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Freshwater Mussels in the Lower Ohio River in Relation to the Olmsted Locks and Dam Project: Update Through 2001 Studies

Barry S. Payne and Andrew C. Miller

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Environmental Laboratory

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Preface

The study reported herein was conducted by the U.S. Army Engineer Research and Development Center (ERDC) in 2000 and 2001 for the U.S. Army Engineer District, Louisville, Louisville, KY. The purpose was to analyze spatial distribution, density, recruitment, and community composition of mussels in prominent beds in the lower Ohio River in relation to construction and operation of the Olmsted Locks and Dam Project.

Divers for this study were from Mainstream Diving Inc. of Murray, KY. Assistance in the field was provided by Mssrs. Will Green (University of Southern Mississippi) and Mark Farr (University of Georgia) and Ms. Katheryn Barko (University of Wisconsin at Stevens Point). Dr. Andrew C. Miller, Environmental Laboratory (EL), ERDC, served as dive inspector for this work.

During the conduct of this study Dr. Edwin A. Theriot was Director, EL; Dr. Dave Tazik was Chief, Ecosystem Evaluation and Engineering Division (EEED), EL; and Dr. Alfred F. Cofrancesco was Chief, Aquatic Ecology and Invasive Species Branch (AEIB), EEED. Authors of this report were Drs. Barry S. Payne and Andrew C. Miller, AEIB.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston. Commander and Executive Director was COL John W. Morris III, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters

1 Introduction

Background

The U.S. Army Engineer District, Louisville, is replacing Locks and Dams 52 and 53 in the lower Ohio River with a new structure located slightly downstream of Lock and Dam 53 (U.S. Army Engineer District, Louisville 1991) near Olmsted, IL. The structure being built will consist of two 110-ft[1] by 1,200-ft 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. The new locks will be on the right descending bank (RDB) on the Illinois side of the river. During periods of normal and low flow, navigation will pass through the locks. During high flow, vessels will use the navigable pass near the center of the channel. The new project, now being constructed, is at river mile (RM) 964.4. Existing Lock and Dam 53 is at RM 962.8. Existing Lock and Dam 52 is at RM 938.9.

Once completed, the Olmsted project will increase water levels by a maximum of 10 ft in the pool above the dam for approximately 42 percent of the year. This increased stage will occur only during normal and low flow. During high water periods (58 percent of the year), dam sections will be lowered to a horizontal position on the river bottom. Upriver stage will be similar to preproject conditions when these dam sections are down. In addition to upstream changes, the hydraulic regimen immediately downstream of the new structure will be altered, as will navigation traffic patterns. 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 at RM 964.4, as they have always done.

Potential changes in hydraulics and traffic patterns immediately downriver of the new 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 (Payne, Miller, and Shafer 1994, Payne and Miller 1997). This bed includes the endangered species, *Plethobasus cooperianus* (U.S. Fish and Wildlife Service 1991), and is heavily dominated by a single species, *Fusconaia ebena* (Lea). In addition, the bed and other species have economic, ecological, and cultural value deserving protection. Results of previous studies of this prominent mussel bed are included in Williams (1969), Williams and Schuster

[1] A table of factors for converting U.S. customary units to SI is presented on page viii.

(1982), Neff, Pearson, and Holdren (1981), Miller, Payne, and Siemsen (1986), Miller and Payne (1988, 1991), Payne and Miller (1989, 1997), and Payne, Miller, and Shafer (1994).

River hydraulics determine sedimentation, substratum type, bed stability, and, therefore, where a mussel bed can exist in a large river (Coker et al. 1921). Long-term stability of a mussel bed depends on clay, silt, and sand deposited during seasonal low flows being removed by subsequent high flows without eroding underlying gravel and cobble. Reproduction and recruitment of *F. ebena* potentially relates to hydraulic conditions in several ways (Payne and Miller 2000). Sperm released by males must be entrained in water currents drawn through the mantle cavities of nearby females. Low water velocity associated with low discharge might enhance fertilization success (Yokely 1972). In contrast, high discharge in spring attracts spawning aggregations of *Alosa chyrsochloris*, the only host fish of *F. ebena* glochidia (Coker et al. 1921, Surber 1913), to swiftly flowing water over gravelly shoals (Wallus, Yeager, and Simon 1990). In turn, depositional conditions probably benefit settlement of juvenile mussels after the 1- to 3-week period typically required for metamorphosis (Coker et al. 1921, Howard 1914). Juvenile *F. ebena* probably settle at a length of approximately 0.15 mm (Howard 1914) and are thus susceptible to being swept downstream during high discharge.

Planning and construction of the Olmsted Locks and Dam Project have been the basis of regular quantitative sampling of a prominent mussel bed in a mainstream shoal since 1983. *Fusconaia ebena* heavily dominates the lower Ohio River (LOR) mussel community (Miller, Payne, and Siemsen 1986); relative abundance of the dominant typically varies from 70 to 90 percent. The dominant population is characterized by extreme annual variation in recruitment success; approximately a decade ago, Payne and Miller (1989) described growth and survival of a cohort of 1981 recruits that dominated the population during the 1980's. Continued monitoring has yielded additional information on growth and survival of that important cohort, the early growth and survival of an even more abundant and recent cohort of 1990 recruits (Payne and Miller 2000), and a much longer record of annual variation in recruitment.

Purpose and Scope

The objective of the present study is to evaluate the spatial distribution of mussels in the bed downstream of the Olmsted project as well as selected locations in the upriver pool. In addition, recruitment patterns, community composition, and density of nonindigenous species, including the Asian clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena polymorpha,* were characterized. Special emphasis is given to an evaluation of annual variation in recruitment of the dominant unionid, *F. ebena*, in relation to river hydraulic conditions. 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 Sites and Methods

2000 Studies

Sampling was conducted from 6-9 August 2000 at a major mussel bed downriver of the Olmsted Locks and Dam Project. The mussel bed occurs approximately at RM 967 to 969, a few miles downstream of both the construction project at RM 964.4 and existing Lock and Dam 53 (Figure 1). A second mussel bed was sampled upstream of the project and Post Creek Outlet (PC) at RM 956.5.

At the Olmsted mussel bed (OLM), four sites were quantitatively sampled 10 times each using 0.25-m^2 quadrats (Table 1). Substratum within each quadrat was transferred into a 10-L plastic bucket, winched to the surface, and processed through a nested series of sieves (smallest mesh equaled 6 mm). All live unionids and *C. fluminea* were sorted from the sediment and kept for later measurement of shell length. All four sites were within a central portion of the bed along the RDB, approximately 0.1 to 0.3 mile upstream of the point where Humphrey Creek empties into the river on the opposite bank (Figure 2). Two of these sites were essentially subsites of a single location and are indicated by WP 1 and 2 in Figure 2. The same was true of the second pair of sites, indicated by WP 3 and 4 in Figure 2. In addition to the 0.25-m^2 quadrats sampled for native mussels, five 0.0625-m^2 quadrats were sampled for zebra mussels *(D. polymorpha*) at each site of quantitative sampling. The mussel bed spans from 266 ft farshore to 280 ft nearshore (Payne and Miller 1998). All sites were within the central portion of the bed with respect to depth.

In addition, eight sites were sampled semiquantitatively for unionids and quantitatively for zebra mussels (Table 1). These sites are indicated by WP 9-14 and 18-19 in Figure 2. At each site, one diver moved approximately 100 ft nearshore and a second diver moved approximately 100 ft farshore, describing substratum and mussel density. At their final position, each diver removed all unionids (by feel) from substratum within four placements of a 0.25-m^2 quadrat. Thus, a total of 64 semiquantitative samples of native mussels were collected throughout the mussel bed.

Six sets of qualitative samples were collected at OLM (Table 1 and Figure 2). Four of these were based on 30-min searches by each of two divers. Two were based on 15-min searches by each of two divers. In addition, a 45-min search by each of two divers was conducted for mussels other than the dominant taxon

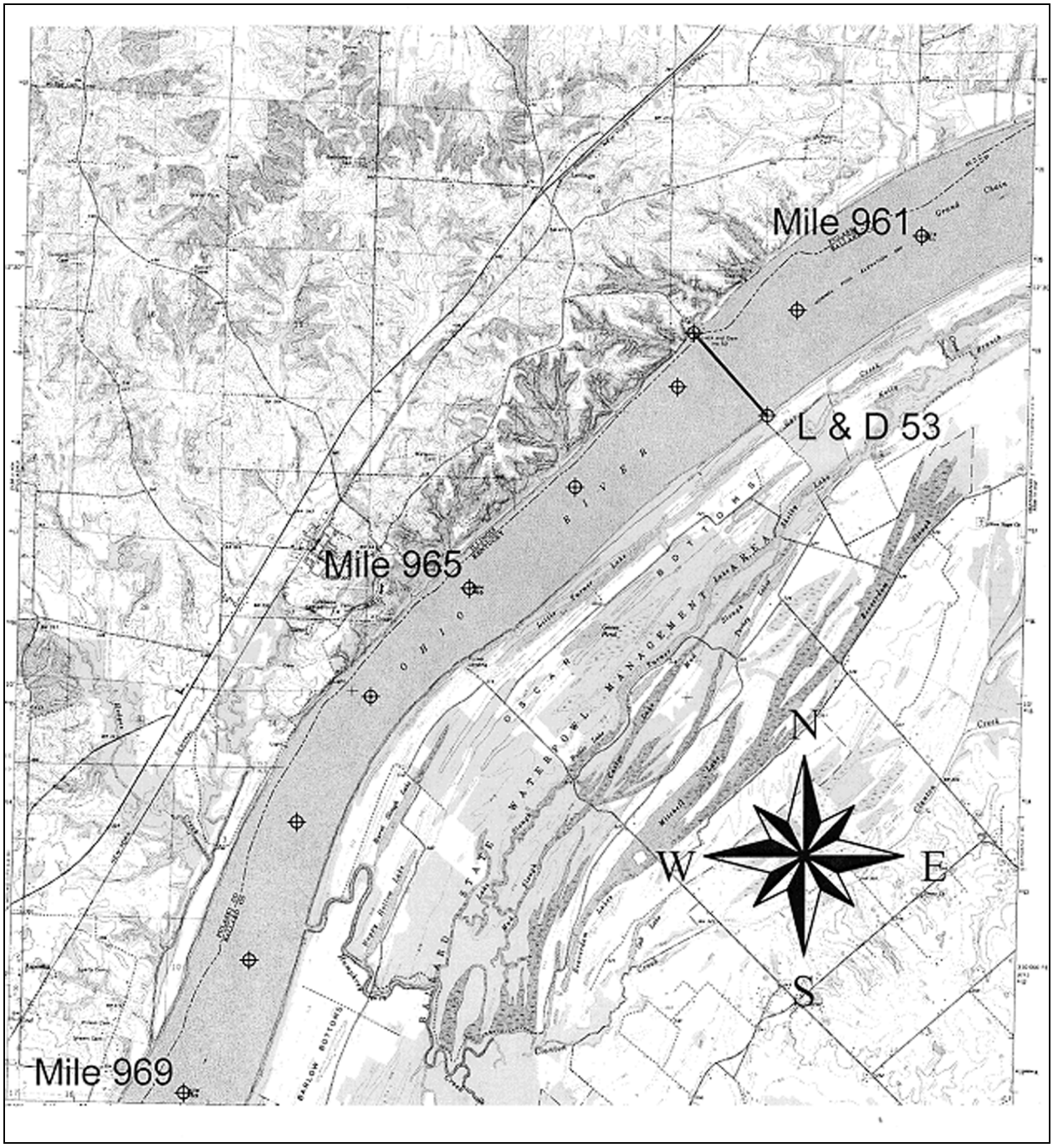

Figure 1. Lower Ohio River from RM 961 to 969

Table 1
Waypoints (WP) for Lower Ohio River Sites Quantitatively Sampled, 6-9 August 2000

Date	Location	WP	Latitude	Longitude	Quant	Qual	Zebra	Notes	Semiquant
6 Aug	LOR, OLM	1	37.147683	89.096487	1		1		
6 Aug	LOR, OLM	2	37.147538	89.096460	2				
6 Aug	LOR, OLM	3	37.150049	89.095736	3		2		
6 Aug	LOR, OLM	4	37.149936	89.095833	4	1			
6 Aug	LOR, OLM	5	37.149941	89.096004		2			
7 Aug	LOR, PC	6	37.229705	88.954556	1	1	1		
7 Aug	LOR, PC	7	37.230445	88.954754	2	2	2		
7 Aug	LOR, PC	8	37.230751	88.954346	3	3	3		
8 Aug	LOR, OLM	9	37.157639	89.092282		3			1
8 Aug	LOR, OLM	10	37.157993	89.092528					2
8 Aug	LOR, OLM	11	37.157425	89.091911					3
8 Aug	LOR, OLM	12	37.151819	89.095661					4
8 Aug	LOR, OLM	13	37.150939	89.095178		4			5
8 Aug	LOR, OLM	14	37.149791	89.095173		5		Two 15-min	6
8 Aug	LOR, OLM	15	37.180186	89.059999				Damsite	
8 Aug	LOR, OLM	16	37.156518	89.090495				Upriver buoy	
8 Aug	LOR, OLM	17	37.136654	89.099910				Downriver buoy	
8 Aug	LOR, OLM	18	37.144223	89.096954		6		Two 15-min	7
8 Aug	LOR, OLM	19	37.144566	89.097973				Non-*F. ebena*	8

(*F. ebena*). Such selective qualitative searches in the past have been more successful than any method for obtaining specimens of locally very rare species, including *P. cooperianus*.

At the PC location, three sites (Table 2; WP 6-8 are shown in Figure 3) were quantitatively sampled for native unionids by removing substratum with mussels from replicate (n = 10) 0.25-m^2 quadrats. These sites were distributed along a nearshore to farshore gradient. At each site, five 0.0625-m^2 quadrats were sampled for *D. polymorpha*. In addition, at the nearshore, midshore, and farshore locations, each of two divers conducted a 30-min qualitative search for unionids.

The anchored boat positions at all sites in each mussel bed were recorded using a hand-held Garvin geographic positioning system. Recorded latitudes and longitudes (in decimal degrees) are summarized in Tables 1 and 2.

2001 Studies

Studies in 2001 were similar to those in 2000 with a few exceptions. Sampling was conducted from 27-29 July in 2001. Four sites (WP 1-4 in Figure 4) were quantitatively sampled for native mussels at OLM as in 2000. However, at OLM in 2001 an extensive set of qualitative samples was collected

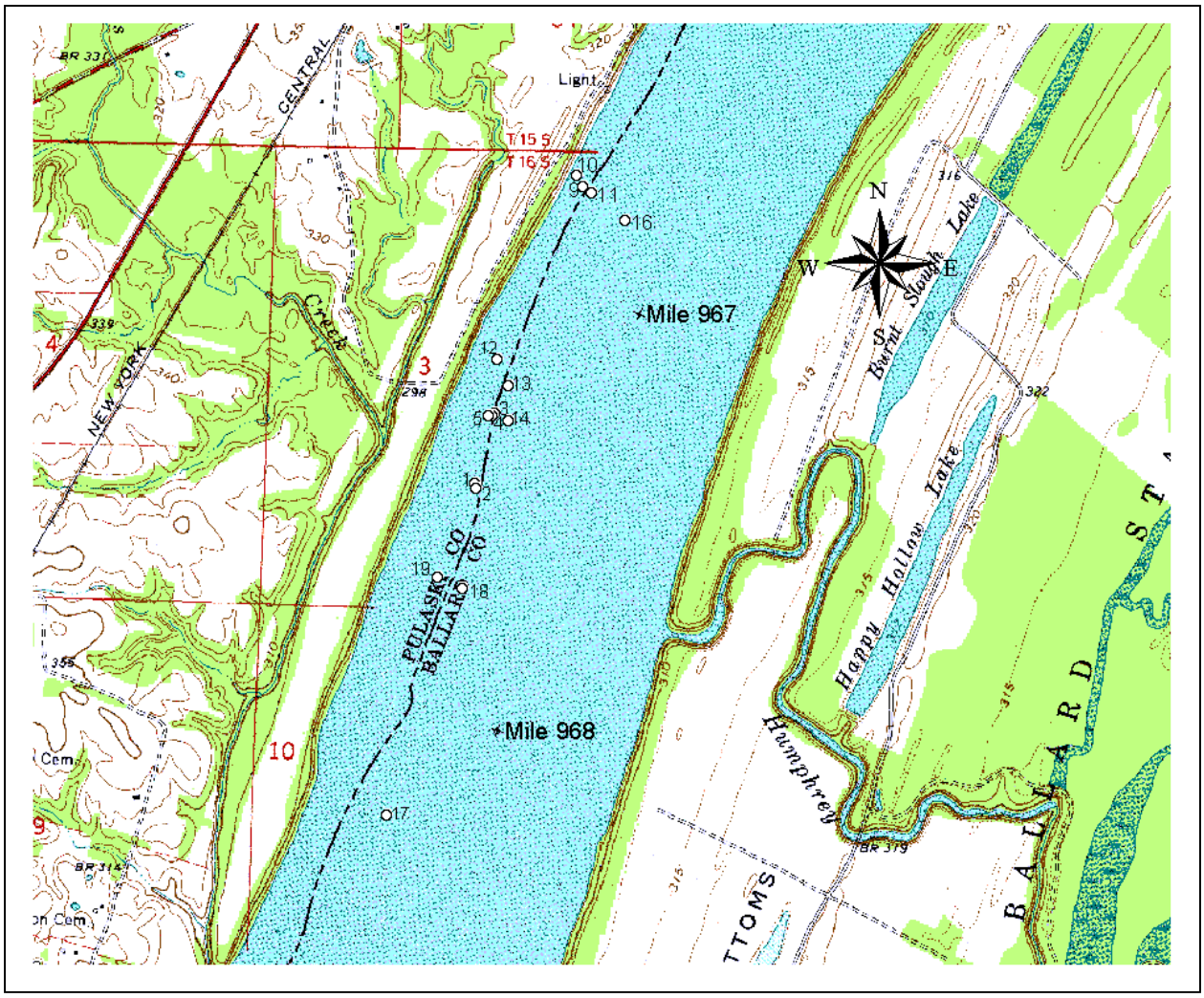

Figure 2. Sampling sites at the OLM mussel bed, lower Ohio River, 2000

(at WP 1-4, 5-11, and 27-30 in Figure 4). Semiquantitative sampling was not conducted in 2001. Also near OLM in 2001, six sites along the Kentucky shore opposite of the lock construction site were sampled (WP 20-25 in Figure 5).

