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THE UNIONIDAE OF THE LOWER MUSKINGUM RIVER
(RM 34.1 - 0), OHIO, U.S.A.

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ABSTRACT - The lower 55 km (34 miles) of the Muskingum River were surveyed in October 1992 for Unionidae by hand-picking, brailing, and diving. Muskrat middens were examined from October 1992 through October 1993. Forty species and 11,145 individuals were found. Nine of these were encountered only as weathered shells and are presumed extirpated from the study area. Five federally endangered taxa were found, although only *Cyprogenia stegaria* (Rafinesque 1820) was collected alive. Other federally endangered taxa found as weathered shells were: *Lampsilis abrupta* (Say 1831), *Pleurobema cicatricosus* (Say 1829), *Pleurobema clava* (Lamarck 1819), and *Pleurobema plenum* (Lea 1840). Fourteen Ohio endangered species were found (including federally endangered species). Four of these appear to be reproducing and may occur nowhere else in the state: *Ellipsaria lineolata* (Rafinesque 1820); *Pleurobema cyphyus* (Rafinesque 1820); *Pleurobema cordatum* (Rafinesque 1820); and *Quadrala metanera* (Rafinesque 1820). Mussels are distributed in six beds located downstream of the first five km of each of four locks and dams. Average bed densities ranged from 3.1 to 41.9 individuals/m², with a maximum density reaching 124 individuals/m². The fauna is dominated by five species, all of which have some commercial value: *Obliquaria reflexa* Rafinesque 1820; *Quadrala pustulosa* (Lea 1831); *Anibiema plicata* (Say 1817); *Pleurobema cordatum*; and *Quadrala quadrula* (Rafinesque 1820). The commercially valuable *Megalomias nervosa* (Rafinesque 1820) is becoming established in the lowest pool with recruitment evident. The State of Ohio is closed to commercial collecting, although poaching pressure for the cultured pearl industry is a serious threat to these beds.

Key Words: Unionidae, Muskingum River, Ohio, zoogeography.

INTRODUCTION

The Muskingum River is the largest river system in Ohio and historically has supported at least 63 unionid species (Bates, 1970; Stansbery & King, 1983; Stansbery *et al.*, 1985). It also has an extensive history of malacological collections, making it one of the best studied rivers for unionids in the country. The most comprehensive survey was that of Stansbery & King (1983). They concluded that large, potentially commercial, beds existed from Dam 4 at Lowell to the mouth at the Ohio River. Although commercial harvesting of mussels is now illegal in Ohio, some beds were collected heavily prior to passage of that legislation, and other beds have been harvested illegally since.

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Table with columns for Family, CCRM, PPRM, NRM, NFRM, and PPM, and rows for various species including Psychomyzidae, Hydrobiidae, Lymnaeidae, Physidae, and Sphaeriidae.

TABLE A-6. (cont.)

The Muskingum River has been impounded by locks and dams to facilitate navigation between the Ohio River and Zanesville. Many of these structures have fallen into disrepair due to inadequate maintenance funds, and several now are inoperable. Government agencies are now considering the fate of these locks and dams. Options include refurbishing the structures, removing them and returning the river to a free-flowing state, or letting them further deteriorate.

Impoundments have been shown to be deleterious to unionids (Harman, 1974). Most freshwater mussels require free-flowing water to survive. In the Muskingum River mainstream, the only places that remain "free-flowing," are those that are immediately downstream of dams. It is here that the largest remaining mussel beds persist. The construction associated with repairing or removing the dams could have a serious impact on those beds due to the release of sediments contained above the dams.

As of 23 August, 1993, 51 species of freshwater mussels have been placed on the Federally Endangered Species List. At the time of the study of Stansbery & King (1987) five Muskingum River unionids were federally endangered. Eleven Muskingum River species now are federally endangered (U.S. Fish & Wildlife Service, 1991; Table 1). With few exceptions, these are all big river species. That is, they are more likely to reside in the downstream reaches of the river than in the headwaters.

TABLE 1. Federally Endangered species recorded from the Muskingum River (after Stansbery & King, 1987, and US Fish & Wildlife Service, 1991).

Common Name	Scientific Name	Date Listed
Fanshell	<i>Cyprogenia stegaria</i>	21 June 1990
White Catpaw	<i>Epiblasma o. obliquata</i>	10 July 1990
Tubercled Blossom	<i>Epiblasma t. torulosa</i>	14 June 1976
Northern Riffleshell	<i>Epiblasma t. rangiana</i>	23 February 1993
Cracking Pearlmussel	<i>Hemistena lata</i>	28 September 1989
Pink Mucket	<i>Lampsilis abrupta</i>	14 June 1976
Ring Pink	<i>Obovaria retusa</i>	29 September 1989
White Wartybuck	<i>Pleurobema cinctiricosus</i>	14 June 1976
Orange-foot Pimpleback	<i>Pleurobema striatius</i>	14 June 1976
Clubshell	<i>Pleurobema clava</i>	23 February 1993
Rough Pigtoe	<i>Pleurobema plenum</i>	14 June 1976

We must document the existence and densities of any species prior to potential human disruption of their habitats. It is critical that this information be gathered for endangered species. Obviously the first

step toward preserving and managing these rare organisms is to find where they still exist. Therefore, it was important that the lower reach of the Muskingum River, which potentially supports nine federally endangered species, be surveyed prior to any action taken on the locks and dams. In 1992, Ecological Specialists, Inc., (ESI) of St. Peters, Missouri, was contracted to survey the lower 43 miles of the Muskingum River. Funds were made available for the study through the Ohio Division of Wildlife's "Do Something Wild!" state income tax checkoff. Data for this study are from ESI (1993).

