of barge traffic on distribution and survival of ichthyoplankton and small fishes in the upper Mississippi River," *Transactions of the American Fisheries Society* 115, 162-165.
- Hunter, R. D., and Bailey, J. F. (1992). "*Dreissena polymorpha* zebra mussels: Colonization of soft substrata and some effects on unionid bivalves," *The Nautilus* 106, 60-67.
- Killgore, K. J., Miller, A. C., and Conley, K. C. (1987). "Effects of turbulence on yolk-sac larvae of paddlefish," *Transactions of the American Fisheries Society* 116, 670-673.
- Lewandowski, K. (1976). "Unionidae as a substratum for *Dreissena polymorpha* Pall.," *Polish Archives of Hydrobiology* 23, 409-420.
- McMahon, R. F. (1983). "Ecology of an invasive pest bivalve, *Corbicula fluminea*." W. D. Russell-Hunter, ed., *The Mollusca, Vol. 6, Ecology*. Academic Press, Inc., Orlando, FL, 505-561.

- Miller, A. C., Payne, B. S., and Siemsen, T. (1986). "Description of the habitat of the endangered mussel *Plethobasus cooperianus*," *The Nautilus* 100, 14-18.
- Miller, A. C., and Payne, B. S. (1988). "The need for quantitative sampling to characterize size demography and density of freshwater mussel communities," *Bulletin of the American Malacological Union, Inc.* 6, 49-54.
- _____. (1991). "Investigation of freshwater mussels (Unionidae) at selected sites in the lower Ohio and Cumberland rivers, September 1990," Technical Report EL-91-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- _____. (1994). "Co-occurrence of native freshwater mussels (unionidae) and the non-indigenous *Corbicula fluminea* at two stable shoals in the Ohio River, U.S.A.," *Malacological Review* 27, 87-97.
- Murray, H. D., and Leonard, A. B. (1962). *Handbook of unionid mussels in Kansas*. Museum of Natural History, University of Kansas, Lawrence, KS.
- Nalepa, T. F. (1994). "Decline of native unionid bivalves in Lake St. Clair after infestation by the zebra mussel, *Dreissena polymorpha*," *Canadian Journal of Fisheries and Aquatic Sciences* 51, 2227-2233.
- Neff, S. E., Pearson, W. D., and Holdren, G. C. (1981). "Aquatic and terrestrial communities in the lower Ohio River (RM 930-981)," Contract Report submitted to the U.S. Army Engineer District, Louisville, Louisville, KY.
- Parmalee, P. W. (1967). "The fresh-water mussels of Illinois," *Illinois State Museum Popular Science Series* 8, 1-108.
- Payne, B. S., Killgore, K. J., and Miller, A. C. (1990). "Mortality of yolk-sac larvae of paddlefish, *Polydon spathula*, entrained in high-velocity water currents," *Journal of Mississippi Academy of Sciences* 35, 7-9.
- Payne, B. S., and Miller, A. C. (1987). "Effects of current velocity on the freshwater bivalve *Fusconaia ebena*," *Bulletin of the American Malacological Union, Inc.* 5, 177-179.
- _____. (1989). "Growth and survival of recent recruits to a population of *Fusconaia ebena* (Bivalvia: Unionidae) in the lower Ohio River," *American Midland Naturalist* 121, 99-104.