Studies at PC involved four quantitative sampling sites in 2001 (two pairs of closely adjacent sites identified as WP 12-15) and qualitative samples at these plus four additional sites (WP 16-19). The locations of these sites are shown in Figure 6.

A summary of the sampling scheme with latitude and longitude data is provided in Table 2.

Table 2
Waypoints and Coordinates for Sampling Sites in the Lower Ohio River, 27-29 July 2001

					Quantitative Samples		Qualitative Samples		
WP	Longitude	Latitude	Date	Site	Unionids	*D. polymorpha*	Minutes	No.	Total, min
1	89.096412	37.147436	27-Jul-01	Olmsted Bed	10	5	30	2	60
2	89.096444	37.147399	27-Jul-01	Olmsted Bed	10	5	30	2	60
3	89.095940	37.149614	27-Jul-01	Olmsted Bed	10	5	30	2	60
4	89.095886	37.149362	27-Jul-01	Olmsted Bed	10	5	30	2	60
5	89.095291	37.151417	27-Jul-01	Olmsted Bed			15	2	30
6	89.095264	37.152522	27-Jul-01	Olmsted Bed			15	2	30
7	89.093451	37.156379	27-Jul-01	Olmsted Bed			15	2	30
8	89.097667	37.144319	27-Jul-01	Olmsted Bed			15	2	30
9	89.096337	37.143901	27-Jul-01	Olmsted Bed			15	2	30
10	89.098826	37.144738	27-Jul-01	Olmsted Bed			15	2	30
11	89.096466	37.145714	27-Jul-01	Olmsted Bed			15	2	30
12	88.955746	37.230370	28-Jul-01	Post Creek	10	5	30	2	60
13	88.956208	37.230220	28-Jul-01	Post Creek	10	5	30	2	60
14	88.955231	37.229764	28-Jul-01	Post Creek	10	5	30	2	60
15	88.955510	37.229807	28-Jul-01	Post Creek	10	5	30	2	60
16	88.956385	37.229362	28-Jul-01	Post Creek			14	2	28
17	88.953177	37.230086	28-Jul-01	Post Creek			15	2	30
18	88.954432	37.229362	28-Jul-01	Post Creek			15	2	30
19	88.951391	37.230177	28-Jul-01	Post Creek			15	2	30
20	89.060884	37.175814	29-Jul-01	Olmsted - Replacement			15	2	30
21	89.068356	37.170787	29-Jul-01	Olmsted - Replacement			15	2	30
22	89.067434	37.171319	29-Jul-01	Olmsted - Replacement			15	2	30
23	89.065084	37.172552	29-Jul-01	Olmsted - Replacement			15	2	30
24	89.062241	37.174602	29-Jul-01	Olmsted - Replacement			15	2	30
25	89.063105	37.173915	29-Jul-01	Olmsted - Replacement			15	2	30
26	89.097297	37.150751	29-Jul-01	Olmsted - Shore Site					
27	89.092169	37.158245	29-Jul-01	Olmsted Bed			15	2	30
28	89.091874	37.157779	29-Jul-01	Olmsted Bed			15	2	30
29	89.100039	37.137287	29-Jul-01	Olmsted Bed			15	2	30
30	89.100988	37.137330	29-Jul-01	Olmsted Bed			15	2	30

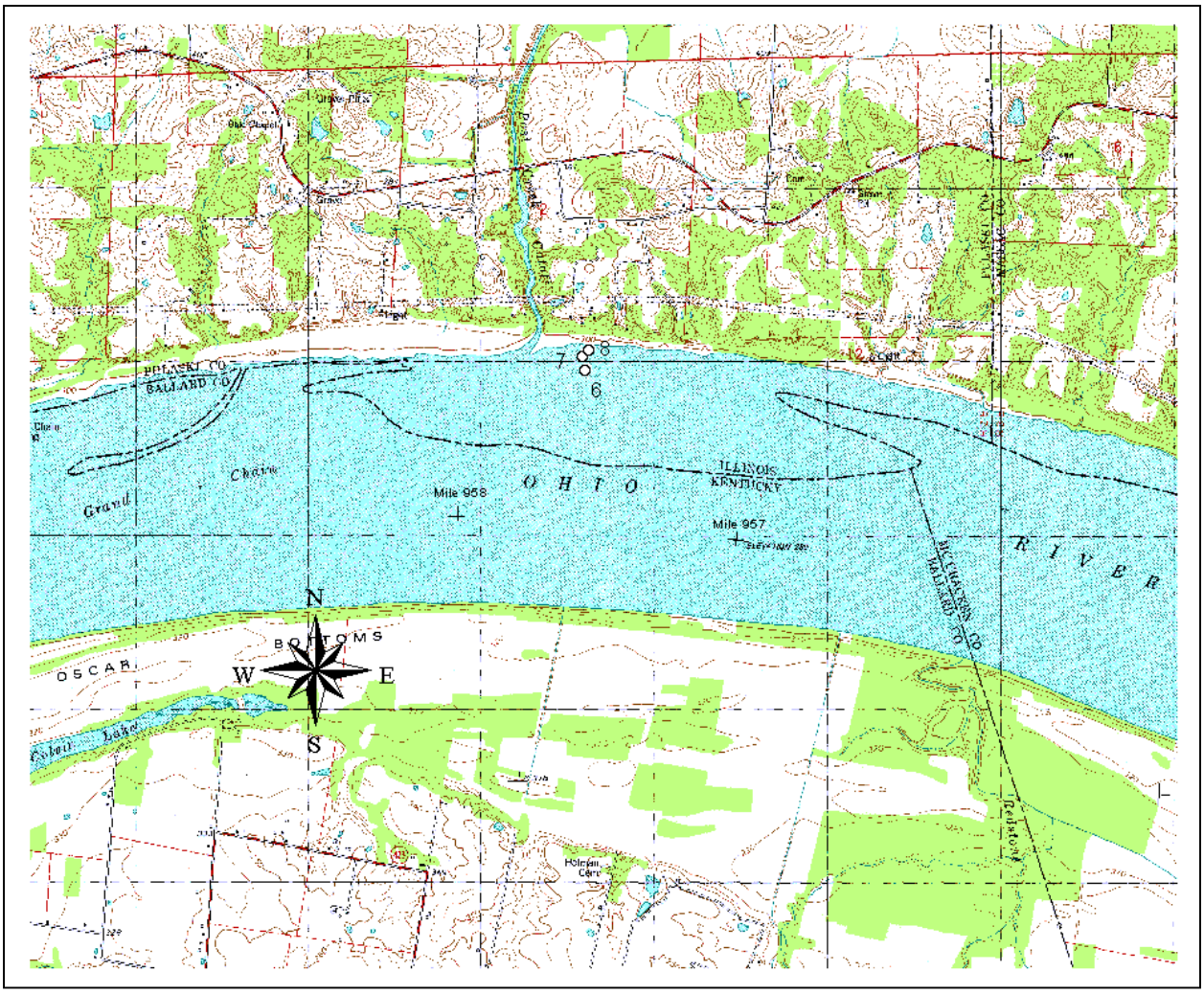

Figure 3. Sampling sites at the PC mussel bed, lower Ohio River, 2000

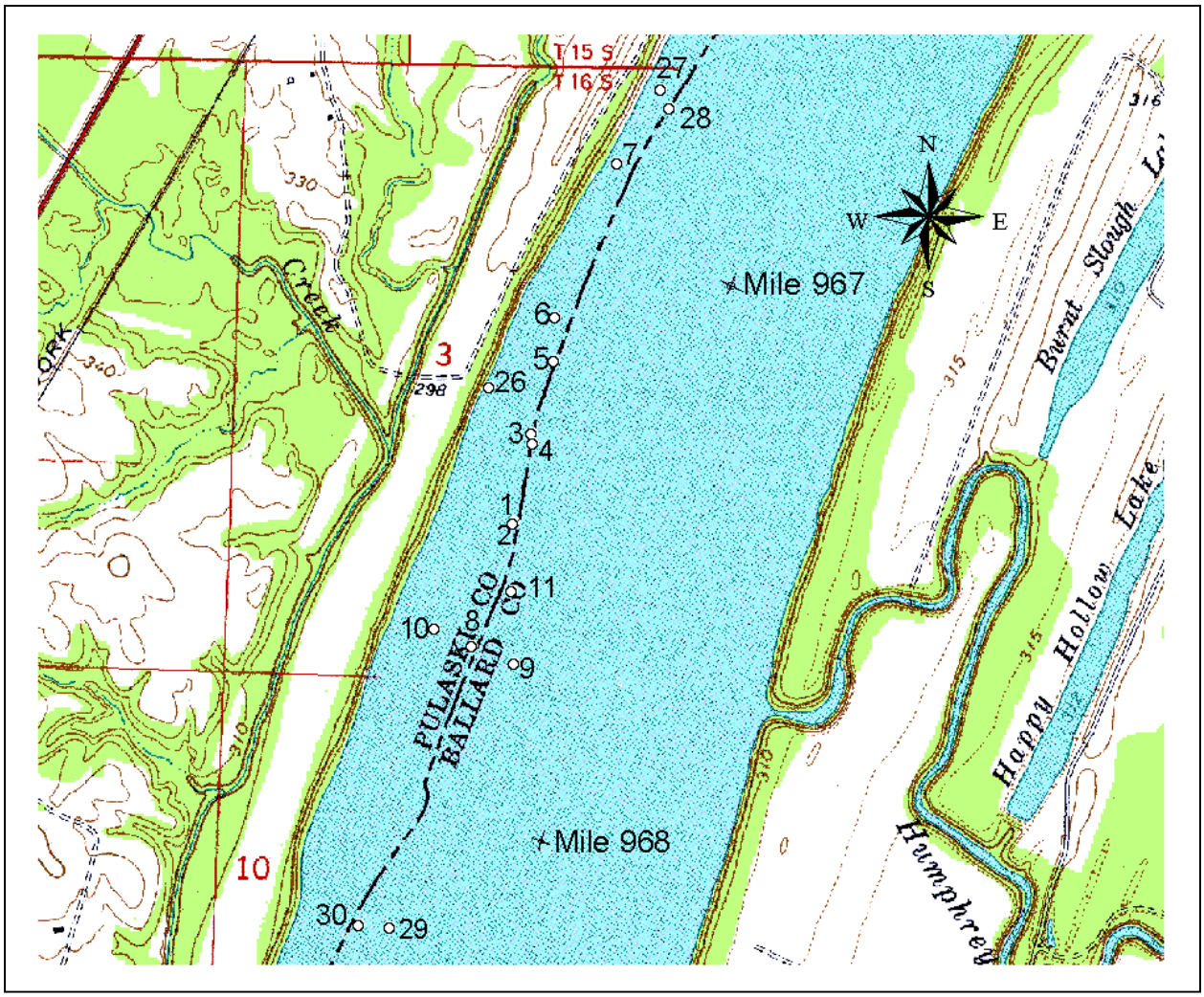

Figure 4. Sampling sites at the OLM mussel bed, lower Ohio River, 2001

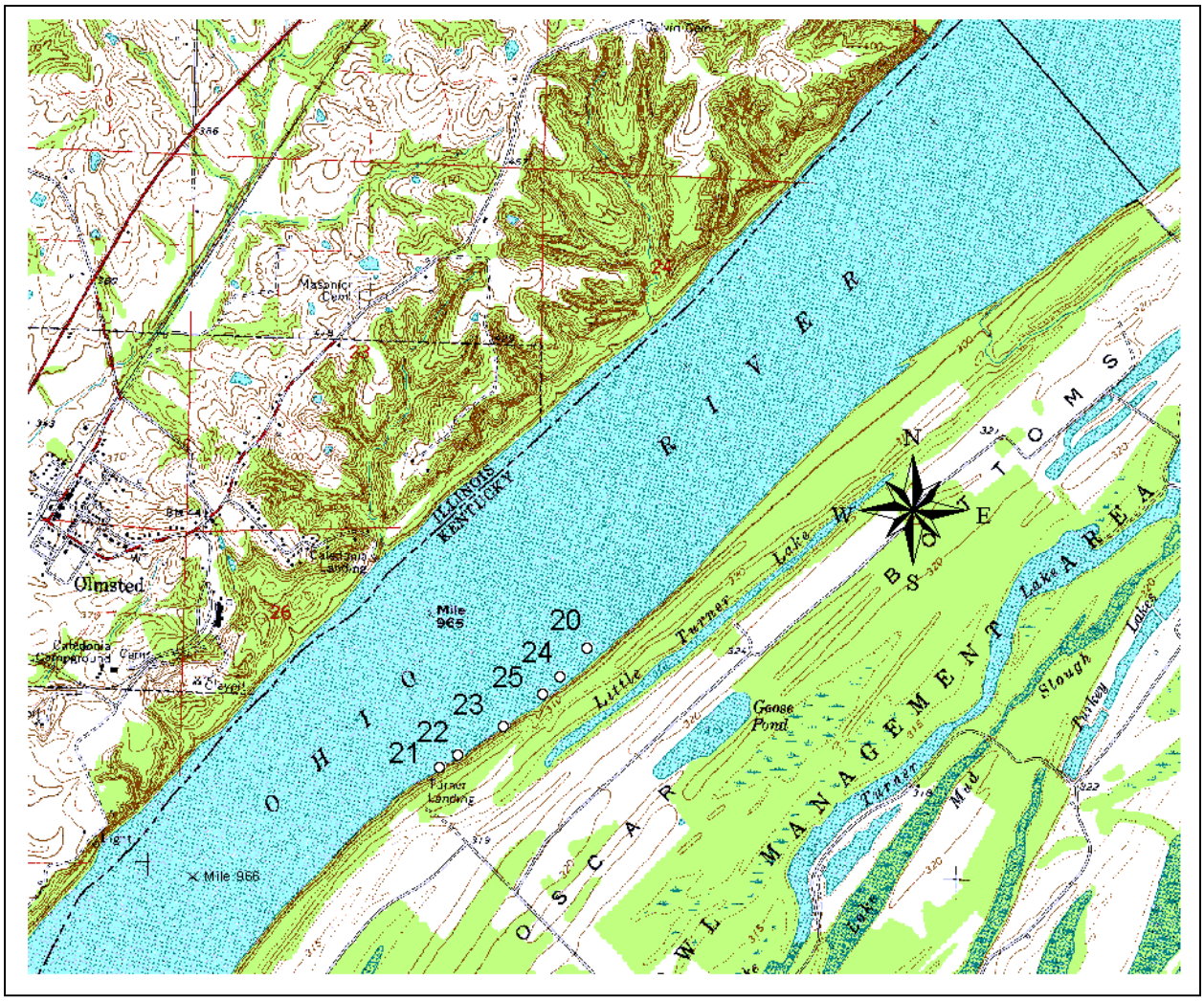

Figure 5. Sampling sites across from the OLM Locks and Dam Project, lower Ohio River, 2001