METHODS & MATERIALS

The purpose of this study was to characterize the beds below Dam 5 (Luke Chute) to the mouth (Table 2; Fig. 1). This encompasses the potential range for most big river species. Beds were located by systematically brailling at 0.8 km intervals within the study area from 23 September to 1 October 1992. Three transects were brailled at each interval at equally spaced locations parallel to the shore. Each braill run lasted 10 minutes, and covered 0.3-0.4 km. Braill runs were conducted in a downstream direction and were numbered from right to left descending bank. The existence of a bed was indicated by the presence of mussels caught on several successive braill runs. Once found, a bed was delimited by more intense brailling. This typically consisted of making five braill runs of five minute duration each between the half mile intervals until no mussels were found.

TABLE 2. Study area.

Location	Muskingum River Miles	Length (mi.)	Length (km)
Dam 5 - Dam 4	34.1 - 25.1	9.0	14.4
Dam 4 - Dam 3	25.1 - 14.2	10.9	17.5
Dam 3 - Dam 2	14.2 - 5.8	8.4	13.5
Dam 2 - mouth*	5.8 - 0.0	5.8	7.4

*Dam 1 was submerged when Willow Island Lock & Dam was constructed on the Ohio River.

Within each bed, five weighted 30 m lines were placed randomly parallel to the shore. A diver collected unionids at forty 1/4 meter² random quadrat sites. Samples were collected in each bed to estimate the composition and density of each bed. Each quadrat was excavated to a depth of approximately 15-20 cm. The diver also qualitatively collected in each bed for several hours to estimate diversity. The dive survey ran from 23 to 30 October 1992.

Living mussels were identified, measured, weighed, and returned along the same transect line by the diver. Many specimens were either too old or too eroded to give an age estimate. Juveniles under 10 g generally could not be weighed accurately, and very large specimens occasionally exceeded the limits of the scales. Methods were chosen to generate comparable types of data with those of Stansbery & King (1987) and Bates (1970). These surveys provide a baseline description of the area prior to any future changes, manmade or otherwise, that might occur. Methods follow the guidelines of Miller & Payne (1988) for characterizing mussel communities.

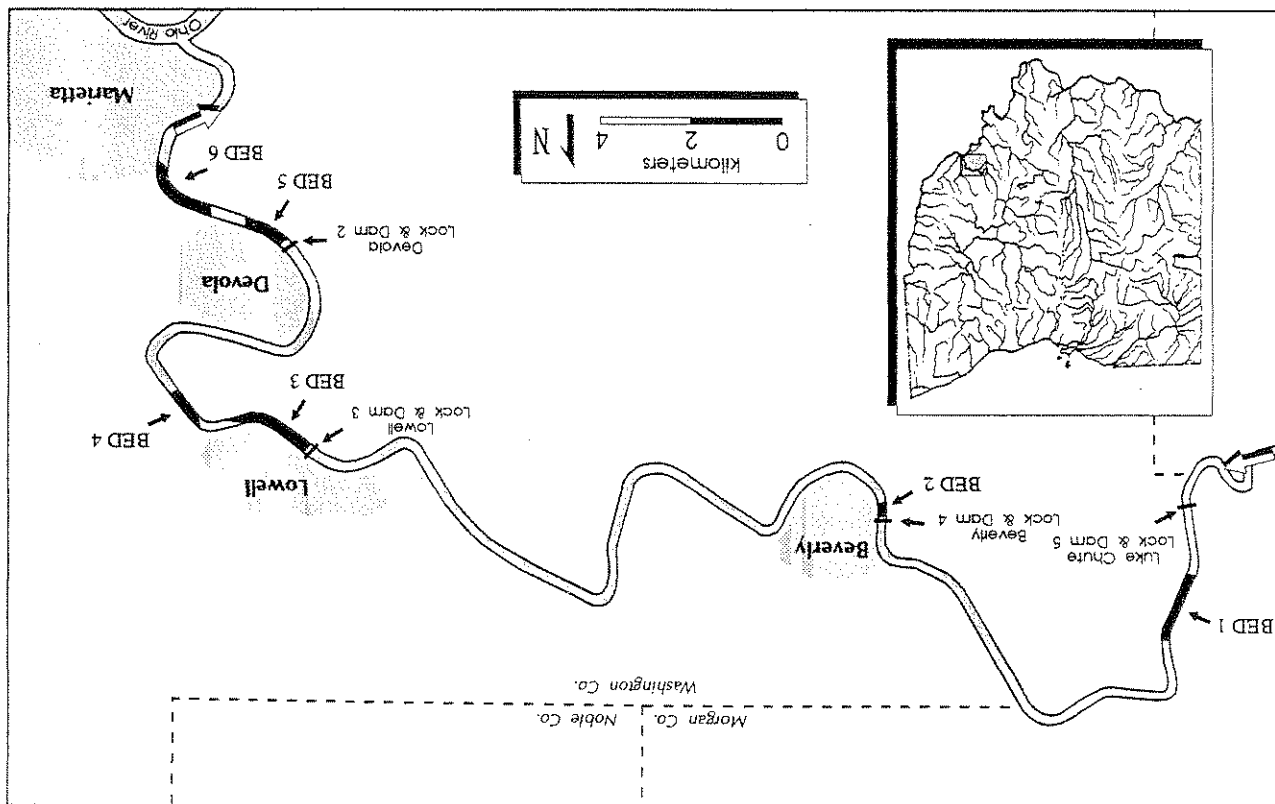


FIG. 1. Study area, lower Muskingum River. Inset - location of study area in Ohio.