- Payne, B. S., Miller, A. C., and Aldridge, D. W. (1987). "Environmental effects of navigation traffic: Laboratory studies of the effects on mussels of intermittent exposure to turbulence and suspended solids," Technical Report EL-87-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Payne, B. S., Miller, A. C., and Shafer, D. (1994). "An analysis of freshwater mussels (Unionidae) in the lower Ohio River at two beds near Olmsted, Illinois: 1992 studies," Technical Report EL-94-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Starrett, W. C. (1971). "A survey of the mussels (Unionidae) of the Illinois River: A Polluted Stream," *Illinois Natural History Survey Bulletin* 30(5), 266-403.
- Taylor, R. W. (1989). "Changes in freshwater mussel populations of the Ohio River: 1,000 BP to recent times," *Ohio Journal of Science* 89, 188-191.
- U.S. Army Corps of Engineers. (1991). Draft Supplement I, Final Environmental Impact Statement for the Replacement of Locks and Dams 52 and 53 (Olmsted Locks and Dams) Lower Ohio River, IL-KY, U.S. Army Engineer District, Louisville, Louisville, KY.
- U.S. Fish and Wildlife Service. (1991). "Endangered and threatened wildlife and plants," *Federal Register*, July 15, 1991, 50 CFR 17.11 and 17.12.
- Williams, J. C. (1969). "Mussel fishery investigations, Tennessee, Ohio and Green rivers," Project Completion Report for Investigations Projects Conducted Under the Commercial Fisheries Research and Development Act of 1964, U.S. Fish and Wildlife Service and Kentucky Department of Fish and Wildlife Resources.
- Williams, J. C., and Schuster, G. A. (1982). "Freshwater mussel investigations in the Ohio River Mile 317.0 to Mile 981.0," A report submitted to the Department of Fish and Wildlife Resources, Division of Fisheries, Frankfort, KY.
- Williams, J. D., Warren, M. L., Cummings, K. S., Harris, J. L., and Neves, R. J. (1993). "Conservation status of freshwater mussels of the United States and Canada," *Fisheries* 18, 6-22.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 1997	3. REPORT TYPE AND DATES COVERED Final report	
4. TITLE AND SUBTITLE Spatial Distribution of Mussels at a Bed in the Lower Ohio River Near Olmsted, Illinois			5. FUNDING NUMBERS	
6. AUTHOR(S) Barry S. Payne, Andrew C. Miller				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Waterways Experiment Station 3909 Halls Ferry Road, Vicksburg, MS 39180-6199			8. PERFORMING ORGANIZATION REPORT NUMBER Technical Report EL-97-3	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Engineer District, Louisville P.O. Box 59, Louisville, KY 40201-0059			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>Surveys were conducted to assess the spatial distribution of mussels in and near a prominent mussel bed in the lower Ohio River just downstream of the construction site of a new lock and dam at River Mile (RM) 964.4. Assessments were made of native mussel community characteristics, density, population demography of dominant species, and density and distribution of nonindigenous bivalves. Special emphasis was on delineating the boundaries of the native mussel bed to support analysis of potential impacts of construction and operation of the Olmsted Locks and Dam Project at RM 964.4 on the Ohio River.</p> <p>The upstream and downstream limits of moderate (20 to 50 individuals per square meter) to high-density (>50 individuals per square meter) assemblages of native mussels occurred at RMs 966.3 and 968.0, respectively. The nearshore edge of the bed approximately corresponds to the 279-ft (85.039-m) elevation contour and is determined by recent patterns of low river stage. The major drought of 1988 exposed elevations as high as 277 ft (84.429 m) for at least 24 consecutive days. The farshore limit of the bed approximately corresponds to the 267-ft (81.381-m) elevation contour and is associated with increasingly erosional conditions toward the thalweg. Substratum changes from a stable mix of cobble, gravel, and sand to scoured sand and bedrock moving from nearshore to farshore across the bed.</p> <p style="text-align: right;">(Continued)</p>				
14. SUBJECT TERMS <i>Corbicula fluminea</i> <i>Dreissena polymorpha</i> Lower Ohio River			15. NUMBER OF PAGES 61	
Olmsted Locks and Dam Project Unionids			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

13. (Concluded).

The community is species rich (32 species have been collected since 1983), but diversity is low due to a very inequitable distribution of species relative abundance. *Fusconaia ebena* is heavily dominant and comprised 84 percent of the native mussel community in 1994. This dominant population in turn is comprised mostly of individuals representing two extremely successful year classes (probably 1981 and 1990 cohorts). This mussel community has successfully coexisted with the Asian clam, *Corbicula fluminea*, since the late 1950s. During surveys conducted since 1983, the density of *C. fluminea* has ranged greatly, from thousands of individuals per square meter from 1983 to 1987 to less than 100 individuals per square meter in 1994. This change in Asian clam abundance has had no apparent effect on the unionid community. Another nonindigenous bivalve, the zebra mussel, *Dreissena polymorpha*, capable of bysally attaching to unionids, first appeared near this bed in 1991. The density of this species rose from 39 to 39,000 individuals per square meter from 1993 to 1994. In 1994, a young cohort of zebra mussels heavily infested most native unionids in the mussel bed, but there was little evidence of unionid mortality. Continued monitoring is needed to evaluate potential effects of this second introduced species on native mussels.

Drought, natural patterns of recruitment, and species introductions are natural factors that potentially affect native mussels in the lower Ohio River. Effects of construction and operation of the Olmsted Locks and Dam Project can best be monitored by regularly monitoring density, diversity, and size demography of dominant native mussel populations in the lower Ohio River.