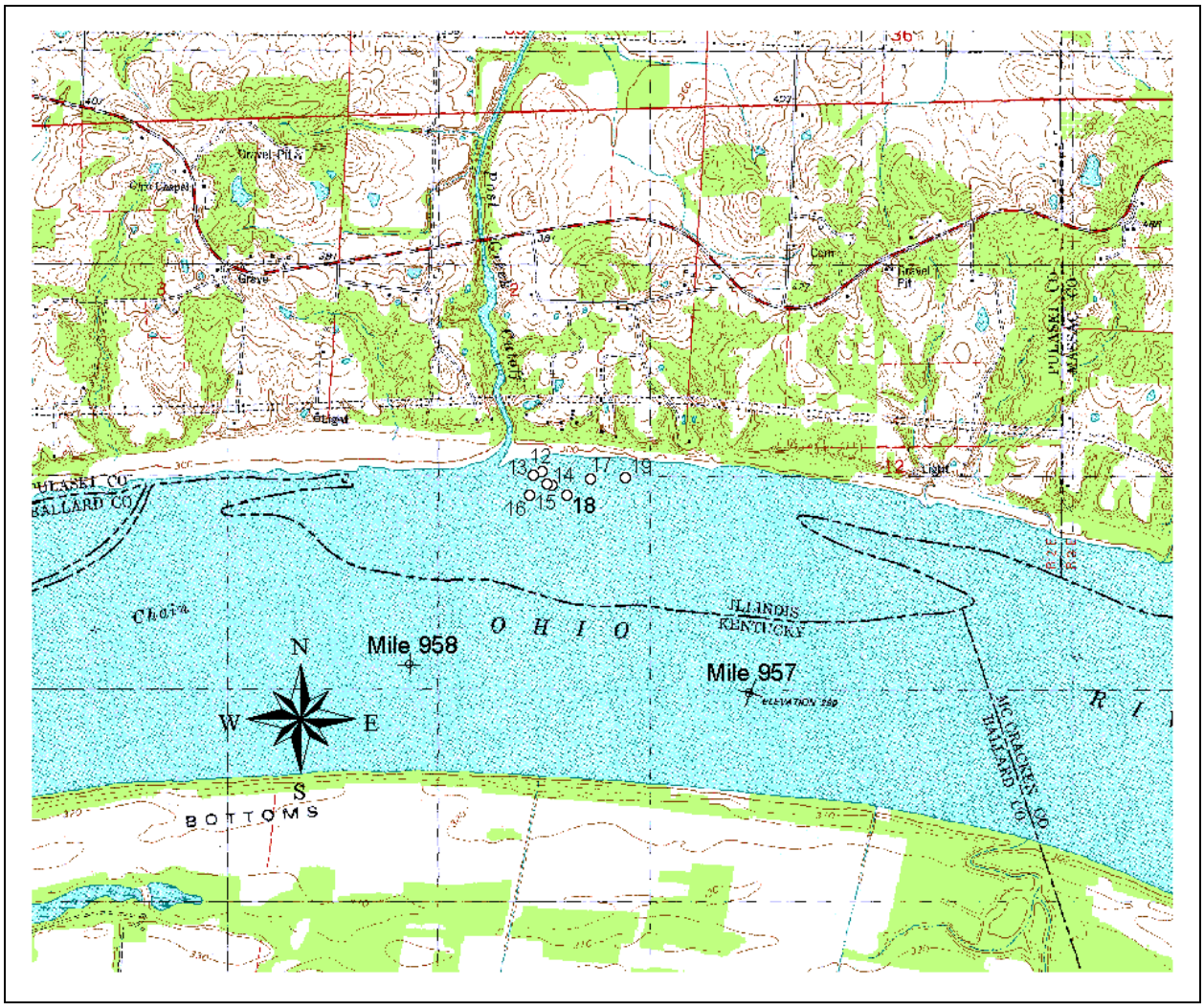

Figure 6. Sampling sites at the PC mussel bed, lower Ohio River, 2001

3 Results

Olmsted 2000

Quantitative studies

A total of 15 species of native mussels were included among 536 individuals obtained by quantitative sampling of the Olmsted bed in 2000. All four sites were heavily dominated by *F. ebena* (Tables 3 and 4). Relative abundance of *F. ebena* was consistently high among the four sites, ranging from 80.4 percent at WP 4 to 90.8 percent at WP 1. Mussel density was high and identical (65.2 individuals/m^2) at the closely adjacent sites WP 1 and WP 2. Approximately one third fewer mussels occurred at the other two closely adjacent sites, WP 3 (41.2 individuals/m^2) and WP 4 (42.8 individuals/m^2). *Quadrula pustulosa* (5.0 percent), *Obliquaria reflexa* (2.2 percent), *Ellipsaria lineolata* (2.1 percent), and *Q. quadrula* (1.3 percent) were the only species other than *F. ebena* that individually comprised at least 1 percent of the native mussel community.

Recently recruited mussels (individuals less than 30 mm long) comprised approximately 25 percent of the community. Eight of the fifteen species of native unionids collected by quantitative methods included at least one individual less than 30 mm long. The community-wide evidence of recent recruitment was especially impressive because of the difficulty inherent in obtaining recruits in small samples of all species other than the heavily dominant *F. ebena*. Although a total of only 78 individuals of species other than *F. ebena* were obtained in quantitative samples, 30 of these individuals were less than 30 mm long.

Due to the heavy dominance of *F. ebena*, diversity was extremely low, measuring just 0.31 (Shannon's Index). A total of 15 species were included among the 875 individuals collected. Evenness expresses Shannon's index as a fraction of maximum possible diversity, which corresponds to equal abundance of all species (Pileou 1969). In the case of 15 species, maximum diversity equals 1.18 (i.e., the logarithm of 15). Thus, evenness was only 0.26. By any measure, the community at Olmsted, although rich in species, is low in diversity due to the extreme dominance of *F. ebena*.

The number of *F. ebena* per 0.25-m^2 quadrat (n = 40) ranged from 0 to 22 and averaged 11.8 (S.D. = 4.26). All other native mussels ranged from 0 to 5 individuals/0.25-m^2 quadrat with an average value of 1.90 (S.D. = 1.30). There

Table 3
Number of Individuals of Each Species Obtained by Quantitative Sampling at Four Sites in the Lower Ohio River Near Olmsted, 2000

Species	Waypoint				Total
	1	2	3	4	
Fusconaia ebena	148	137	88	86	459
Quadrula pustulosa	1	10	7	9	27
Obliquaria reflexa	5	3	3	1	12
Ellipsaria lineolata	2	5	1	3	11
Quadrula quadrula	1	2		4	7
Leptodea fragilis	1		1	1	3
Ligumia recta	2		1		3
Obovaria olivaria	1	1		1	3
Quadrula nodulata		2	1		3
Elliptio crassidens		1		1	2
Quadrula metanevra	1	1			2
Amblema plicata			1		1
Lampsilis teres		1			1
Pleurobema cordatum	1				1
Truncilla donaciformis				1	1
Total individuals	163	163	103	107	536
Total species	10	10	8	9	15
Corbicula fluminea (nonindigenous)	8	4	7	16	35

was no apparent relationship between the density of the dominant and all other species (Figure 7).

Fusconaia ebena at OLM in 2000 ranged from 7.5 to 80.6 mm long (Figure 8). Approximately 16 percent of the population was represented by a single cohort of recent recruits that ranged from 7.5 to 18.1 mm with an average length of 12.2 mm. These probably represented 1998 recruits. Approximately 10 percent of the population was represented by 1997 recruits that had an average length of 24.2 mm and ranged from 19.7 to 30.8 mm. Other moderately recent recruits, possibly representing 1995 and 1996 recruitment, ranged from approximately 31 to 42 mm. The dominant 1990 cohort mainly was represented by mussels ranging from 47.5 to 70.3 mm long with an average length of 59.0 mm. This cohort comprised 65 percent of the population in 2000. The once dominant 1981 cohort (Payne and Miller 2000) was probably represented by mussels that ranged from 73.1 to 80.6 mm long. The remaining survivors of this old cohort comprised only 2 percent of the population in 2000.

Potential density dependence in recruitment patterns was investigated for the dominant *F. ebena* population. The two recent recruitment cohorts (1997 and 1998 year classes) were less than 40 mm long. Therefore, the density of *F. ebena* less than 40 mm long was plotted in relation to the density of *F. ebena* greater than 40 mm long (Figure 9). No relationship was evident. Thus, within the

Table 4
Species Percent Relative Abundance and Summary Statistics for Quantitative Sampling at Four Sites in the Lower Ohio River Near Olmsted, 2000

Species	Waypoint				Total
	1	2	3	4	
F. ebena	90.80	84.05	85.44	80.37	85.63
Q. pustulosa	0.61	6.13	6.80	8.41	5.04
O. reflexa	3.07	1.84	2.91	0.93	2.24
E. lineolata	1.23	3.07	0.97	2.80	2.05
Q. quadrula	0.61	1.23	0.00	3.74	1.31
Q. nodulata	0.00	1.23	0.97	0.00	0.56
L. fragilis	0.61	0.00	0.97	0.93	0.56
L. recta	1.23	0.00	0.97	0.00	0.56
O. olivaria	0.61	0.61	0.00	0.93	0.56
Q. metanevra	0.61	0.61	0.00	0.00	0.37
E. crassidens	0.00	0.61	0.00	0.93	0.37
A. plicata	0.00	0.00	0.97	0.00	0.19
P. cordatum	0.61	0.00	0.00	0.00	0.19
L. teres	0.00	0.61	0.00	0.00	0.19
T. donaciformis	0.00	0.00	0.00	0.93	0.19
Total individuals	163	163	103	107	536
Total species	10	10	8	9	15
Mean density (individuals/m^2)	62.0	63.6	38.4	36.4	50.1
Species diversity (H´)					0.31
Evenness					0.26

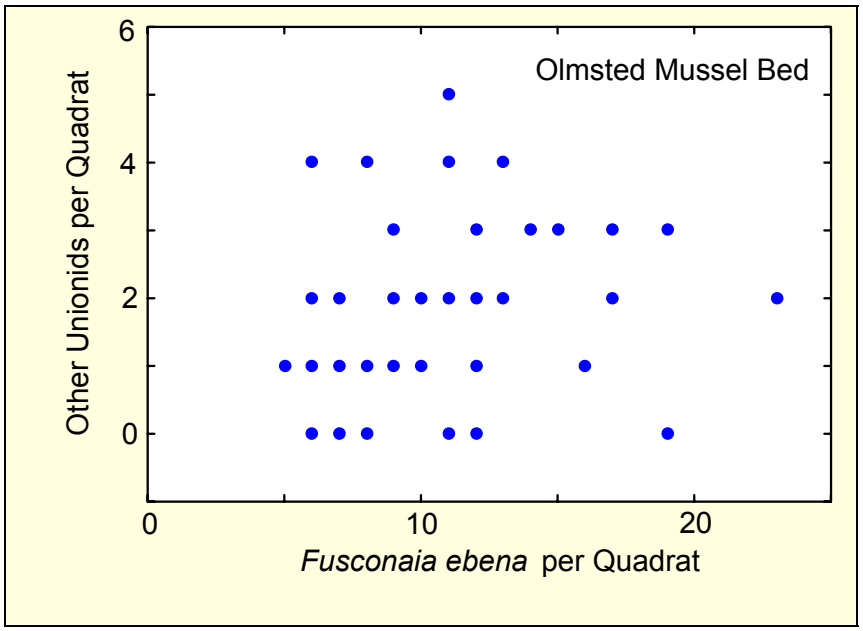

Figure 7. Relationship of *F. ebena* density to that of other unionids in the OLM mussel bed

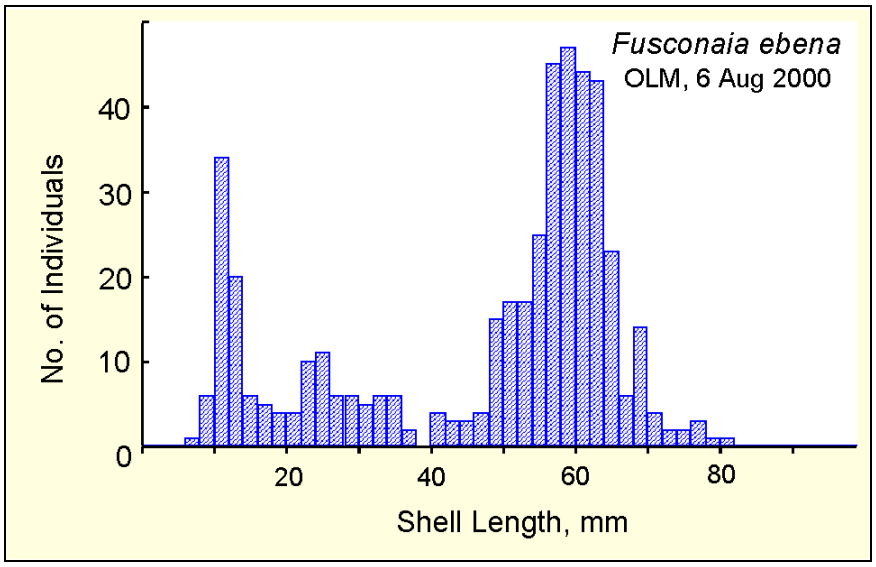

Figure 8. Length frequency of *F. ebena*, OLM mussel bed, 2000

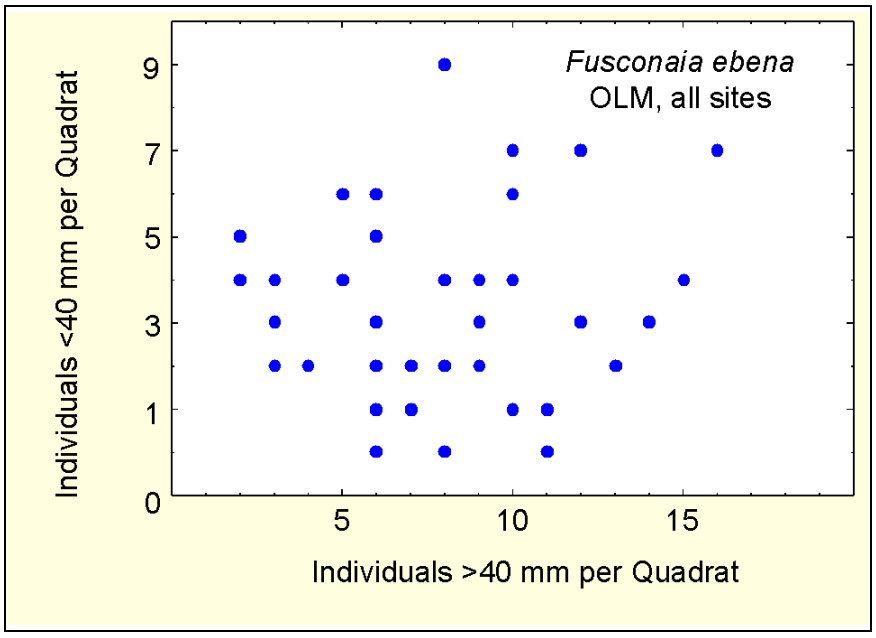

Figure 9. Relationship of density of large and small *F. ebena* in the OLM mussel bed, 2000

central portion of the mussel bed, where all data were obtained, density of recent recruits was independent of the density of adults.

Semiquantitative mapping

Mussel density at the semiquantitative mapping sites (WP 9-14, 18, and 19) ranged from 0 to 73 individuals/m^2. The nearshore diver at WP 10 and 12 was

above the 279 elevation contour that essentially defines the nearshore limit of the mussel bed (see Payne and Miller 1998); mussel density at these two locations averaged 0 and 3 individuals/m^2. Sites of highest mussel density also exhibited extremely heavy dominance by *F. ebena* (Table 5).

Table 5
Relative Abundance of Species at Semiquantitative Mapping Sites in the Lower Ohio River Near Olmsted, 2000

Species	WP 9[1]		WP 10		WP 11		WP 12		WP 13		WP 14		WP 18		WP 19		All	
	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	n	%
F. ebena	7	17	0	8	10	56	0	11	43	64	62	11	50	17	13	28	397	87.6
Q. quadrula	0	1	0	4	1	0	1	0	2	4	1	1	0	0	0	0	15	3.3
Q. pustulosa	0	1	0	1	0	2	0	0	1	2	0	0	2	0	1	2	12	2.6
E. lineolata	1	1	0	0	2	0	0	1	0	1	0	0	0	0	1	1	8	1.8
O. olivaria	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	4	0.9
A. plicata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	3	0.7
L. cardium	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	3	0.7
Q. metanevra	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	3	0.7
E. crassidens	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0.4
M. nervosa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0.4
O. reflexa	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0.4
L. recta	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0.2
Q. nodulata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0.2
No. of quads	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	64	
Total individuals	8	22	0	13	16	59	3	14	46	73	64	14	52	18	17	34	453	
Total species	2	6	0	3	5	3	3	4	3	4	3	4	2	2	6	7	13	
Avg. density	8	22	0	13	16	59	3	14	46	73	63	14	52	18	17	34	28.3	

[1] NS = nearshore, FS = farshore.