After completion of the trailing and diving study, one of us (GTW) continued to sample muskrat middens throughout 1993. Several additional species were recovered, and these are included in the above data.

RESULTS

Six beds were located by trail. Summary statistics for each bed are given in Table 3. Statistics on species age, length, and weight use data from all living specimens in both the quantitative and qualitative surveys. A total of 11,145 specimens was found in the study. Of those, 1,875 were living (17%). Remaining specimens were recovered from muskrat middens and individuals stranded by high water. A few specimens were collected only as weathered shells. All living specimens were returned to the river with the exception of 100 specimens of two common species to be used by other workers for DNA analysis at Ohio University.

TABLE 3. Summary statistics for beds.

Bed	Location	Length (km)	Ave. Density (ind/sq. m)	Diversity (No. spp.)	No. Ohio Endangered	No. Federal Endangered
1	Luke Chute	3.6	3.0	26	6	1
2	Beverly	0.8	30.9	19	2	0
3	Lowell	2.9	17.7	25	7	1
4	Lowell	1.9	9.0	21	7	1
5	Devola	1.6	41.9	34	13	5
6	Devola	1.6	31.0	18	7	1

A total of 40 species was found in the study (Table 4), seven of which were present only as weathered shells. Five species are federally endangered: *Cyprogenia stegaria* (Rafinesque 1820), which was found living or freshdead in three beds, and as a weathered shell in another; and *Lampsilis abrupta* (Say 1831); *Plethobasus cicatricosus* (Say 1829); *Pleurobema clava* (Lamarck 1819); and *Pleurobema plenum* (Lea 1840), which occurred only as weathered or subfossil shells. Fourteen species were Ohio endangered, in addition to the federally endangered species: *Ellipsaria lineolata* (Rafinesque 1820); *Ellipio crassidens* (Lamarck 1819); *Fusconia macilata* (Rafinesque 1820); *Megaloniais nervosa* (Rafinesque 1820); *Plethobasus cyphus* (Rafinesque 1820); *Pleurobema cordatum* (Rafinesque 1820); *Pleurobema rubrum* (Rafinesque 1820); *Quadrula cylindrica* (Say 1817); and *Quadrula metameva* (Rafinesque 1820). Age distributions for all species found living in

TABLE 4. Comparison of unionid fauna in Muskingum River beds, 1992-93.

Endangered	Species	No. Individuals						Total	%
		Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6		
	<i>Actinonaias ligamentina</i>	17	6	4	1*	3	5	36	0.32%
	<i>Alasmidonta marginata</i>					1*	1	1	0.00%
	<i>Ambelena plicata</i>	69	261	353	214	504	105	1506	13.51%
	<i>Anodonta grandis</i>	1	4	4	4	5	14	14	0.13%
	<i>Anodonta imbecillis</i>		1	1			2	2	0.02%
	<i>Cyclonaias tuberculata</i>	6					6	6	0.05%
F/OH	<i>Cyprogenia stegaria</i>	1*	1	16	9	6	2	10	0.09%
OH	<i>Ellipsaria lineolata</i>	7	1	1	150	41	224	201%	
OH	<i>Elliptio crassidens</i>	1*					1	1	0.00%
	<i>Elliptio dilatata</i>	2					2	2	0.02%
	<i>Fusconia flava</i>	2		1*			4	4	0.04%
OH	<i>Fusconia maculata</i>	5		7	3	2	3	20	0.18%
F/OH	<i>Lampsilis abrupta</i>					1*		1	0.00%
	<i>Lampsilis radiata luteola</i>	1	1		1		3	3	0.03%
	<i>Lampsilis ventricosa</i>	7	8	3	1	8	1	28	0.25%
	<i>Lasnigona complanata</i>	7	3	2	1	18	31	31	0.28%
	<i>Lasnigona costata</i>	2		2	1	1	6	6	0.05%
	<i>Leptodea fragilis</i>	33	18	46	3	51	8	159	1.43%
	<i>Ligumia recta</i>					1	1	1	0.00%
OH	<i>Megalonias nerussa</i>	85	325	856	19	1610	179	3074	0.37%
	<i>Obliquaria reflexa</i>	1		8	2	25	12	48	0.43%
	<i>Obovaria subrotunda</i>					1*		1	0.00%
F/OH	<i>Plethobasus cinctiricosus</i>				1	2	3	6	0.05%
OH	<i>Plethobasus cyphus</i>					1		1	0.00%
F/OH	<i>Pleurobema clara</i>					1*		1	0.00%
OH	<i>Pleurobema cordatum</i>	22	21	202	146	781	279	1451	13.02%
F/OH	<i>Pleurobema plenum</i>			1*			3	3	0.03%
OH	<i>Pleurobema rubrum</i>	1	2	5	2	6	9	27	0.24%
	<i>Pleurobema sintoxia</i>	8	11	16	2	51	5	93	0.83%
	<i>Potamilus alatus</i>	3	1	2	1	7	14	14	0.13%
	<i>Potamilus ohioensis</i>						2	2	0.02%
	<i>Ptychobranchus fasciolaris</i>	1				1*		1	0.00%
OH	<i>Quadrula c. cylindrica</i>					3	61	31	0.86%
OH	<i>Quadrula metanetra</i>			1	3	61	108	96	0.86%
	<i>Quadrula pustulosa</i>	156	550	1222	42	695	108	2773	24.88%
	<i>Quadrula quadrata</i>	46	96	52	24	638	390	1246	11.18%
	<i>Simpsoniopsis ambigua</i>					1*		1	0.00%
	<i>Strophitus unilatus</i>		1	2	2	71	7	196	1.76%
	<i>Truncilla donaciformis</i>	54	15	47		10		10	0.09%
	<i>Truncilla truncata</i>								
Total No. Species =		26	19	25	21	34	18	40	
Total No. Individuals =		540	1326	2855	483	4736	1205	11145	
Densities (no. ind./m ²) =		3.1	31.0	17.8	9.0	41.9	31.2		

*Weathered shells only; F = Federal; OH = Ohio.

both quantitative and qualitative surveys (two or more specimens) are given in Appendix A for all beds combined.