Fusconaia ebena heavily dominated semiquantitative samples. Relative abundance of the dominant species equaled 87.6 percent (Table 5). A total of 13 species were represented among 453 mussels collected by semiquantitative sampling. Species obtained by semiquantitative but not quantitative methods were *Lampsilis cardium* and *Megalonaias nervosa.*

Qualitative studies

A total of 17 species of native mussels were represented among 860 individuals collected qualitatively at Olmsted (Table 6). *Fusconaia ebena* heavily dominated (84.5 percent); site-specific dominance ranged from 66.1 to 96.6 percent. *Quadrula pustulosa* (5.2 percent*), Q. quadrula* (3.1 percent), *Ellipsaria lineolata* (2.0 percent), and *Q. metanevra* (1.1 percent) each comprised more than 1 percent of the community. Five species were represented by only a single individual among the 860 mussels collected qualitatively. Notably, one of

Table 6
Summary of Results from Qualitative Sampling at the Olmsted Mussel Bed, August 2000

Species	Waypoint						Total Individuals	Percent Abundance
	4	5	9	13	14	18		
F. ebena	118	151	78	128	81	171	727	84.53
Q. pustulosa	14	10	11	6	2	2	45	5.23
Q. quadrula	7	4	8	6	1	1	27	3.14
E. lineolata	4	5	4	4	0	0	17	1.98
Q. metanevra	4	2	0	1	0	2	9	1.05
A. plicata	0	0	7	1	0	0	8	0.93
M. nervosa	0	0	5	1	0	0	6	0.70
E. crassidens	0	1	2	1	0	0	4	0.47
L. recta	2	0	1	1	0	0	4	0.47
O. olivaria	0	1	0	1	0	1	3	0.35
O. reflexa	0	0	0	3	0	0	3	0.35
C. tuberculata	1	0	0	0	1	0	2	0.23
L. cardium	0	0	0	1	0	0	1	0.12
L. fragilis	0	0	0	1	0	0	1	0.12
P. alatus	0	0	1	0	0	0	1	0.12
P. cooperianus	1	0	0	0	0	0	1	0.12
Q. nodulata	0	0	1	0	0	0	1	0.12
Total time	60	60	60	60	30	30	300	
Total species	8	7	10	13	4	5	17	
Total individuals	151	174	118	155	85	177	860	
Individuals/minute	2.52	2.90	1.97	2.58	2.83	5.90	2.87	

these five species was the Federally endangered *Plethobasus cooperianus*. This individual was found at WP 4 , where a total of eight species were included among 151 individuals collected (0.053 species per individual). The most diverse collections per sampling effort were at WP 9 and 13, where the number of species per individual collected equaled 0.0854 and 0.084, respectively. Seven and five specimens of *Amblema plicata plicata* and *Megalonaias nervosa,* respectively, were obtained at WP 9. Only a single individual of either of these species was found at any other site (both at WP 13). The least diverse site was at WP 18 where species per individual collected averaged only 0.028. The extent of variation in species per individual (a simple measure of diversity which accounts for variable sampling effort) among the six sites indicated that patches of more (and less) diverse mussel assemblages were scattered among the generally low diversity community at OLM that is heavily dominated by *F. ebena*. However, even at the two most diverse sites, *F. ebena* still was clearly dominant (66.1 and 82.6 percent).

A selective qualitative search for mussels exclusive of *F. ebena* led to collection of only 27 individuals and seven species (Table 7). No species were added to the total of 17 collected by the nonselective qualitative searches summarized in the preceding paragraph.

Table 7
Mussels Collected During a Search for Pustulose Mussels, Excluding *F. ebena*, at the Olmsted Mussel Bed, August 2000

Species	Individuals	Percent Abundance
Q. pustulosa	11	40.74
E. lineolata	6	22.22
Q. metanevra	4	14.81
C. tuberculata	2	7.41
P. alatus	2	7.41
A. plicata	1	3.70
E. crassidens	1	3.70
Total species	7	
Total individuals	27	

Cumulative species richness

The best estimate of richness was provided by combining all samples, whether quantitative, semiquantitative, qualitative, or selectively qualitative. A total of 20 species were represented among 1,423 mussels collected at Olmsted in 2000 (Table 8). The total richness of this mussel bed was estimated at 30 in 1992 based on a cumulative sample of nearly 10,000 individuals (Payne, Miller, and Shafer 1994, Payne and Miller 1997). Species collected recently from the bed but not in 2000 include *Actinonaias ligamentina*, *Anodonta imbecillis*, *Arcidens confragosus*, *Fusconaia flava*, *Lampsilis ovata*, *Lasmigona complanata*, *Plethobasus cyphyus*, *Potamilus purpuratus*, *Tritogonia verrucosa*, and *Truncilla truncata*. With the exception of *T. truncata,* which commonly comprised 5 to 20 percent of the community in earlier samples (Payne, Miller, and Shafer 1994, Payne and Miller 1997), all species not obtained in 2000 are locally rare and likely not to be obtained in a moderate-sized sample.

Truncilla truncata is characterized by small maximum adult size and short lifespan (approximately 2 to 4 years). Such species are especially susceptible to decimation by the extremely high density infestation of *D. polymorpha* in the mid-1990's. Like relatively short-lived pleurocerid snails that were previously dense on the mussel bed, the absence of *T. truncata* from the mussel bed since the mid-1990s probably reflects near or total elimination of this species from this location. A single *T. donaciformis* was obtained in 2000. This congener of *T. truncata* is even smaller and shorter lived, and, like *T. truncata*, was once a common species at this location.

Nonindigenous species

The sample for demographic analysis of the *C. fluminea* was not large (n = 35). Density of this population at OLM averaged only 3.5 individuals/m^2. The *C. fluminea* population at OLM was represented by a single cohort of small individuals ranging from 6 to 17 mm (Figure 10). The lack of large individuals

Table 8
Relative Abundance of Species Collected at All Waypoints and by All Methods in the Lower Ohio River Near Olmsted, 2000

Species	Quantitative	Semiquantitative	Qualitative	Total	
	WP 1-4	WP 9-14, 18-19	WP 4, 5, 9, 13, 14, 18	n	%
F. ebena	459	397	727	1583	85.52
Q. pustulosa	27	12	45	84	4.54
Q. quadrula	7	15	27	49	2.65
E. lineolata	11	8	17	36	1.94
O. reflexa	12	2	3	17	0.92
Q. metanevra	2	3	9	14	0.76
A. plicata	1	3	8	12	0.65
O. olivaria	3	4	3	10	0.54
E. crassidens	2	2	4	8	0.43
L. recta	3	1	4	8	0.43
M. nervosa	0	2	6	8	0.43
L. cardium	1	3	1	5	0.27
Q. nodulata	3	1	1	5	0.27
L. fragilis	3	0	1	4	0.22
C. tuberculata	0	0	2	2	0.11
L. teres	1	0	0	1	0.05
P. cooperianus	0	0	1	1	0.05
P. cordatum	1	0	0	1	0.05
P. alatus	0	0	1	1	0.05
T. donaciformis	1	0	0	1	0.05
T. truncata	1	0	0	1	0.05
Total time			300		
Total individuals	536	453	860	1851	
Total species	15	13	17	21	
CPUE[1]		1	2.86		

[1] CPUE = catch-per-unit effort.

in this population suggests a simple, annual life history (i.e., a single recruitment period each year with complete mortality of the adult cohort soon after reproduction occurs).

The density of *D. polymorpha* was moderately low at OLM, averaging 1,910 individuals/m^2 (S.D. = 1,193) and ranging among all samples from 592 to 3,488 individuals/m^2. Researchers estimated that dead shells and shell debris of zebra mussels comprised, on average, approximately 15 percent of the bulk of both live and dead zebra mussels per sample. The population was comprised of two cohorts. The cohort representing small mussels was much more abundant that the cohort of large mussels (Figure 11). The extremely dominant cohort

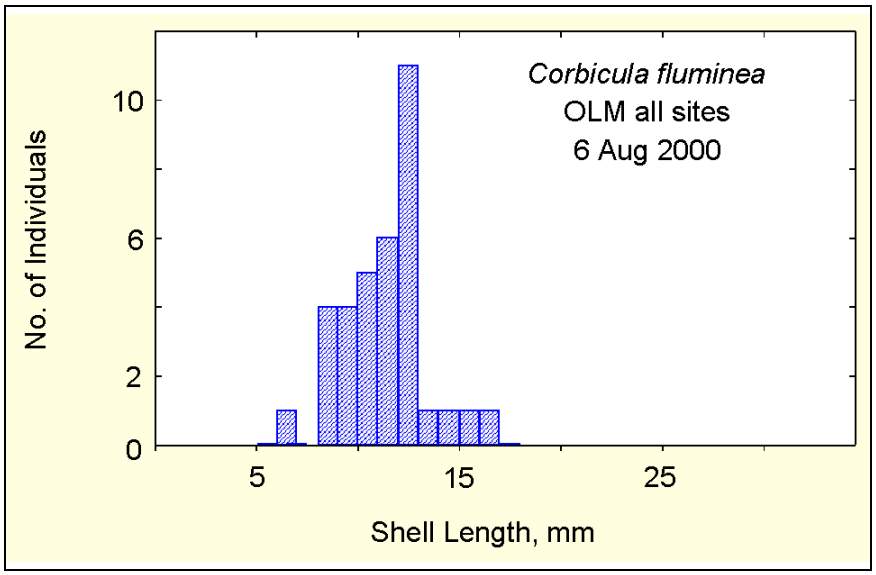

Figure 10. Length frequency of *C. fluminea*, OLM mussel bed, 2000

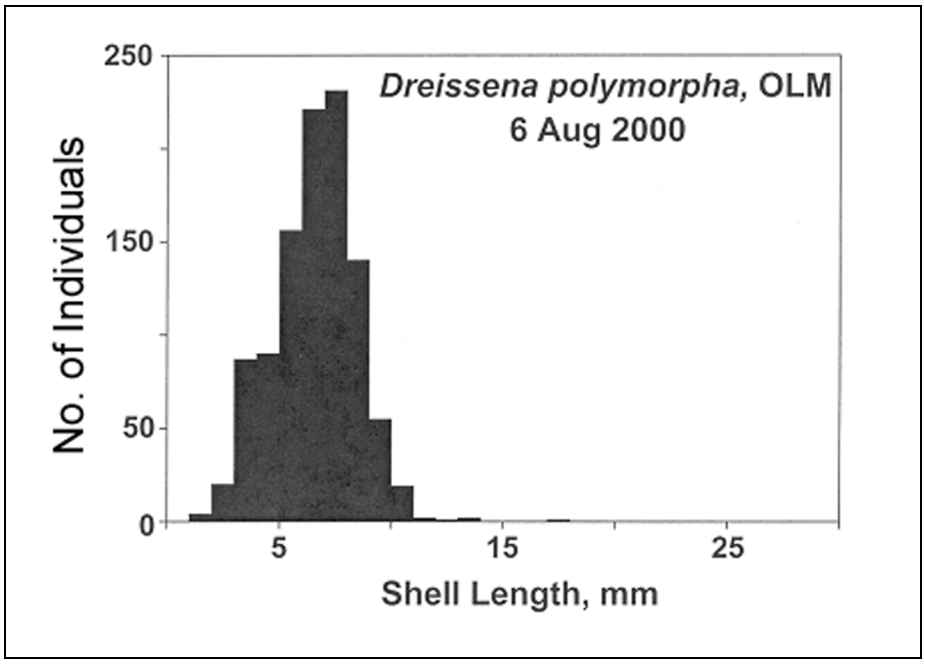

Figure 11. Length frequency of *D. polymorpha*, OLM mussel bed, 2000

probably represented fall 1999 recruitment. Individuals in this cohort ranged from 2 to 12 mm long and had a modal length of 7.5 mm (in previous years, recruitment occurred mainly in the fall in the lower Ohio River). Only a few individuals of the fall 1998 cohort were still alive in early August 2000. These individuals ranged from 15 to 20 mm long. The dive crew performing the present study had worked earlier in the summer at this location for other reasons.

At that time they observed a high density of adult zebra mussels (presumably the 1998 cohort).

Post Creek 2000

Quantitative studies

Fusconaia ebena was much lower in relative abundance at Post Creek than Olmsted. Among 170 unionids obtained from 30 quantitative samples at Post Creek, 84 were *F. ebena* (49.4%) (Tables 9 and 10). *Quadrula pustulosa* was also abundant (19.4 percent). *Obliquaria reflexa* (9.4 percent), *Quadrula quadrula* (6.5 percent), *Amblema plicata* (4.1 percent), *Ellipsaria lineolata* (2.9 percent), and *Quadrula metanevra* (2.9 percent) were common. A total of 14 species were represented in quantitative samples at Post Creek. Diversity and evenness were moderate. The Shannon-Weaver Index (using natural logarithms) equaled 1.65 compared to a maximum possible value of 2.56 for a community with 13 species. Thus, evenness was 1.65 divided by 2.56, or 0.64.

Mussel density was consistent among the three sites; site-specific averages ranged only from 22.0 to 23.3 individuals/m^2 (Table 11). Among all 30 samples, densities ranged from 0 to 52.0 individuals/m^2. For all three sites combined, unionid density averaged 22.7 individuals/m^2 (S.D. = 11.1).

Table 9
Number of Individuals of Each Species from Quantitative Samples at Three Sites in the Lower Ohio River Near Post Creek, 2000

Species	Waypoint			Total
	1	2	3	
F. ebena	40	16	28	84
Q. pustulosa	7	16	10	33
O. reflexa	1	9	6	16
Q. quadrula	1	6	4	11
A. plicata	1	2	4	7
E. lineolata	2	1	2	5
Q. metanevra		2	3	5
T. truncata		3		3
C. tuberculata	1		1	2
L. recta		1		1
O. olivaria	1			1
P. alatus	1			1
Q. nodulata		1		1
Total individuals	55	57	58	170
Total species	9	10	8	13

Table 10
Percent Abundance of Each Species from Quantitative Samples at Three Sites in the Lower Ohio River Near Post Creek, 2000

Species	Waypoint			Total
	1	2	3	
F. ebena	72.73	28.07	48.28	49.41
Q. pustulosa	12.73	28.07	17.24	19.41
O. reflexa	1.82	15.79	10.34	9.41
Q. quadrula	1.82	10.53	6.90	6.47
A. plicata	1.82	3.51	6.90	4.12
E. lineolata	3.64	1.75	3.45	2.94
Q. metanevra	0.00	3.51	5.17	2.94
T. truncata	0.00	5.26	0.00	1.76
C. tuberculata	1.82	0.00	1.72	1.18
L. recta	0.00	1.75	0.00	0.59
O. olivaria	1.82	0.00	0.00	0.59
P. alatus	1.82	0.00	0.00	0.59
Q. nodulata	0.00	1.75	0.00	0.59
Species richness				13
Shannon's diversity index, H´				1.65
Max H´(ln S)[1]				2.56
Evenness (H´/ln S)				0.64

[1] ln S = natural logarithm of the number of species.

Size structure of the *F. ebena* population at Post Creek (Figure 12) was similar to that at Olmsted (Figure 8). Individuals at Post Creek ranged from 8 to 82 mm. Similar to the Olmsted assemblage, an abundant cohort of very recent recruits (probably 1998 settlement) was centered at 11 mm; the other abundant cohort of 1990 recruits had an average length of slightly less than 60 mm and still dominated the population. A minor but substantial cohort was also centered at 20 to 24 mm and probably represented 1997 or 1996 recruitment. The few individuals ranging from 76 to 82 mm may have represented the remaining survivors of the once dominant 1981 cohort.

Qualitative studies

A total of 504 individuals and 14 species were collected by qualitative methods at Post Creek (Table 12). Species-per-individual measures of diversity equaled 0.074, 0.076, and 0.061 at WP 6, 7, and 8, respectively. Compared to Olmsted, the mussel community at Post Creek was consistently diverse. Overall at Post Creek, relative abundance of *F. ebena* equaled 43.3 percent, with site-specific relative abundance of this species ranging from 25.7 percent at WP 7 to 59.3 percent at WP 6. Indeed, at WP 7, *Q. pustulosa* was slightly more abundant (28.7 percent) than *F. ebena*. No species were collected at Post Creek that were not also obtained at Olmsted. *Fusconaia ebena* tended to increase in relative

Table 11
Summary of Quantitative Data, Lower Ohio River Near Post Creek, August 2000

WP	Quad #	Number of Unionids	Number of *Corbicula*
6	1	4	0
6	2	4	1
6	3	2	3
6	4	13	0
6	5	4	4
6	6	9	3
6	7	0	2
6	8	9	3
6	9	5	0
6	10	5	0
Site 1 Summary		AVG = 5.50 STD = 3.81	AVG = 1.60 STD = 1.58
7	1	7	3
7	2	7	5
7	3	5	7
7	4	4	10
7	5	3	6
7	6	8	6
7	7	5	6
7	8	3	8
7	9	10	5
7	10	5	4
Site 2 Summary		AVG = 5.70 STD = 2.26	AVG = 6.00 STD = 2.00
8	1	7	2
8	2	6	1
8	3	5	6
8	4	6	1
8	5	10	6
8	6	2	4
8	7	3	3
8	8	6	3
8	9	8	3
8	10	5	4
Site 3 Summary		AVG = 5.80 STD = 2.30	AVG = 3.30 STD = 1.77
All Sites Summary		AVG = 5.67 STD = 2.78	AVG = 3.63 STD = 2.53

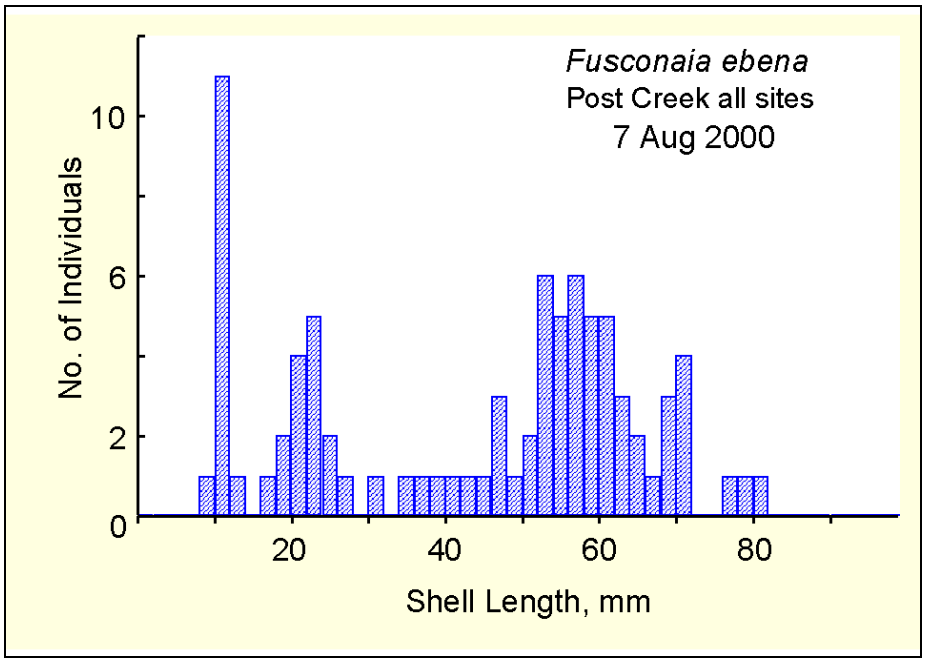

Figure 12. Length frequency of *F. ebena*, PC mussel bed, 200

Table 12
Summary Information from Qualitative Sampling for Freshwater Mussels, Post Creek Site, Lower Ohio River, August 2000

Species	Waypoint			Total Individuals	Percent Abundance
	6	7	8		
F. ebena	80	44	94	218	43.25
Q. pustulosa	11	49	49	109	21.63
E. lineolata	18	14	10	42	8.33
Q. quadrula	5	25	12	42	8.33
A. plicata	4	8	14	26	5.16
O. reflexa	4	13	7	24	4.76
Q. metanevra	9	2	4	15	2.98
M. nervosa	1	4	2	7	1.39
Q. nodulata	0	5	2	7	1.39
E. crassidens	2	2	2	6	1.19
C. tuberculata	0	2	1	3	0.60
T. verrucosa	0	2	1	3	0.60
L. cardium	1	0	0	1	0.20
P. alatus	0	1	0	1	0.20
Total time	60	60	60	180	
Total species	10	13	12	14	
Total individuals	135	171	198	504	
Individuals/minute	2.25	2.85	3.3	2.8	

abundance farshore; *Quadrula pustulosa* was slightly more abundant than *F. ebena* in the nearshore samples. The farshore community was more typical than the nearshore of that generally encountered in gravelly substratum in the lower Ohio River – *F. ebena* comprised 62 percent of the farshore community. Most species were locally uncommon; six of fourteen species collected at the farshore location individually comprised less than 1 percent of the community.

Nonindigenous species

Size structure of the *C. fluminea* population at Post Creek (Figure 13) was virtually identical to that at Olmsted (Figure 10); density was substantially higher at Post Creek than at Olmsted. The same cohort of small individuals that comprised the entire population sample from Olmsted also comprised the entire population at Post Creek. These individuals ranged from 6 to 18 mm and the cohort was centered at 10 to 13 mm.

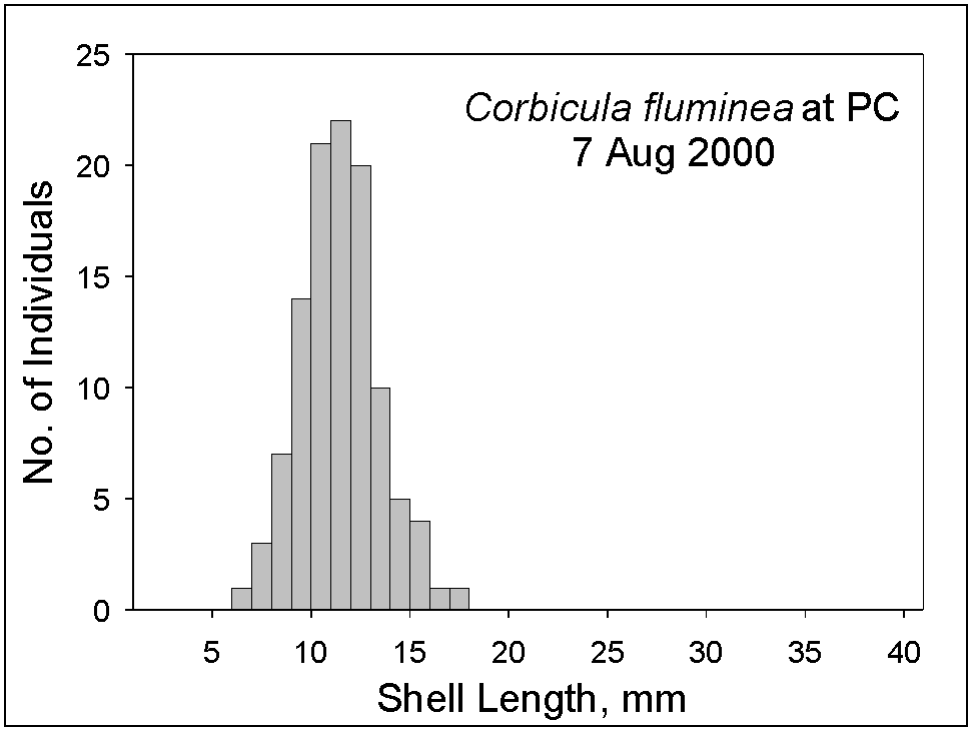

Figure 13. Length frequency of *C. fluminea,* PC mussel bed, 2000

Density of *Corbicula* at Post Creek was low. Average density for the three sites quantitatively sampled ranged from 6 to 24 individuals/m^2.

Dreissena polymorpha at Post Creek were more dense than the population at Olmsted but had the same size structure (Figure 14). The considerably lower abundance of the cohort of largest mussels at Post Creek (Figure 14) versus Olmsted (Figure 11) may indicate a recruitment or survival difference between these locations. Several *D. polymorpha* greater than 20 mm long were present at Olmsted, but few such large individuals were present at Post Creek.

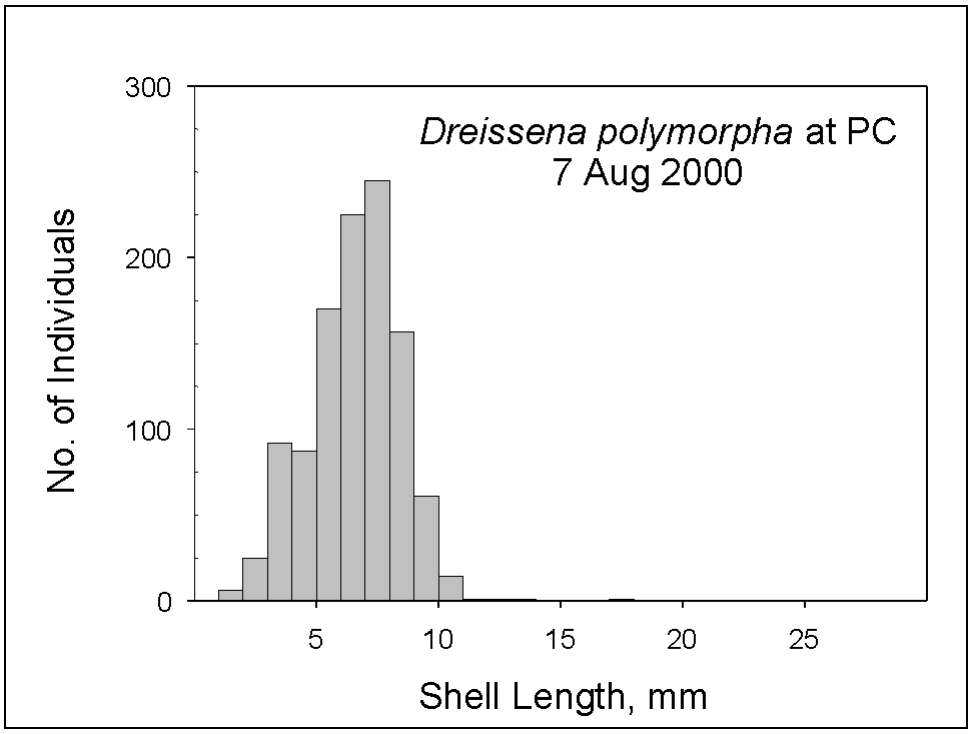

Figure 14. Length frequency of *D. polymorpha*, PC mussel bed, 2000

Olmsted 2001

Quantitative studies

A total of 16 species of native mussels were included among 188 individuals obtained by quantitative sampling of the Olmsted bed in 2001. All four sites were heavily dominated by *F. ebena* (Tables 13 and 14). Relative abundance of *F. ebena* was consistently high among the four sites, ranging from 87.9 percent at WP 1 to 77.6 percent at WP 2. Mussel density was moderately low at all four sites; average values per site ranged from 14.8 individuals/m^2 at WP 4 to 22.4 individuals/m^2 at WP 1. *Quadrula pustulosa* (6.4 percent), *Ellipsaria lineolata* (5.9 percent), *Q. metanevra* (3.2 percent), and *Q. quadrula* (2.1 percent) each comprised more than 2 percent of the community. One individual of the Federally endangered species *Plethobasus cooperianus* was obtained in quantitative samples (at WP 3).

Recently recruited mussels (individuals less than 30 mm long) comprised 38 percent of the community (Table 14). Nearly a third of all species included at least some individuals less than 30 mm long. The community-wide evidence of recent recruitment was especially impressive because of the difficulty inherent in obtaining recruits in small samples of all species other than the heavily dominant *F. ebena*. Only 50 individuals of all 15 species other than *F. ebena* were obtained in quantitative samples, yet four of these species showed clear evidence of recent recruitment.

Table 13
Number of Individuals by Species Obtained from Quantitative Samples at Four Sites in the Lower Ohio River Near Olmsted, 2001

Species	Waypoint				Total
	1	2	3	4	
F. ebena	38	38	35	27	138
Q. pustulosa	6	4	1	1	12
E. lineolata	3	3	3	2	11
Q. metanevra	2	3		1	6
Q. quadrula	1		1	2	4
O. reflexa	3				3
O. olivaria	1			1	2
T. donaciformis		1		1	2
L. fragilis			1	1	2
Q. nodulata			1	1	2
L. recta	1				1
T. truncata			1		1
P. alata			1		1
L. cardium	1				1
P. cooperianus			1		1
A. plicata			1		1
Total individuals	56	49	46	37	188
Total species	9	5	10	9	16

Due to the heavy dominance of *F. ebena*, diversity was low, measuring just 1.19 (Shannon's index) (Table 14). Evenness expresses Shannon's index as a fraction of maximum possible diversity, which corresponds to equal abundance of all species (Pileou 1969). In the case of 16 species, maximum diversity equals 2.77 (i.e., the natural logarithm of 12). Thus, evenness of mussel species relative abundance in the quantitative samples at Olmsted was 0.43. By any measure, the community at Olmsted, although rich in species, is low in diversity due to the high dominance of *F. ebena*.

Fusconaia ebena at OLM in 2001 ranged from 12.7 to 77.3 mm long (Figure 15). Approximately 45 percent of the population was represented by a single cohort of recent recruits that ranged from 12 to 28 mm, with an average length of 21.4 mm. These probably represented 1998 recruits. Individuals ranging from approximately 28 to 52 mm represented recruitment mostly from 1995, 1996, and 1997, although the individual year classes could not be discerned in the moderate sample (n = 138) of *F. ebena* obtained by quantitative methods in 2001.

The abundant 1990 cohort no longer dominated the population in 2001. Most individuals of this cohort were within a length range of 56 to 72 mm, with an average length of approximately 64 mm. This cohort comprised 65 percent of

Table 14
Percent Abundance of Each Species Obtained from Quantitative Samples at Four Sites in the Lower Ohio River Near Olmsted, 2001

Species	Waypoint				Total
	1	2	3	4	
F. ebena	67.86	77.55	76.09	72.97	73.40
Q. pustulosa	10.71	8.16	2.17	2.70	6.38
E. lineolata	5.36	6.12	6.52	5.41	5.85
Q. metanevra	3.57	6.12	0.00	2.70	3.19
Q. quadrula	1.79	0.00	2.17	5.41	2.13
O. reflexa	5.36	0.00	0.00	0.00	1.60
O. olivaria	1.79	0.00	0.00	2.70	1.06
T. donaciformis	0.00	2.04	0.00	2.70	1.06
L. fragilis	0.00	0.00	2.17	2.70	1.06
Q. nodulata	0.00	0.00	2.17	2.70	1.06
L. recta	1.79	0.00	0.00	0.00	0.53
T. truncata	0.00	0.00	2.17	0.00	0.53
P. alatus	0.00	0.00	2.17	0.00	0.53
L. cardium	1.79	0.00	0.00	0.00	0.53
P. cooperianus	0.00	0.00	2.17	0.00	0.53
A. plicata	0.00	0.00	2.17	0.00	0.53
Total individuals	56	49	46	37	188
Total species	9	5	10	9	16
% individuals <30mm					38.29
% species <30 mm					31.25
Mean density (individuals per m^2)	22.4	19.6	18.4	14.8	18.8
Standard deviation of density	11.2	6.4	14.4	8.0	10.4
Species diversity (H´)					1.19
Evenness					0.43

the population as recently as 2000, but accounted for only 30 percent in 2001. Reduced relative abundance of this cohort in 2001 versus 2000 probably reflects a combination of spatial and temporal variation in sampling, more complete representation of the 1998 cohort in 2001 versus 2000 quantitative samples, and mortality. The once dominant 1981 cohort (Payne and Miller 2000) was not recognizable in the moderate sample of 2001 (it had only comprised 2 percent of the population in 2000).

Quadrula pustulosa was also obtained by quantitative methods in a sufficient number (57) to allow detailed analysis of size demography (Figure 16). Similar to *F. ebena*, there was clear evidence of moderately strong recent recruitment. Individuals ranged from 16 to 66 mm long, with 21 percent of the population being comprised of recent recruits less than 30 mm long. The most abundant cohorts in this population were centered at 28 to 32 mm and 46 to 50 mm.