Bed 1 - Luke Chute (Lock & Dam 5). Brailing indicated the presence of a diffuse bed extending from Lock & Dam #5 to approximately 3.6 km downstream. Although this bed had the least average

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density of any of the beds studied (3 individuals/m²), it had the second highest diversity. Twenty-six species were found in Bed 1 (Table 5). All but three were present as living or freshdead specimens.

Quadrula pustulosa dominated the fauna, comprising 29% of the individuals found. Of the five commercially valuable taxa in the Muskingum River, as defined by Stansbery & King (1983), four occur in this bed and account for 66% of all specimens: *Quadrula pustulosa* (Lea 1831) (29%); *Obliquaria reflexa* Rafinesque 1820 (16%); *Ambelena plicata* (Say 1817) (13%); and *Quadrula quadrata* (Rafinesque 1820) (8.5%). However, the shells are not of high commercial quality (J. Duckworth, Ducktrail Diving Service, personal communication). Thirteen species, nearly half of the diversity of the bed, occur in relative abundances of less than 1% each. Many of the less common species, such as *Elliptio dilatata* (Rafinesque 1820), *Ptychobranchus fasciolaris* (Rafinesque 1820), and *Lampsilis radiata luteola* (Lamarck 1819), typically are found in smaller streams and may be abundant in the Muskingum River tributaries. A living, old individual of *Pleurobema rubrum* (one of the rarest unionid species in Ohio) was found in this bed.

Bed 2 - Beverly (Lock & Dam 4). Brailing indicated the presence of a small, but very dense bed extending from Lock & Dam #4 to approximately 0.8 km downstream. This lower limit marks the mouth of Wolf Creek. Although this bed had the second highest average density of any of the beds studied (31 individuals/m²), it had the second lowest diversity (Table 5). Only 19 species were found in Bed 2 (Table 6). All were present as living or freshdead specimens. *Quadrula pustulosa* dominated the fauna, comprising 42% of the individuals found. Four of the five commercially valuable taxa occur in this bed and account for nearly 94% of all specimens: *Quadrula pustulosa* (42%); *Obliquaria reflexa* (25%); *Ambelena plicata* (20%); and *Quadrula quadrata* (7%). The shells are of high commercial quality (J. Duckworth, personal communication). Twelve species, 2/3 of the diversity of the bed (mostly headwater species), occur in relative abundances of less than 1% each.

Bed 3 - Lowell (Lock & Dam 3). Brailing indicated the presence of a small, but very dense bed extending from Lock & Dam #3 to approximately 2.9 km downstream. The mouth of Bear Creek marks the lower bed limit. This bed had a medium average density (18 individuals/m²), and a high diversity. Twenty-five species were found in

Species	Best Condition	Endangered	No. Ind.	%	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)	Total No. Species = 19				
										No. Ind. = 1326	Ave. Density (no. ind./m ²) = 31.0			
<i>Quadrula pustulosa</i>	L		550	41.48%	12.8	3	21	69.7	148.5	L				
<i>Obliquaria reflexa</i>	L		325	24.51%	11.0	10	63	68.0	125.0	L				
<i>Amblyema plicata</i>	L		261	19.68%	0.0	0	0	122.0	375.0	L				
<i>Quadrula quadrala</i>	L	OH	96	7.24%	11.5	4	18	85.4	181.5	L				
<i>Pleurobema cordatum</i>	L	OH	21	1.58%	14.4	6	22	90.4	250.0	L				
<i>Leptodea fragilis</i>	L		18	1.36%	5.3	3	8	101.5	107.5	L				
<i>Truncilla donaciformis</i>	L		15	1.13%	4.0	3	5	34.0	10.0	L				
<i>Potamius alatus</i>	D		11	0.83%	NA	NA	NA	NA	NA	D				
<i>Lampsilis centrifica</i>	L		8	0.60%	10.0	10	10	148.0	610.0	L				
<i>Actinonaias ligamentina</i>	L		6	0.45%	15.3	14	16	138.3	370.0	L				
<i>Anodonta grandis</i>	D		4	0.30%	NA	NA	NA	NA	NA	D				
<i>Lasmitigona complanata</i>	D		3	0.23%	NA	NA	NA	NA	NA	D				
<i>Pleurobema sintoxia</i>	L		2	0.15%	14.5	13	16	98.5	250.0	L				
<i>Anodonta imbecillis</i>	D		1	0.08%	NA	NA	NA	NA	NA	D				
<i>Ellipsaria lineolata</i>	L	OH	1	0.08%	8.0	8	8	95.0	180.0	L				
<i>Lampsilis radata luteola</i>	D		1	0.08%	NA	NA	NA	NA	NA	D				
<i>Potamius ohioensis</i>	L		1	0.08%	5.0	5	5	135.0	230.0	L				
<i>Pychohbranchius fasciolaris</i>	D		1	0.08%	NA	NA	NA	NA	NA	D				
<i>Strophitus undulatus</i>	D		1	0.08%	NA	NA	NA	NA	NA	D				

L = living; D = freshdead; W = weathered; F = federal; OH = Ohio; NA = not applicable (only live individuals measured).