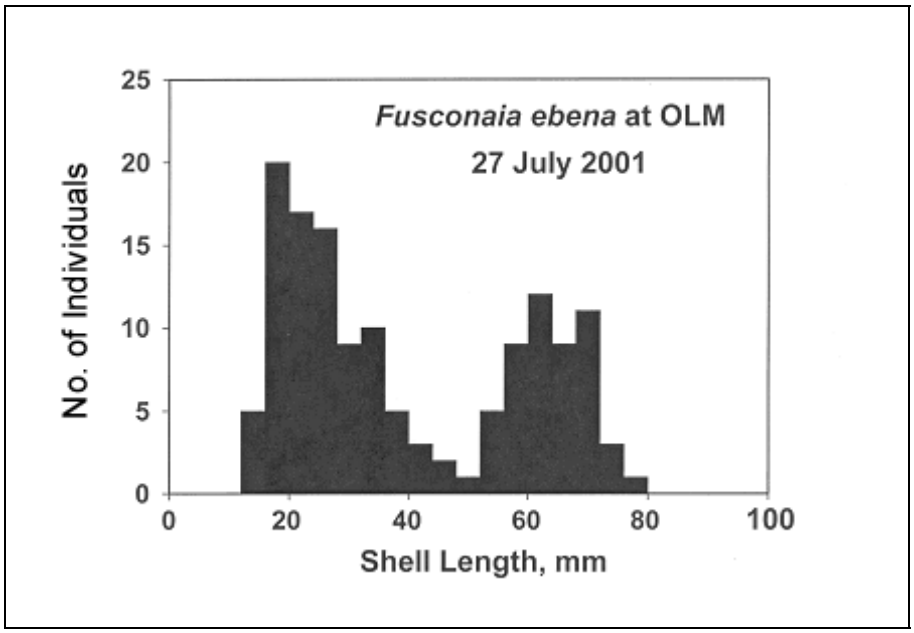

Figure 15. Length frequency of *F. ebena*, OLM mussel bed, 2001

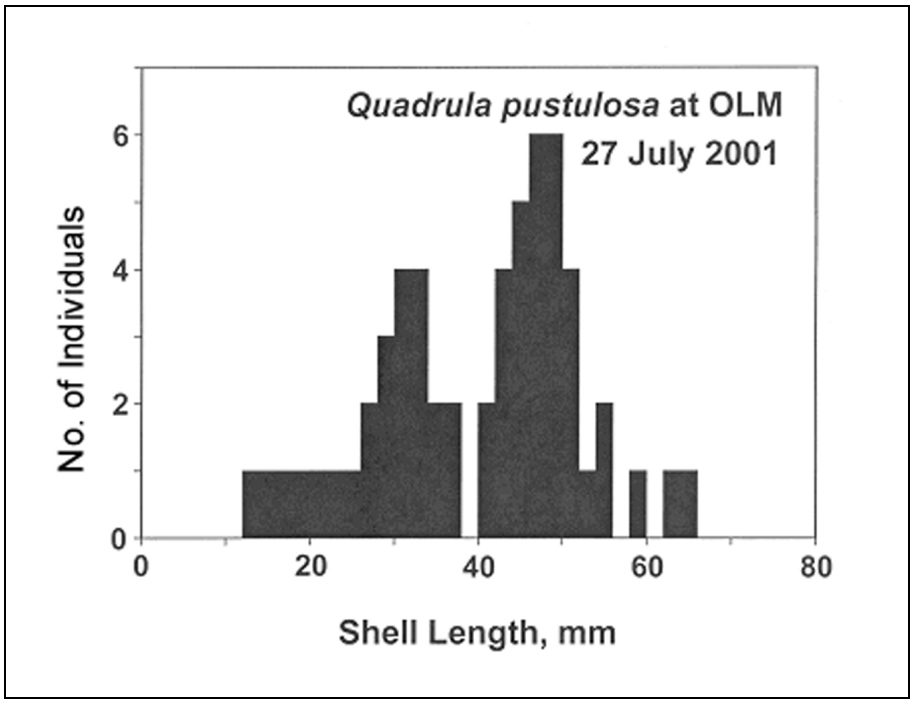

Figure 16. Length frequency of *Q. pustulosa*, OLM mussel bed, 2001

Ellipsaria lineolata (n = 22) ranged from 40 to 80 mm long (Figure 17). Although no individuals less than 30 mm long were obtained, the moderate abundance of mussels ranging from 40 to 50 mm represented relatively recent recruitment of this species.

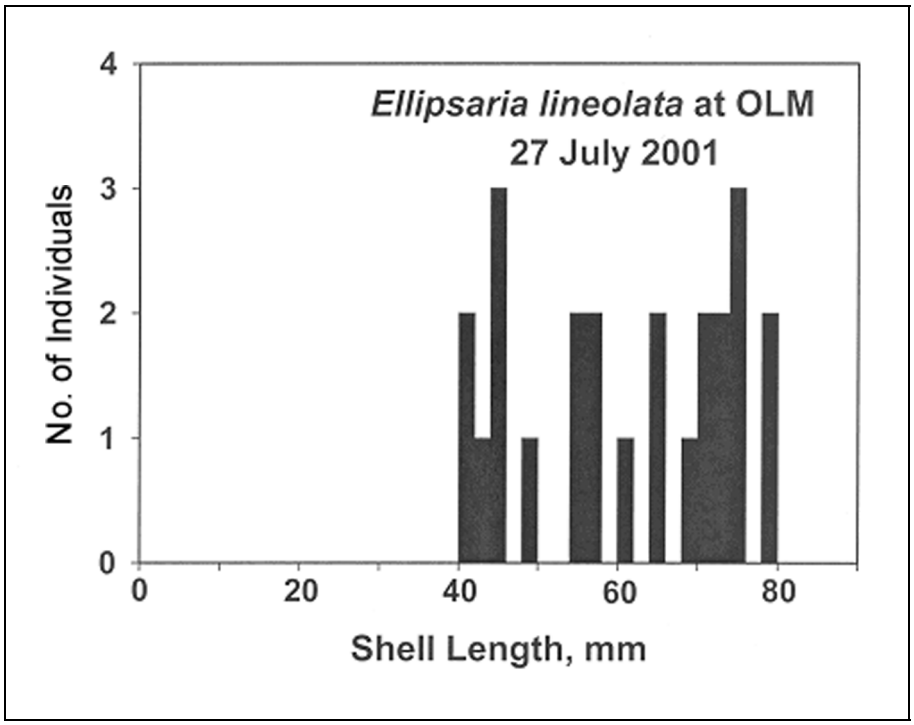

Figure 17. Length frequency of *E. lineolata*, OLM mussel bed, 2001

Qualitative studies

A total of 17 species of native mussels were represented among 240 individuals collected qualitatively at Olmsted at the same locations (WP 1-4) at which quantitative samples were collected (Table 15). *Fusconaia ebena* dominated (57.8 percent), although dominance of this species was less than in quantitative samples (73.4 percent). Slightly reduced dominance of this species in qualitative than quantitative samples probably reflected the abundance of relatively recent recruits to this population, as small mussels were more likely to be obtained in quantitative samples involving substratum removal and sieving. *Ellipsaria lineolata* (12.0 percent), *Q. metanevra* (8.8 percent*), Q. quadrula* (6.4 percent), and *Q. pustulosa* (6.2 percent) each comprised more than 5 percent of the community as represented by qualitative sampling. *Elliptio crassidens* (1.1 percent), *Lampsilis teres* (0.3 percent), and *Pleurobema cordatum* (0.3 percent) were collected by qualitative but not quantitative methods. As with quantitative sampling, a single specimen of the endangered species, *P. cooperianus*, was obtained by qualitative methods (at WP 1). The combined results of quantitative and qualitative sampling at WP 1-4 yielded a total of 19 species among 428 individuals.

Results of qualitative samples collected from sites scattered throughout the mussel bed are summarized in Table 16. WP 10 and 6 occurred at the nearshore limit of the mussel bed; thus, densities at these locations were the lowest of all samples. Catch-per-unit effort (CPUE) (mussels per minute) at WP 6 and 10 equaled 0.07 and 0.20 nearshore (at an elevation greater than 279 ft) and

Table 15
Relative Abundance of Mussels Obtained by Qualitative Methods in the Lower Ohio River Near Olmsted, 2001

Species	Waypoint				Total	%
	1	2	3	4		
F. ebena	60	58	50	48	216	57.75
E. lineolata	13	10	12	10	45	12.03
Q. metanevra	10	12	4	7	33	8.82
Q. quadrula	3	4	10	7	24	6.42
Q. pustulosa	6	3	5	9	23	6.15
A. plicata	1	2	3	2	8	2.14
L. recta	4	1	0	1	6	1.60
E. crassidens	0	1	0	3	4	1.07
P. alatus	1	0	1	2	4	1.07
L. fragilis	0	2	0	1	3	0.80
Q. nodulata	0	2	0	0	2	0.53
L. teres	0	0	1	0	1	0.27
M. nervosa	0	1	0	0	1	0.27
O. olivaria	0	1	0	0	1	0.27
O. reflexa	0	0	0	1	1	0.27
P. cooperianus	1	0	0	0	1	0.27
P. cordatum	0	0	1	0	1	0.27
Total time (minutes)	60	60	60	60	240	
Total individuals	99	97	87	91	374	
Total species	9	12	9	11	17	
CPUE	1.65	1.62	1.45	1.52	1.56	

0.73 farshore (at an elevation equal to or slightly less than 279 ft). CPUE at all other locations ranged from 0.67 to 4.80. Averaged for all 11 sites, CPUE equaled 1.62. A total of 534 mussels were collected, and 16 species were represented. In comparison, CPUE ranged from 1.45 to 1.65 for qualitative sampling at WP 1-4 where quantitative sampling was also conducted and showed that mussel density ranged from 14.8 to 22.4 individuals/m^2.

Fusconaia ebena heavily dominated semiquantitative samples. Relative abundance of the dominant species equaled 62.2 percent (Table 16). Species obtained by semiquantitative but not quantitative methods were *Megalonaias nervosa*, *Cyclonaias tuberculata*, *Pleurobema cordatum*, *Potamilus alatus,* and *Elliptio crassidens*. Only one to five individuals of each of these species were obtained. Thus, the difference between quantitative and semiquantitative methods reflected inconsistency in obtaining locally rare species with a moderate sampling effort in addition to the greater spatial coverage offered by the latter methods.

Table 16
Relative Abundance of Species and CPUE at Qualitative Mapping Sites in the Lower Ohio River Near Olmsted, 2001

Species	WP 5		WP 6		WP 7		WP 8		WP 9		WP 10		WP 11		WP 27		WP 28		WP 29		WP 30		All Sites	
	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	n	%
F. ebena	15	26	1	3	2	4	13	32	40	72	0	2	25	32	4	9	10	15	4	9	9	5	332	62.17
Q. pustulosa	2	5	0	0	1	3	1	6	1	0	1	0	0	0	1	4	4	2	2	0	12	1	46	8.61
Q. quadrula	5	4	0	0	1	4	1	4	0	0	0	4	0	0	2	1	2	3	1	0	4	2	38	7.12
E. lineolata	0	2	0	0	0	1	5	7	0	0	0	0	1	3	0	1	3	1	2	0	4	2	32	5.99
Q. metanevra	0	3	0	1	0	0	2	3	1	0	0	1	3	6	0	1	1	1	3	3	3	0	32	5.99
A. plicata	2	0	0	6	3	0	0	2	0	0	0	0	1	0	3	0	2	0	0	0	4	0	23	4.31
L. recta	1	0	0	0	0	0	0	1	0	0	0	1	2	0	0	1	0	0	0	0	0	0	6	1.12
O. olivaria	0	0	0	0	0	0	0	1	0	0	2	1	0	0	0	0	0	0	0	0	2	0	6	1.12
C. tuberculata	1	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	5	0.94
M. nervosa	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0.75
P. cordatum	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	3	0.56
P. alatus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	0.37
Q. nodulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	0.37
E. crassidens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0.19
L. fragilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0.19
O. reflexa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0.19
Total minutes	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	330	
Total individuals	26	40	1	11	7	13	22	58	42	72	3	11	34	42	13	18	23	23	14	13	38	10	534	
Total species	6	5	1	4	4	5	5	10	3	1	2	7	7	4	6	7	7	6	7	3	7	4	16	
CPUE	1.73	2.67	0.07	0.73	0.47	0.87	1.47	3.87	2.80	4.80	0.20	0.73	2.27	2.80	0.87	1.20	1.53	1.53	0.93	0.87	2.53	0.67	1.62	

Qualitative samples from five locations along the Kentucky shore near the damsite (WP 20-25) yielded four more individuals and two species (Table 17). These sites were not part of the mussel bed and were in clay and mud instead of the gravelly sand on the opposite shore. However, *Lasmigona complanata*, a species known to occur on the bed, was found along the Kentucky shore but not from the mussel bed in 2001.

Table 17
Results of Qualitative Surveys at Replacement Sites in the Lower Ohio River Near Olmsted, 2001

Species	WP 20		WP 21		WP 22		WP 23		WP 24		WP 25		All Sites	
	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	n	%
Q. quadrula	0	0	0	1	0	1	1	0	0	0	0	0	3	75.0
L. complanata	0	0	0	1	0	0	0	0	0	0	0	0	1	25.0
Total minutes	15	15	15	15	15	15	15	15	15	15	15	15	180	
Total individuals	0	0	0	2	0	1	1	0	0	0	0	0	4	
Total species	0	0	0	2	0	1	1	0	0	0	0	0	2	
CPUE	0.00	0.00	0.00	0.13	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.02	

Cumulative species richness

The best estimate of richness was provided by combining all samples, including quantitative and qualitative samples at WP 1-4, qualitative samples for mapping collected at WP 5-11 and 27-30, and qualitative samples along the Kentucky shore at the damsite (WP 20-25). A total of 22 species were represented among 1,100 individuals collected by all methods near Olmsted in 2001 (Table 18). The total richness of this mussel bed was estimated at 30 in 1992 based on a cumulative sample of nearly 10,000 individuals (Payne and Miller 1997). Species collected recently from the bed but not in 2000 include *Actinonaias ligamentina*, *Anodonta imbecillis*, *Arcidens confragosus*, *Fusconaia flava*, *Lampsilis ovata*, *Plethobasus cyphyus*, *Potamilus purpuratus*, and *Tritogonia verrucosa.* All species not obtained in 2001 are locally rare and likely not to be obtained in a moderate-sized sample.

Nonindigenous species

The *C. fluminea* population was comprised almost entirely of a single cohort ranging from 6 to 15 mm long, with modal length of 10 to 11 mm (Figure 18). This cohort probably represents 2001 recruitment. The few mussels represented by the 15- to 16-mm size class may represent the few surviving individuals of an older cohort.

The *D. polymorpha* population was comprised almost entirely of a single cohort ranging mostly from 3 to 10 mm long, with modal length of 6 to 7 mm (Figure 19). A few individuals ranged from 14 to 17 mm long (barely evident in

Table 18
Relative Abundance of Species Collected at All Waypoints and by All Methods in the Lower Ohio River Near Olmsted, 2001

	Quantitative	Qualitative			Total	
Species	WP 1-4	WP 1-4	WP 5-11, 27-30	WP 20-25	n	%
F. ebena	138	216	332	0	686	62.36
E. lineolata	11	45	32	0	88	8.00
Q. pustulosa	12	23	46	0	81	7.36
Q. metanevra	6	33	32	0	71	6.45
Q. quadrula	4	24	38	3	69	6.27
A. plicata	1	8	23	0	32	2.91
L. recta	1	6	6	0	13	1.18
O. olivaria	2	1	6	0	9	0.82
P. alatus	1	4	2	0	7	0.64
Q. nodulata	2	2	2	0	6	0.54
C. tuberculata	0	0	5	0	5	0.45
E. crassidens	0	4	1	0	5	0.45
L. fragilis	1	3	1	0	5	0.45
M. nervosa	0	1	4	0	5	0.45
O. reflexa	3	1	1	0	5	0.45
P. cordatum	0	1	3	0	4	0.36
P. cooperianus	1	1	0	0	2	0.18
T. donaciformis	2	0	0	0	2	0.18
L. complanata	0	0	0	1	1	0.09
L. cardium	1	0	0	0	1	0.09
L. teres	0	1	0	0	1	0.09
T. truncata	1	0	0	0	1	0.09
Total time		240	330	180		
Total individuals	188	374	534	4	1,100	
Total species	16	17	16	2	22	
CPUE		1.56	1.62	0.02		

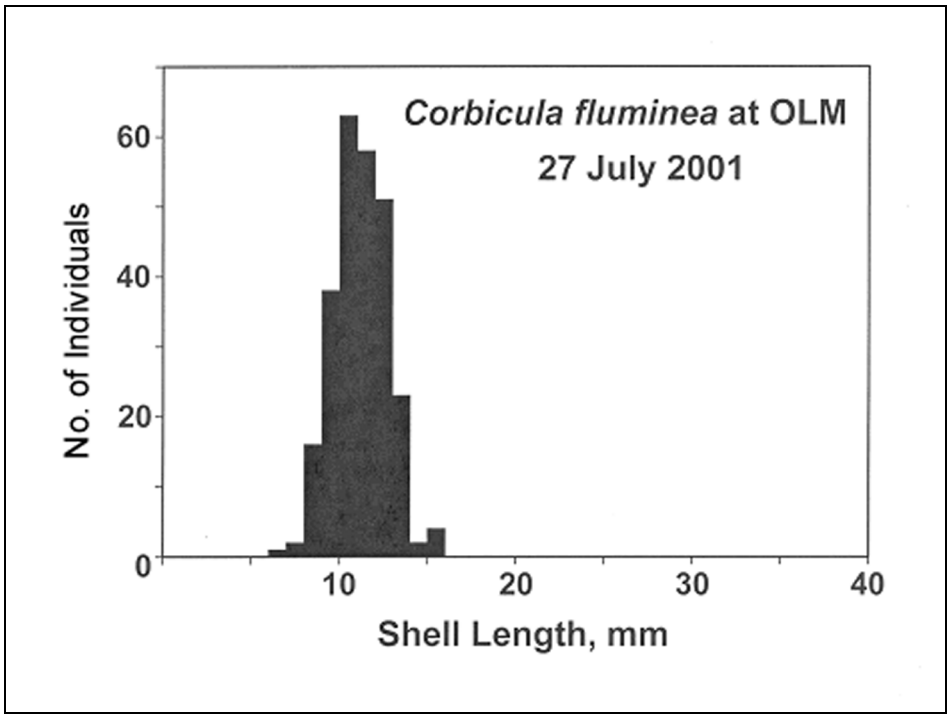

Figure 18. Length frequency of *C. fluminea*, OLM mussel bed, 2001

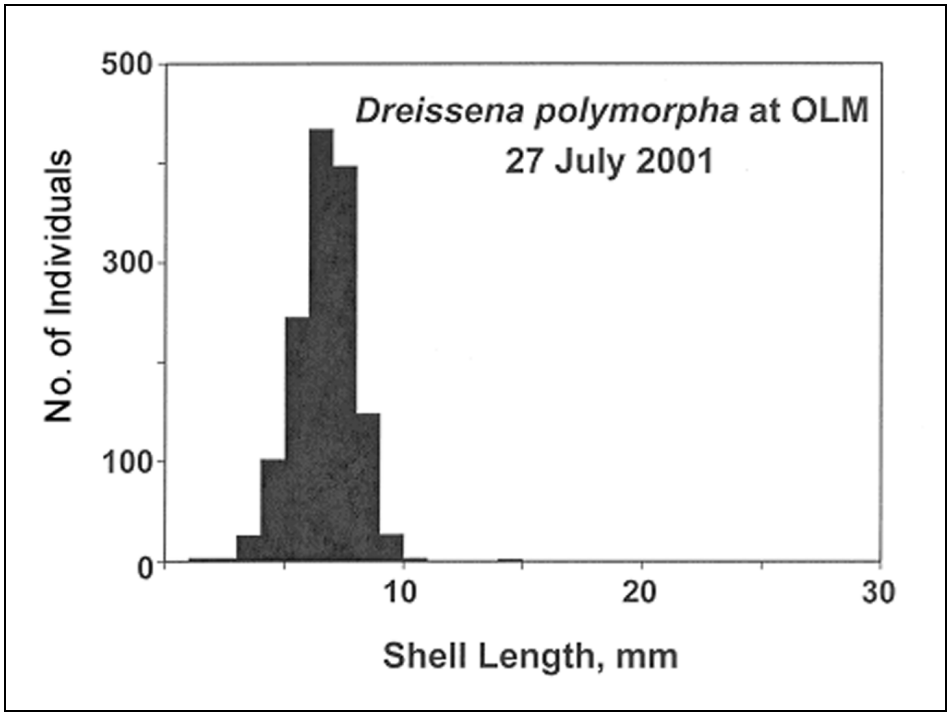

Figure 19. Length frequency of *D. polymorpha*, OLM mussel bed, 2001

Figure 19). These larger individuals probably represented the few survivors of an older cohort.