TABLE 6. Summary of species composition in Bed 2 (Beverly) from diving surveys. Species listed in order of abundance.

Species	Best Condition	Endangered	No. Ind.	%	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)	Total No. Species = 26				
										No. Ind. = 540	Ave. Density (no. ind./m ²) = 3.1			
<i>Quadrula pustulosa</i>	L		156	28.89%	14.8	7	20	75.5	192.7	L				
<i>Obliquaria reflexa</i>	L		85	15.74%	10.3	4	18	62.7	109.1	L				
<i>Amblyema plicata</i>	L		69	12.78%	12.2	4	20	113.9	345.8	L				
<i>Truncilla donaciformis</i>	L		54	10.00%	5.3	5	6	45.3	21.7	L				
<i>Quadrula quadrala</i>	L		46	8.52%	7.0	7	7	75.0	120.0	L				
<i>Leptodea fragilis</i>	L		33	6.11%	4.9	3	9	96.0	122.3	L				
<i>Pleurobema cordatum</i>	L	OH	22	4.07%	14.5	8	20	97.3	294	L				
<i>Actinonaias ligamentina</i>	D		17	6.11%	16.4	10	22	135.7	560.3	D				
<i>Potamius alatus</i>	L		8	1.48%	9.7	17	12	163.5	442.5	L				
<i>Ellipsaria lineolata</i>	L	OH	7	1.30%	16.0	11	22	110.0	486.0	L				
<i>Lampsilis centrifica</i>	L		7	1.30%	15.8	13	19	135.4	617.0	L				
<i>Lasmitigona complanata</i>	L		7	1.30%	12.4	9	17	155.6	443.0	L				
<i>Cyclonaias tuberculata</i>	L		6	1.11%	17.2	16	23	98.8	320.0	L				
<i>Fusconaias maculata</i>	L	OH	5	0.93%	17.6	16	19	106.6	339.0	L				
<i>Potamius ohioensis</i>	D		3	0.56%	NA	NA	NA	NA	NA	D				
<i>Elliptio dilatata</i>	L		2	0.37%	15.0	13	17	115.5	190.0	L				
<i>Fusconaias flava</i>	D		2	0.37%	NA	NA	NA	NA	NA	D				
<i>Lasmitigona costata</i>	L		2	0.37%	11.0	11	11	142.0	300.0	L				
<i>Pleurobema sintoxia</i>	L		2	0.37%	15.0	15	15	98.0	237.5	L				
<i>Anodonta grandis</i>	D		1	0.19%	NA	NA	NA	NA	NA	D				
<i>Cyprogenia stegaria</i>	W	F/OH	1	0.19%	NA	NA	NA	NA	NA	W				
<i>Elliptio crassidens</i>	W	OH	1	0.19%	NA	NA	NA	NA	NA	W				
<i>Lampsilis radata luteola</i>	W		1	0.19%	NA	NA	NA	NA	NA	W				
<i>Obovaria subrotunda</i>	L		1	0.19%	11.0	11	11	69.0	120	L				
<i>Pleurobema rubrum</i>	L	OH	1	0.19%	?	?	?	93.0	370.0	L				
<i>Pychohbranchius fasciolaris</i>	L		1	0.19%	13.0	13	13	115.0	240.0	L				

L = living; D = freshdead; W = weathered; F = federal; OH = Ohio; NA = not applicable (only live individuals measured); ? = could not be measured.

TABLE 5. Summary of species composition in Bed 1 (Luke Chute) from diving surveys. Species listed in order of abundance.

Bed 3 (Table 7). Three were present only as weathered specimens.

Quadrula pustulosa dominated the fauna, comprising 43% of the individuals found. All five of the commercially valuable taxa listed by Stansbery & King (1983) occur in this bed. They account for nearly 88% of all specimens: *Quadrula pustulosa* (43%); *Obliquaria reflexa* (30%); *Amblyma plicata* (12%); *Quadrula quadrula* (2%), and *Megalomaias nervosa* (0.04%). The shells were not of high commercial quality (J. Duckworth, personal communication). Eighteen species, nearly 3/4 of the diversity of the bed, occur in relative abundances of less than 1% each. These include the most upstream occurrences of several big river taxa in this study: *Megalomaias nervosa* and *Quadrula metanevra*. The headwater species found in Beds 1 and 2 have disappeared from the fauna by this point.

Bed 4 — Lowell (between Lock & Dam 2 and 3). Brailling indicated the presence of a small, but diverse bed extending from downstream of Bear Creek to approximately 1.9 km downstream. This bed had a low average density (9 individuals/m²), but a fairly high diversity. Twenty-one species were found in Bed 4 (Table 8).

Amblyma plicata dominated the fauna, comprising 44% of the individuals found. All five of the commercially valuable taxa occur in this bed, accounting for nearly 63% of all specimens: *Amblyma plicata* (44%); *Quadrula pustulosa* (9%); *Quadrula quadrula* (5%); *Obliquaria reflexa* (4%); and *Megalomaias nervosa* (0.8%). The shells were not of high commercial quality (J. Duckworth, personal communication). Numbers of both *Quadrula pustulosa* and *Obliquaria reflexa* dramatically decreased between Beds 3 and 4. Fifteen species, nearly 3/4 of the diversity of the bed, occur in relative abundances of less than 1% each. These include several rare big river taxa: *Plethobasius cyphitis*, and the federally endangered *Cyprogenia stegaria*, which was found as a freshdead shell.

Bed 5 — Devola (Lock & Dam 2). Brailling indicated the presence of a large, dense bed extending from Lock & Dam #2 to approximately 1.6 km downstream. This bed had the highest average density (42 individuals/m²), with a maximum density of 124 individuals/m², the highest encountered in the study. This bed also had the greatest diversity. Thirty-four species were found in or adjacent to Bed 5 (Table 9). Seven taxa were found as weathered or subfossil shells only.

Obliquaria reflexa dominated the fauna, comprising 34% of the individuals found. All five of the commercially valuable taxa occur in this bed, accounting for nearly 74% of all specimens: *Obliquaria reflexa*

TABLE 7. Summary of species composition in Bed 3 (Lowell) from diving surveys. Species listed in order of abundance.

Species	Best Condition	Endangered	No. Ind.	% Total	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)
<i>Quadrula pustulosa</i>	L		1222	42.80%	15.1	6	23	74.5	176.2
<i>Obliquaria reflexa</i>	L		856	29.98%	14.6	4	23	68.1	138.7
<i>Amblyma plicata</i>	L		353	12.36%	16.6	5	24	118.8	371.5
<i>Pleurobema cordatum</i>	L	OH	202	7.08%	13.1	7	23	93.4	256.2
<i>Quadrula quadrula</i>	L		32	1.82%	12.3	9	16	95.0	232.2
<i>Truncatella domaciformis</i>	L		47	1.65%	3.0	1	5	35.0	25.0
<i>Leptodea fragilis</i>	L		46	1.61%	7.8	4	10	120.5	188.3
<i>Ellipsaria lineolata</i>	L	OH	16	0.56%	17.4	11	22	108.0	360.5
<i>Potamilius alatus</i>	D		16	0.56%	10.0	7	17	127.3	253.0
<i>Obovaria subrotunda</i>	L		8	0.28%	16.0	16	16	70.0	140.0
<i>Fusconia maculata</i>	L	OH	7	0.25%	16.3	15	17	104.5	307.5
<i>Pleurobema sinuata</i>	L		5	0.18%	14.3	9	20	98.0	285.0
<i>Actinonaias ligamentina</i>	L		4	0.14%	13.0	13	13	134.3	566.7
<i>Anodonta grandis</i>	D		4	0.14%	NA	NA	NA	NA	NA
<i>Lampsilis ventricosa</i>	L		3	0.11%	15.0	15	15	146.0	560.0
<i>Lampsilis complanata</i>	D		2	0.07%	7.0	7	7	147.5	85.0
<i>Lampsilis costata</i>	L		2	0.07%	12.0	12	12	142.0	260.0
<i>Potamilius obtusis</i>	D		2	0.07%	NA	NA	NA	NA	NA
<i>Strophitus undulatus</i>	D		2	0.07%	NA	NA	NA	NA	NA
<i>Anodonta imbecillis</i>	D		1	0.04%	NA	NA	NA	NA	NA
<i>Fusconia flava</i>	L		1	0.04%	NA	NA	NA	NA	NA
<i>Megalomaias nervosa</i>	L	OH	1	0.04%	32.0	32	32	112.0	?
<i>Pleurobema plicatum</i>	W	F/OH	1	0.04%	NA	NA	NA	NA	NA
<i>Pleurobema rubrum</i>	W	OH	1	0.04%	NA	NA	NA	NA	NA
<i>Quadrula metanevra</i>	L		1	0.04%	18.0	18	18	95.0	210.0

L = living; D = freshdead; W = weathered; F = federal; OH = Ohio; NA = not applicable (only live individuals measured).

Ave. Density (no. ind./m²) = 17.8

No. Ind. = 2855

Species	Best Condition	Endangered	No. Ind.	% Total	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)
<i>Obliquaria reflexa</i>	L		1610	34.04%	14.6	9	21	70.0	113.7
<i>Pleurobema cordatum</i>	L	OH	781	16.51%	13.5	6	22	85.7	214.0
<i>Quadrula pustulosa</i>	L		695	14.69%	13.7	6	19	68.8	148.9
<i>Quadrula quadrata</i>	L		638	13.49%	13.3	5	20	86.9	196.9
<i>Ambelma plicata</i>	L		504	10.66%	15.9	2	26	107.8	307.7
<i>Ellipsaria lineolata</i>	L	OH	150	3.17%	11.0	2	24	88.7	213.8
<i>Truncilla donaciformis</i>	L		71	1.50%	2.0	1	3	20.9	?
<i>Quadrula metanerva</i>	L	OH	61	1.29%	14.0	8	18	86.8	223.3
<i>Lepidodea fragilis</i>	L		51	1.08%	5.9	3	11	113.6	161.0
<i>Potamilius alatus</i>	L		51	1.08%	9.6	5	15	131.9	235.0
<i>Obovaria subrotunda</i>	L		25	0.53%	18.0	18	18	73.0	180.0
<i>Megaloniaus nervosa</i>	L	OH	19	0.40%	23.8	7	33	198.6	?
<i>Lasmsgona complanata</i>	L		18	0.38%	9.9	4	17	134.5	353.8
<i>Truncilla truncata</i>	L		10	0.21%	2.5	2	3	23.0	?
<i>Lampsilis ventricosa</i>	L		8	0.17%	16.7	15	20	134.0	609.0
<i>Potamilius ohioensis</i>	D		7	0.15%	NA	NA	NA	NA	NA
<i>Cyprogenia stegaria</i>	L	F/OH	6	0.13%	13.3	9	17	68.0	165.0
<i>Pleurobema sintoxia</i>	L		6	0.13%	14.8	9	18	95.0	260.0
<i>Anodonta grandis</i>	D		5	0.11%	NA	NA	NA	NA	NA

TABLE 9. Summary of species composition in Bed 5 (Devola) from diving surveys. Species listed in order of abundance.