Post Creek 2001

Quantitative studies

A total of 11 species of native mussels were included among 138 individuals obtained by quantitative sampling of the Post Creek bed in 2001 (Tables 19 and 20). *Fusconaia ebena* and *Q. pustulosa* shared dominance; the relative abundance of the former species tended to be higher farshore while the relative abundance of the latter species tended to be higher nearshore. Regardless, the dominance of *F. ebena* that characterized the Olmsted mussel bed was not observed at the Post Creek location. *Ellipsaria lineolata* (9.4 percent), *Q. quadrula* (8.0 percent), and *O. reflexa* (5.8 percent) were all common at the Post Creek bed.

Mussel density was moderately low at all four sites quantitatively sampled at Post Creek. Density ranged from 4.2 to 15.2 individuals/m^2, and averaged 13.8 for all four sites. Shannon's index of species evenness (Pileou 1969) was moderately high (0.75); diversity was moderate (1.75). The moderate diversity reflected both high evenness of species relative abundance but also a low species richness. The latter resulted from the moderately low density of mussels at sites quantitatively sampled.

Table 19
Number of Individuals of Each Species from Quantitative Samples at Four Sites in the Lower Ohio River Near Post Creek, 2001

Species	Waypoint				Total
	12	13	14	15	
F. ebena	12	8	14	12	46
Q. pustulosa	13	18	7	7	45
E. lineolata	2	3	3	5	13
Q. quadrula	5	3		3	11
O. reflexa	2	3		3	8
Q. metanevra	1		3		4
A. plicata	1	1		1	3
Q. nodulata	1	2			3
C. tuberculata		2			2
O. olivaria	1	1			2
E. crassidens		1			1
Total individuals	38	42	27	31	138
Total species	9	10	4	6	11

Table 20
Percent Abundance of Each Species Obtained from Quantitative Samples at Four Sites in the Lower Ohio River Near Post Creek, 2001

Species	Waypoint				Total
	12	13	14	15	
F. ebena	31.58	19.05	51.85	38.71	33.33
Q. pustulosa	34.21	42.86	25.93	22.58	32.61
E. lineolata	5.26	7.14	11.11	16.13	9.42
Q. quadrula	13.16	7.14	0.00	9.68	7.97
O. reflexa	5.26	7.14	0.00	9.68	5.80
Q. metanevra	2.63	0.00	11.11	0.00	2.90
A. plicata	2.63	2.38	0.00	3.23	2.17
Q. nodulata	2.63	4.76	0.00	0.00	2.17
C. tuberculata	0.00	4.76	0.00	0.00	1.45
O. olivaria	2.63	2.38	0.00	0.00	1.45
E. crassidens	0.00	2.38	0.00	0.00	0.72
Total individuals	38	42	27	31	138
Total species	9	10	4	6	11
% individuals <30mm					16.67
% species <30 mm					45.45
Density (individuals per m^2)	15.2	4.2	10.8	12.4	13.8
Standard deviation of density	9.2	10.6	5.3	8.7	8.7
Species diversity (H')					1.75
Evenness					0.73

Recently recruited mussels (individuals less than 30 mm long (Table 20)) were about half as abundant at Post Creek (17 percent) than at Olmsted (38 percent) in 2001. However, five of the eleven species of native mussels at Post Creek showed evidence of recent recruitment. Species not showing evidence of recent recruitment were represented by only one to four individuals obtained by quantitative methods, suggesting that recruitment probably is occurring for most species, but that low sample sizes prevent recruits of many species from being obtained.

Fusconaia ebena (n = 46) obtained quantitatively at Post Creek in 2001 ranged from 18 to 74 mm long (Figure 20). The cohort of recent recruits (probably 1998) that ranged from 13 to 27 mm and comprised 27 percent of the population at Olmsted was evident but not nearly so abundant at Post Creek. This cohort comprised only 9 percent of the population at Post Creek. Otherwise, the size and age distribution of *F. ebena* at Post Creek was similar to that at Olmsted.

Quadrula pustulosa (n = 45) obtained by quantitative methods ranged from 12 to 66 mm long (Figure 21). There was clear evidence of moderately strong

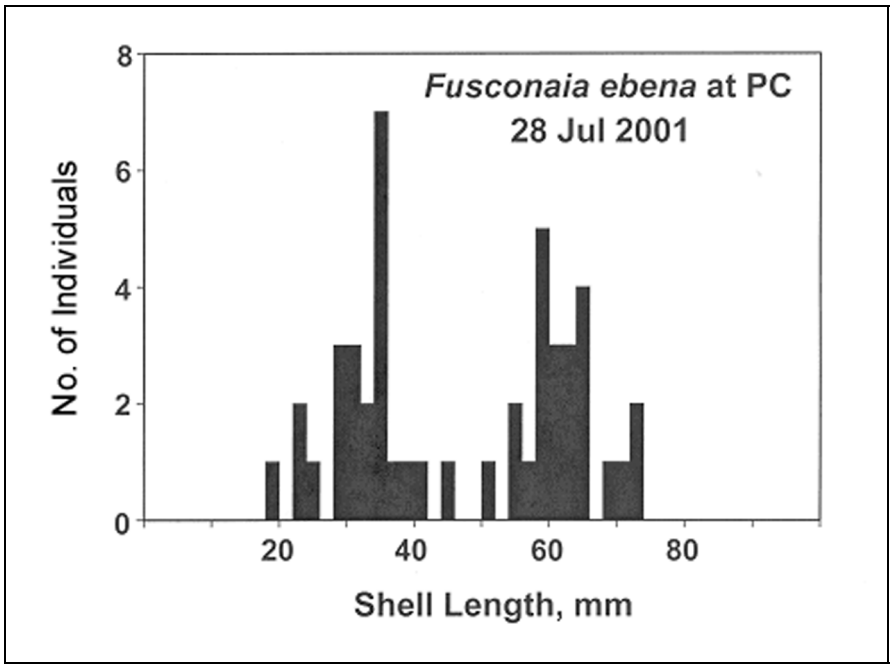

Figure 20. Length frequency of *F. ebena*, PC mussel bed, 2001

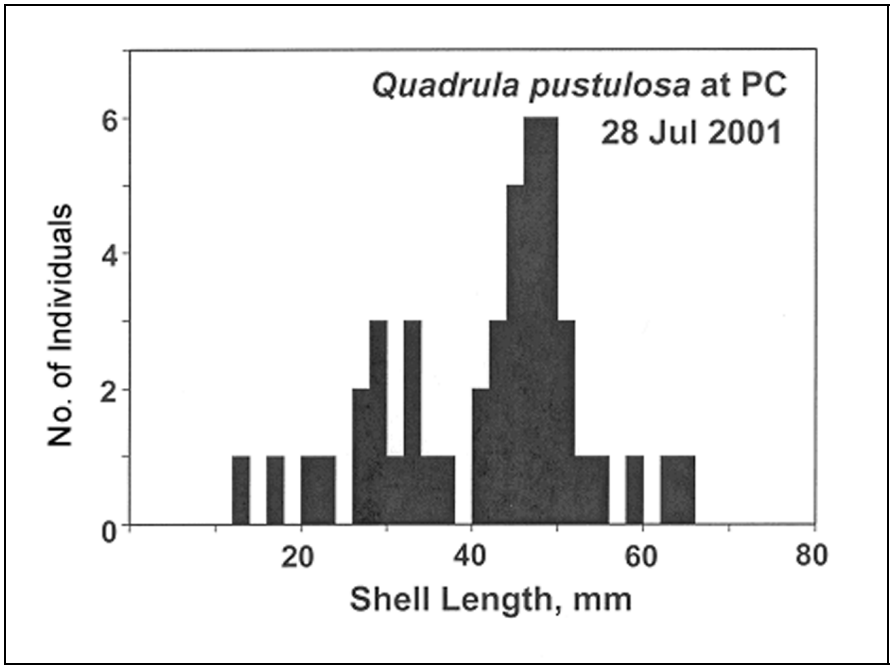

Figure 21. Length frequency of *Q. pustulosa*, PC mussel bed, 2001

recent recruitment; 22 percent of the population was comprised of individuals less than 30 mm long. The most abundant cohorts in this population were centered at 26 to 30 mm and 44 to 50 mm. Thus, the size structure of this population at Post Creek was virtually identical to that at Olmsted in 2001.

Qualitative studies

A total of 19 species of native mussels were represented among 1,230 individuals collected qualitatively at Post Creek at the same sites at which quantitative samples were collected (WP 12-15) (Table 21). Shared dominance of *F. ebena* (31.3 percent) and *Q. pustulosa* (25.5 percent) was apparent in the qualitative results. As with quantitative sampling, *F. ebena* was more abundant at farshore sites (WP 14 and 15) than at nearshore sites (WP 12 and 13) where *Q. pustulosa* was dominant. *Ellipsaria lineolata* (13.3 percent), *Q. quadrula* (10.2 percent*), A. plicata* (7.5 percent), and *Q. metanevra* (4.7 percent) each comprised approximately 5 percent or more of the community as represented by qualitative sampling. Several species were obtained by qualitative but not quantitative methods due to the much higher number of individuals yielded by the less laborious search-by-feel method. All species represented in quantitative samples were also obtained in the qualitative searches. The combined results of quantitative and qualitative sampling at WP 12-15 yielded a total of 19 species among 1,368 individuals. CPUE (mussels per minute) at WP 12-15 ranged from 7.30 to 12.53.

Table 21
Relative Abundance and CPUE for Qualitative Surveys Conducted in the Lower Ohio River Near Post Creek, 2001

	Waypoint				All Sites	
Species	12	13	14	15	n	%
Q. pustulosa	90	124	88	83	385	31.30
F. ebena	28	52	107	127	314	25.53
E. lineolata	22	23	55	64	164	13.33
Q. quadrula	26	25	40	35	126	10.24
A. plicata	28	33	15	16	92	7.48
Q. metanevra	8	12	13	25	58	4.72
C. tuberculata	3	2	12	10	27	2.20
O. reflexa	5	7	3	3	18	1.46
P. alatus	3	2	7	2	14	1.14
Q. nodulata	2	4	1	1	8	0.65
M. nervosa	1	1	1	3	6	0.49
O. olivaria	1	0	2	3	6	0.49
E. crassidens	1	1	1	2	5	0.41
L. cardium	0	0	1	1	2	0.16
P. cyphyus	0	0	0	1	1	0.08
A. confragosus	0	1	0	0	1	0.08
A. ligamentina	0	1	0	0	1	0.08
L. recta	1	0	0	0	1	0.08
P. cordatum	0	0	1	0	1	0.08
Total time	60	60	60	60	240	
Total individuals	219	288	347	376	1,230	
Total species	15	15	16	16	19	
CPUE	7.30	9.60	11.57	12.53	7.70	

Results of qualitative samples collected from other sites in the mussel bed are summarized in Table 22. WP 16 and 18 were both near the farshore limit of the bed; densities at these locations were the lowest of all samples. CPUE (mussels per minute) at WP 16 and 18 ranged from 0.60 to 1.53. In comparison, CPUE ranged from 3.53 to 7.53 at WP 17 and 19 located relatively nearshore. As with previous results, *Q. pustulosa* showed its highest relatively abundance nearshore.

Table 22
Relative Abundance and CPUE for Additional Qualitative Sampling Sites in the Lower Ohio River Near Post Creek, 2001

Species	WP 16		WP 17		WP 18		WP 19		All Sites	
	NS	FS	NS	FS	NS	FS	NS	FS	n	%
Q. pustulosa	4	3	40	19	1	1	37	17	122	32.62
F. ebena	5	4	17	12	10	1	3	11	63	16.85
E. lineolata	3	3	13	6	2	0	18	1	46	12.30
Q. quadrula	2	1	13	3	1	0	10	5	35	9.36
Q. metanevra	2	2	7	3	6	0	4	5	29	7.75
A. plicata	0	1	7	4	0	0	5	8	25	6.68
C. tuberculata	0	0	6	2	1	0	2	2	13	3.48
O. reflexa	2	0	2	1	0	2	3	0	10	2.67
O. olivaria	2	1	1	0	0	0	0	2	6	1.60
P. cordatum	0	0	1	0	0	2	2	0	5	1.34
P. cooperianus	0	1	0	0	1	1	0	1	4	1.07
L. cardium	0	0	0	0	1	1	1	0	3	0.80
L. recta	1	0	0	2	0	0	0	0	3	0.80
P. alatus	0	0	3	0	0	0	0	0	3	0.80
E. crassidens	0	0	1	0	0	0	0	1	2	0.53
M. nervosa	0	0	0	1	0	1	0	0	2	0.53
L. teres	0	0	0	0	0	0	0	1	1	0.27
P. cyphyus	0	0	1	0	0	0	0	0	1	0.27
Q. nodulata	0	0	1	0	0	0	0	0	1	0.27
Total time	15	15	15	15	15	15	15	15	120	
Total individuals	21	16	113	53	23	9	85	54	374	
Total species	8	8	14	10	8	7	10	11	19	
CPUE	1.40	1.07	7.53	3.53	1.53	0.60	5.67	3.60	3.12	

Cumulative species richness

The best estimate of richness was provided by combining all samples, including quantitative and qualitative samples at WP 12-15 plus qualitative samples at WP 16-19 (Table 23). A total of 21 species were represented among 1,742 individuals collected by all methods near Post Creek in 2001. Among these species was the Federally endangered *P. cooperianus*. Four *P. cooperianus* were collected by qualitative methods in 2001.

Table 23
Relative Abundance of Species from All Waypoints and Samples in the Lower Ohio River Near Post Creek, 2001

Species	Quantitative	Qualitative		Total	
	WP 12-15	WP 12-15	WP 16-19	n	%
Q. pustulosa	45	385	122	552	31.69
F. ebena	46	314	63	423	24.28
E. lineolata	13	164	46	223	12.80
Q. quadrula	11	126	35	172	9.87
A. plicata	3	92	25	120	6.89
Q. metanevra	4	58	29	91	5.22
C. tuberculata	2	27	13	42	2.41
O. reflexa	8	18	10	36	2.07
P. alatus	0	14	3	17	0.98
O. olivaria	2	6	6	14	0.80
Q. nodulata	3	8	1	12	0.69
E. crassidens	1	5	2	8	0.46
M. nervosa	0	6	2	8	0.46
P. cordatum	0	1	5	6	0.34
L. cardium	0	2	3	5	0.29
L. recta	0	1	3	4	0.23
P. cooperianus	0	0	4	4	0.23
P. cyphyus	0	1	1	2	0.11
A. ligamentina	0	1	0	1	0.06
A. confragosus	0	1	0	1	0.06
L. teres	0	0	1	1	0.06
Total time		240	120		
Total individuals	138	1,230	374	1,742	
Total species	11	19	19	21	
CPUE		5.13	3.12		

Nonindigenous species

The *C. fluminea* population was comprised almost entirely of a single cohort ranging from 6 to 15 mm long, with modal length of 10 to 11 mm (Figure 22). This cohort probably represents 2001 recruitment. The few mussels represented by the 15- to 16-mm size class may represent the few surviving individuals of an older cohort.