Species	Best Condition	Endangered	No. Ind.	% Total	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)
<i>Ambelma plicata</i>	L		214	44.31%	18.3	13	24	117.6	357.9
<i>Pleurobema cordatum</i>	L	OH	146	30.23%	15.2	8	28	90.9	234.2
<i>Quadrula pustulosa</i>	L		42	8.70%	15.6	12	18	71.6	158.1
<i>Quadrula quadrata</i>	L		24	4.97%	16.4	10	15	90.0	206.7
<i>Obliquaria reflexa</i>	L		19	3.93%	17.9	14	23	72.8	153.2
<i>Ellipsaria lineolata</i>	L	OH	9	1.86%	16.7	15	26	109.7	384.3
<i>Megaloniaus nervosa</i>	L	OH	4	0.83%	30.7	25	34	214.8	?
<i>Fusconia maculata</i>	L	OH	3	0.62%	22.5	21	24	107.3	353.3
<i>Lepidodea fragilis</i>	L		3	0.62%	4.7	3	7	84.7	60.0
<i>Pleurobema sintoxia</i>	L		3	0.62%	19.5	18	21	110.0	325.0
<i>Quadrula metanerva</i>	L	OH	3	0.62%	17.5	17	18	97.5	320.0
<i>Obovaria subrotunda</i>	L		2	0.41%	19.5	19	20	63.5	115.0
<i>Potamilius alatus</i>	L		2	0.41%	13.0	13	13	168.0	515.0
<i>Truncilla donaciformis</i>	L		2	0.41%	2.5	2	3	29.0	10.0
<i>Actinonaias ligamentina</i>	W		1	0.21%	NA	NA	NA	NA	NA
<i>Cyprogenia stegaria</i>	D	F/OH	1	0.21%	NA	NA	NA	NA	NA
<i>Lampsilis ventricosa</i>	L		1	0.21%	18.0	18	18	126.0	500.0
<i>Lasmsgona complanata</i>	D		1	0.21%	?	?	?	178.0	670.0
<i>Lasmsgona costata</i>	L		1	0.21%	13.0	13	13	145.0	365.0
<i>Pleurobema cyphus</i>	L	OH	1	0.21%	14.0	14	14	110.0	305.0
<i>Potamilius ohioensis</i>	L		1	0.21%	4.0	4	4	73.0	30.0

TABLE 8. Summary of species composition in Bed 4 (between Lowell and Devola) from diving surveys. Species listed in order of abundance.

L = living; D = freshdead; W = weathered; F = federal; OH = Ohio; NA = not applicable (only live individuals measured); ? = could not be measured.

(34%); *Quadrula pustulosa* (15%); *Quadrula quadrula* (13.5%); *Amblyema plicata* (11%); and *Megalomias nervosa* (0.4%). The shells were of commercial quality (J. Duckworth, personal communication). The Ohio endangered *Pleurobema cordatum* was the second most abundant species. *Ellipsaria lineolata*, also Ohio endangered, was the sixth most common species. Twenty-four species occurred in relative abundances of less than 1% each. The rare *Pleurobema rubrum* was found living in this bed, and six living or freshdead specimens of the federally endangered *Cyprogenia stegaria* also were found.

Bed 6 - Devola (between Lock & Dam 2 and mouth). Brailling indicated the presence of a large, dense bed extending from approximately 0.8 km below Bed 5 to approximately 1.6 kilometers downstream. This bed had the second highest average density (31 individuals/m²), but the lowest diversity. Only eighteen species were found in Bed 6 (Table 10). All taxa were found as living individuals.

Quadrula quadrula dominated the fauna, comprising 32% of the individuals found. All five of the commercially valuable taxa occur in this bed, accounting for nearly 66% of all specimens: *Quadrula quadrula* (32%); *Obliquaria reflexa* (15%); *Quadrula pustulosa* (9%); *Amblyema plicata* (8.7%); and *Megalomias nervosa* (1.4%). The shells were of commercial quality (J. Duckworth, personal communication). The Ohio endangered *Pleurobema cordatum* was the second most abundant species. *Ellipsaria lineolata* and *Quadrula metanera*, both Ohio endangered, were the sixth and seventh most common species, respectively. Ten species, over half of the fauna, occurred in relative abundances of less than 1% each. These were a mixture of headwater and rare big river taxa. Two living specimens of the federally endangered *Cyprogenia stegaria* also were found.

DISCUSSION

Comparison with earlier surveys.

Bates (1970) surveyed much of the Muskingum River between 1967 and 1970. He reported a total of 25 species from the study area of Luke Chute to the mouth (Table 11). That study was followed by the survey of Stansbery & King (1983), which was conducted from 1979 to 1981, and reported 37 species. This study found 40 species. The total diversity reported in all three surveys is 44. Stansbery *et al.* (1985) documented the historical records of six additional taxa not found in the three surveys. Two of these are federally endangered species: *Obovaria retusa* (Lamarck 1819) and *Plethobius striatus* (Rafinesque

TABLE 9. (cont.)