The *D. polymorpha* population was comprised almost entirely of a single cohort ranging mostly from 2 to 11 mm long, with modal length of 6 to 8 mm (Figure 23). A few individuals ranging from 14 to 18 mm long (barely evident in Figure 23) represent the few survivors of an older cohort.

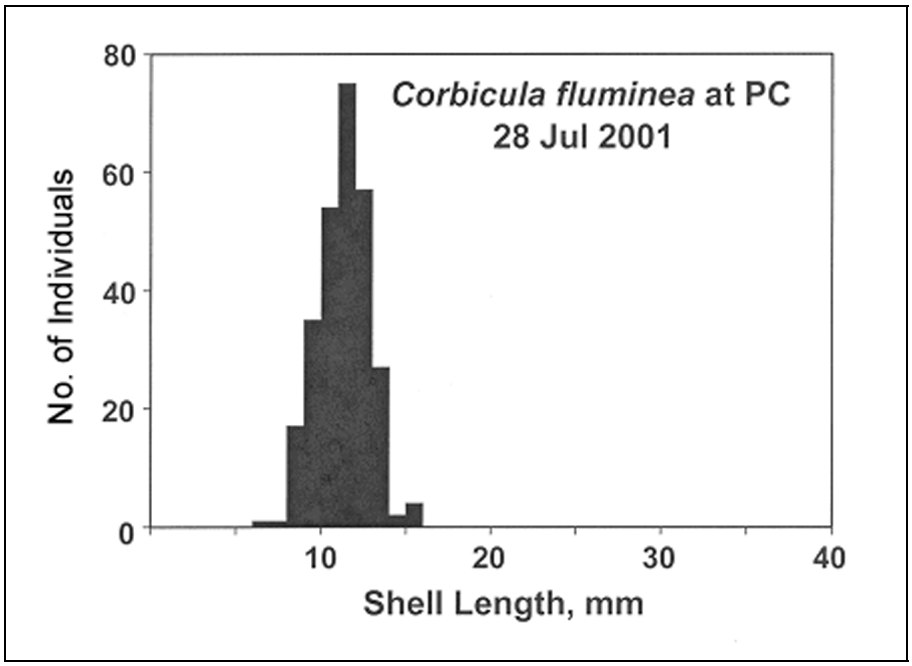

Figure 22. Length frequency of *C. fluminea*, PC mussel bed, 2001

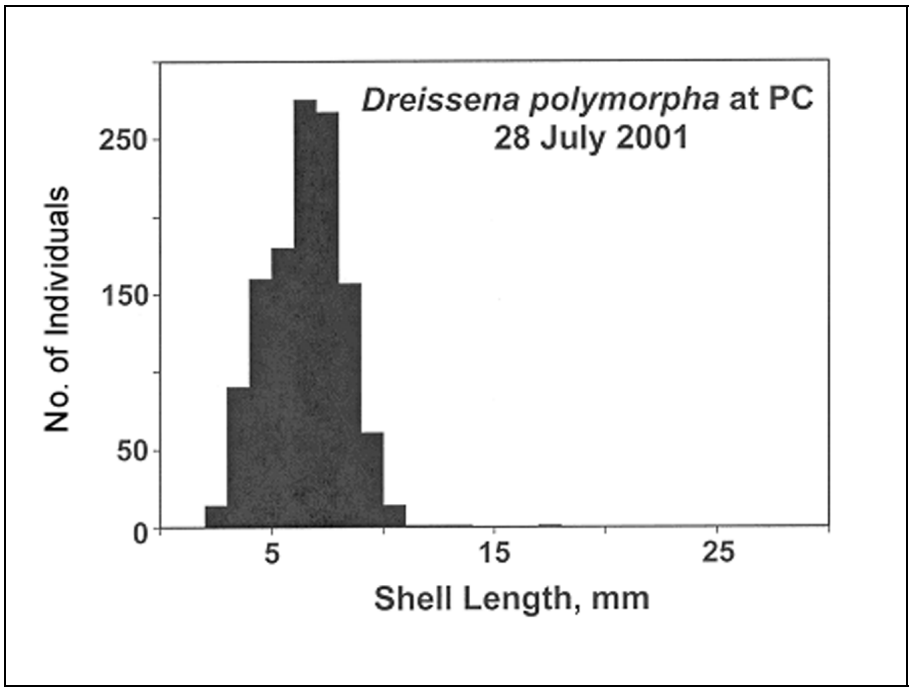

Figure 23. Length frequency of *D. polymorpha*, PC mussel bed, 2001

4 Discussion

The nearshore limit of the Olmsted mussel bed occurs at approximately 278 to 280 ft elevation (Payne and Miller 1997) and reflects historical patterns of extremely low river stage. During the winter of 1980/1981 and the summer and fall of 1988, the 279-ft elevation contour of the shoal was exposed to air for at least 14 consecutive days - enough to kill many unionids. The 281-ft elevation was exposed for maximum periods of 25, 35, and 59 consecutive days in the fall of 1976, winter of 1980/1981, and summer of 1988 – enough to kill most unionids. Thus, it is not surprising that native mussel density is quite low nearshore of the 279-ft elevation contour.

The farshore limit of the mussel bed occurs at approximately elevation 267 ft. This limit is less distinct than the nearshore boundary and reflects lack of suitably stable sand and gravel. Increasingly erosional conditions cause scoured sand and bedrock to be the predominant substratum farshore of elevation 267. However, isolated patches of somewhat more stable substratum (sand or sand and gravel) are occasionally encountered farshore of elevation 267 that support dense assemblages of mussels. In addition, patches of sand that may not be stable for more than a few years temporarily can provide suitable substratum for recent recruits. A lack of large, old mussels in such patches suggests that such substratum and mussels are eventually swept away by scouring flows, preventing the establishment of a complex age structure in mussel assemblages encountered much farshore of elevation 267 (Payne and Miller 1998).

Within the mussel bed, there is a high degree of variability in mussel density. In general, substratum type is not clearly correlated with mussel density between the 279 and 267 elevation contours (Payne and Miller 1998) except that erosional patches of sand or bedrock obviously do not support mussels. Patchiness of mussel density is apparent among quadrats within sites as well as among sites. Both a high degree of sample replication (i.e., at least 10 quadrats per site) and some degree of site replication (at least two closely adjacent subsites per site) are required to establish if location-specific estimates of density are to be confidently compared to establish spatial patterns of density distribution. Although densities of 200 to 300 individuals/m^2 are occasionally encountered, these are outlier data and are always due to extremely dense clusters of recent recruits (especially *F. ebena*). A density range of 50 to 100 individuals/m^2 is more likely to correspond to "local carrying capacity" with respect to a complex, age-structured assemblage.

Fusconaia ebena heavily dominates mussels in the stable shoals of the lower Ohio River. Despite being a species-rich community (with 32 species, Payne and Miller 1997), the mussel bed at Olmsted has low diversity as a mathematical consequence of the high relative abundance of the dominant species. The community at Post Creek is similarly rich in species, but *F. ebena* is much less heavily dominant than at Olmsted. Thus, diversity indices for the Post Creek community indicate moderate diversity. In a broad sense, in which diversity simply equals richness, the lower Ohio River community is indeed diverse at both Olmsted and Post Creek.

Good recruitment appears to be a community-wide phenomenon at Post Creek and Olmsted. The 1990 cohort of *F. ebena* is exceptionally abundant at both locations. However, one or a few individuals of less than 30 mm length have been recovered of nearly all species present on the bed. Obviously, the rarest species yield so few individuals that it is possible to miss recent recruits of those taxa, even if they exist.

Recruitment success appears to be correlated with river discharge conditions (Payne and Miller 2001). In 1981 and 1990 (years with very strong recruitment), rapid rises in river discharge from approximately 25,000 cfs to 60,000 cfs or greater occurred in mid-to-late spring when water temperature is also rising rapidly. The combined conditions of spring temperature rise and a marked rise in discharge from a lower than average seasonal value are appropriate signals for spawning migrations of skipjack herring, the host fish of *F. ebena* glochidia (Payne and Miller 2001) . This fish, like many other riverine species, is adapted to spawn on gravelly or rocky substratum that has been swept clear of fine sand, silt, and clay by recent spates. It is noteworthy that similar discharge conditions occurred in 1998, the most recent year of strong recruitment (Figure 24).

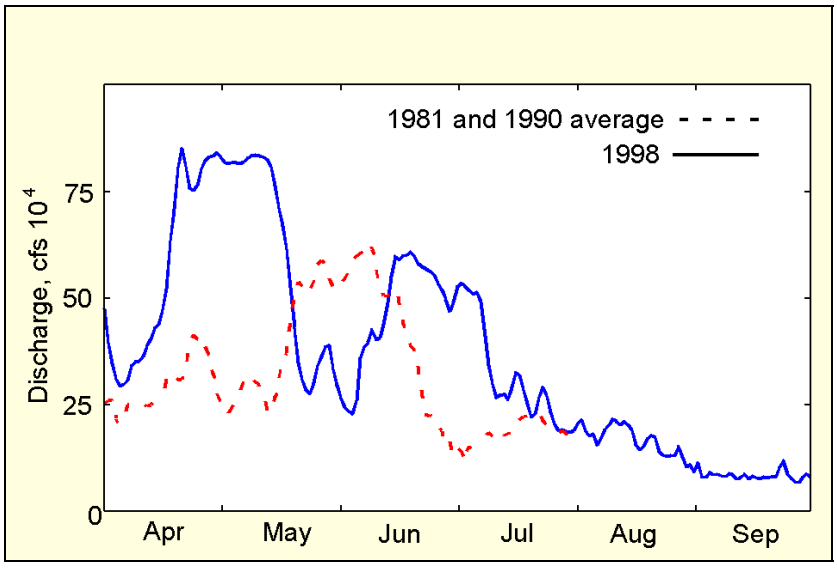

Figure 24. Discharge of the lower Ohio River at Metropolis, IL, averaged for 1981 and 1990 and compared to 1998

Native mussels in the lower Ohio River, including *F. ebena*, have been resilient to high density populations of nonindigenous bivalves. The first such species invasion was by the Asian clam, *C. fluminea*. A dense population of this species in the lower Ohio River was first observed in 1957 (Sinclair and Isom 1961; McMahon 1983). Our sampling at Olmsted began in 1983. From 1983 to 1993, *C. fluminea* was very dense (typically 1,000 to 3,000 individuals/m^2) and populations were characterized by complex age and size structure (typically three to five cohorts) with the oldest and largest individuals being 2 to 3 years old and 30 to 40 mm long. Despite sustained high density and complex demography of *C. fluminea*, no correlation was found between native mussel and *C. fluminea* density within the Olmsted bed (Miller and Payne 1988). A negative relationship would have been evidence of competition between these taxa. Since 1993, *C. fluminea* density has greatly declined, and the population now has simple age structure (typically one or two cohorts) and includes few individuals greater than 15 mm long.

Dreissena polymorpha first appeared in the lower Ohio River in 1991 (Payne, Miller, and Shafer 1994) and has replaced *C. fluminea* as the dense, nonindigenous bivalve existing with native mussels. However, only the 1994 generation of *D. polymorpha* has been extremely dense (49,000 individuals/m^2 in September 1994 to 5,000 individuals/m^2 in July 1995; Figure 18). This dense cohort heavily infested native mussels in 1994 and early 1995, resulting in reduced unionid growth (Payne and Miller 1998), but has not caused major declines in density such as have been reported in the Great Lakes. High density of *D. polymorpha* has not been sustained in the lower Ohio River. Cohorts since the 1994 year class have not been especially dense. It remains to be seen if *D. polymorpha* can occur in sustained abundance in the lower Ohio River at a density sufficiently high to have drastic effects on native bivalves. The most evident effect in the lower Ohio River since 1991 has been suppressed unionid growth during periods of high *D. polymorpha* density or, during periods of low or moderate density, at sites with locally high density.

The size demography of *D. polymorpha* populations at both Olmsted and Post Creek in late July 1999 was characteristic of a stable, complex age structure. The smallest and youngest cohort, centered at 5 to 9 mm and probably representing 1999 recruitment, was the most abundant. The next larger cohort, centered at 14 to 18 mm and probably representing 1998 recruitment, was much less abundant. Finally, the cohort of largest mussels, centered at 22 to 28 mm and probably representing 1997 recruitment, was even less abundant. Density was moderately high at both Olmsted and Post Creek. Multiple cohorts, decreased abundance with age, and moderate to high density, if sustained for several years, would indicate a stable and complexly age structured population of *D. polymorpha* in the lower Ohio River.

5 Future Considerations

Personnel of the U.S. Army Engineer Research and Development Center have used qualitative and quantitative methods to collect bivalves in the lower Ohio River since 1983. The Federally endangered *Plethobasus cooperianus* continues to be represented among the mussel community in the lower Ohio River; several individuals were collected in the present effort. Results indicate that mussel beds of the lower Ohio River remain characterized by high richness, heavy dominance of *F. ebena*, good recruitment rates of juveniles (albeit annually quite variable), and resilience to nonindigenous species invasions. Growth rates of *F. ebena* have been reduced in years of heavy infestation by *D. polymorpha*. However, native mussel populations remain abundant. In this present update, there was evidence that the short-lived and most susceptible unionids, *Truncilla donaciformis* and *T. truncata*, are again part of the mussel community near Olmsted. The resilience of most unionids may be a consequence of the inability, thus far, of zebra mussels to establish sustained, high-density populations. However, the mussel bed clearly was resilient to long-term high density of *C. fluminea* (from approximately 1958 to the late 1980's). *Fusconaia ebena* was once the dominant thick-shelled unionid of stable river shoals throughout the lower Ohio River and the upper Mississippi River. In the lower Ohio River its dominance has corresponded with other indicators of a healthy community, including high richness, resilience, recruitment, and presence of an endangered species. These traits all suggest that mussel beds of the lower Ohio River remain among the most ecologically valuable and interesting in the nation.

River hydraulic conditions are important with respect to the location of mussel beds and patterns of annual recruitment in the lower Ohio River. The nearshore limit of the mussel bed at Olmsted closely coincides with sustained periods of low water. Because most unionids are long-lived, river stage must be considered over a few decades rather than just a few years to reveal this relationship. Similarly, long-term analysis of data revealed an apparent relationship between river discharge pattern from April through July and recruitment of *F. ebena*. Two years with exceptionally strong recruitment, 1981 and 1990, were remarkably closely matched with respect to hydraulic conditions that may have benefited both the probability of successful attachment of glochidia to fish gills and subsequent settlement of juveniles from fish. The discharge pattern of April through July 1981 and 1990 was somewhat similar to patterns in both 1995 and 1997. Both recent years supported moderate *F. ebena* recruitment. The best very recent recruitment year was 1998; as in other years with good recruitment, 1998 was characterized by an abrupt spring rise in

discharge from an atypical low value that coincided with spring temperature rise. These conditions may be triggers of riverine fish spawning migrations that especially enhance mussel recruitment.

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 have negative effects on the mussels of the lower Ohio River. Long-term data have proven invaluable for interpreting causes and significance of fluctuations in physical and biological parameters, including population and community demographics and abundance of nonindigenous species.

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14. ABSTRACT

Surveys were conducted in the summers of 2000 and 2001 to assess community characteristics, population demography of dominant species, status of endangered species, and characteristics of nonindigenous populations of freshwater bivalves in the lower Ohio River. Data will be used to analyze ecological effects of construction and operation of a new lock and dam at River Mile (RM) 964.4. Primary focus has been on a prominent mussel bed just downstream of the project at Olmsted, IL. Studies have shown that this mussel bed extends approximately from elevation 278 ft nearshore to 267 ft farshore. Moderate (20 to 50 individuals/m^2) or high density (>50 individuals/m^2) assemblages of mussels tend to be located at more central elevations on the bed from approximately RM 966.4 to 968.3. The downstream and farshore limits of the mussel bed tend to be less distinct than the nearshore and upstream limits.

The community downstream of the project is extremely dominated by *Fusconaia ebena*. A mussel bed being monitored upstream of the project, at RM 957 near Post Creek, is clearly dominated by this species, but much less heavily than at Olmsted. Also, the abundance of *F. ebena* is higher farshore than nearshore at the Post Creek site. Communities at both Olmsted and Post Creek have been resilient to long-term occurrence (since approximately 1960) of the Asiatic clam, *Corbicula fluminea*, and more recent occurrence of the zebra

(Continued)

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mussel, *Dreissena polymorpha*. Both mussel beds are characterized by extreme dominance of a few year classes (especially 1981, 1990, and 1998) of the dominant species. Rapid spring rises in discharge from unseasonally low values occurred in combination with rising water temperatures in spring of all three good recruitment years. These conditions may trigger spawning runs by *F. ebena*'s host fish, *Alosa chrysochloris* (skipjack herring).

The Federally endangered species *Plethobasus cooperianus* continues to be present in both mussel beds. Several individuals of this species were collected during the 2000 and 2001 surveys. Recent infestations of *D. polymorpha* do not appear to have had any adverse effects on this species.