Species	Best Condition	Endangered	No. Ind.	% Total	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)
<i>Actinornias ligamentina</i>	L		3	0.06%	21.7	21	22	160.7	856.7
<i>Fusconia maculata</i>	L	OH	2	0.04%	17.0	16	18	115.5	327.5
<i>Pleurobema cyphus</i>	L	OH	2	0.04%	13.0	13	13	112.0	305.0
<i>Pleurobema plenum</i>	W	F/OH	2	0.04%	NA	NA	NA	NA	NA
<i>Alasmidonta marginata</i>	W		1	0.02%	NA	NA	NA	NA	NA
<i>Fusconia flava</i>	D		1	0.02%	NA	NA	NA	NA	NA
<i>Lampsilis abrupta</i> *	W	F/OH	1	0.02%	NA	NA	NA	NA	NA
<i>Lampsilis radiata luteola</i>	D		1	0.02%	NA	NA	NA	NA	NA
<i>Lasmitigona costata</i>	L		1	0.02%	14.0	14	14	161.0	500.0
<i>Ligumia recta</i> *	D		1	0.02%	NA	NA	NA	NA	NA
<i>Plethobius cincticosus</i> *	W	F/OH	1	0.02%	NA	NA	NA	NA	NA
<i>Pleurobema clava</i> *	W	F/OH	1	0.02%	NA	NA	NA	NA	NA
<i>Pleurobema rubrum</i>	L	OH	1	0.02%	17.0	17	17	93.0	290.0
<i>Quadrula c. cyfindra</i> *	W	OH	1	0.02%	NA	NA	NA	NA	NA
<i>Simpsonia ambigua</i> *	W		1	0.02%	NA	NA	NA	NA	NA

L = Living; D = Freshdead; W = weathered; F = Federal; OH = Ohio; NA = not applicable (only live individuals measured); ? = could not be measured; * = found in adjacent midlands.

Ave. Density (no. ind./m²) = 41.9

No. Ind. = 4736

Total No. Species = 34

TABLE 10. Summary of species composition in Bed 6 (between Devola and mouth) from diving surveys. Species listed in order of abundance.

Species	Best Condition	Endangered	No. Ind.	% Total	Ave. Age (yr)	Min. Age (yr)	Max. Age (yr)	Ave. Length (mm)	Ave. Wt. (g)
<i>Quadrula quadrula</i>	L		390	32.37%	12.1	6	18	87.9	209.5
<i>Pleurobema cordatum</i>	L	OH	279	23.15%	12.0	6	20	85.3	215.0
<i>Obliquaria reflexa</i>	L		179	14.85%	10.2	3	15	57.4	93.3
<i>Quadrula pustulosa</i>	L		108	8.96%	12.5	6	17	69.0	147.7
<i>Ambiema plicata</i>	L	OH	105	8.71%	11.7	2	23	89.2	295.6
<i>Ellipsaria lineolata</i>	L	OH	41	3.40%	11.3	2	25	87.7	227.0
<i>Quadrula mezanera</i>	L	OH	31	2.57%	12.7	8	17	83.3	207.5
<i>Megalomias nervosa</i>	L	OH	17	1.41%	14.2	7	24	168.6	701.5
<i>Obovaria subrotunda</i>	L		12	1.00%	14.0	14	14	66.0	112.5
<i>Pleurobema sintoxia</i>	L		9	0.75%	15.4	9	18	103.4	295.0
<i>Leptodea fragilis</i>	L		8	0.66%	3.4	3	4	81.0	75.7
<i>Truncilla donaciformis</i>	L		7	0.58%	2.2	2	3	18.4	?
<i>Actinonaias ligamentina</i>	L		5	0.41%	14.4	4	21	152.6	483.8
<i>Potamilius alatus</i>	L		5	0.41%	5.8	4	10	124.0	252.5
<i>Fusconaias maculata</i>	L	OH	3	0.25%	13.5	7	20	75.5	190.0
<i>Plethobasus cyphus</i>	L	OH	3	0.25%	10.7	8	14	98.3	226.7
<i>Cyprogenia stegaria</i>	L	F/OH	2	0.17%	10.5	9	11	58.0	102.5
<i>Lampsilis ventricosa</i>	L		1	0.08%	15.0	15	15	138.0	540.0

L = living; D = freshdead; W = weathered; F = federal; OH = Ohio; NA = not applicable (only live individuals measured); ? = could not be measured.

Ave. Density (no. ind./m²) = 31.2

No. Ind. = 1205

Total No. Species = 18

TABLE 11. Comparison of all unionids in three surveys of the lower Muskingum River.

Endangered	Species	Bates (1970)	Slansbery & King (1983)	This study (1992-3)
	<i>Actinonaias ligamentina</i>	x	x	x
	<i>Alasmidonta marginata</i>	x	x	w
	<i>Ambiema plicata</i>	x	x	x
	<i>Anodonta grandis</i>	x	x	x
	<i>Anodonta imbecillis</i>	x	x	x
F/OH	<i>Cyclonaias tuberculata</i>	x	x	x
OH	<i>Cyprogenia stegaria</i>	x	x	x
OH	<i>Ellipsaria lineolata</i>	x	x	x
OH	<i>Elliptio crassidens</i>	x	w	w
F/OH	<i>Elliptio dilatata</i>	x	x	x
	<i>Epioblasma l. torulosa</i>	x	w	x
	<i>Epioblasma triquetra</i>	x		
OH	<i>Fusconaias flava</i>	x	x	x
F/OH	<i>Fusconaias maculata</i>	x	w	w
	<i>Lampsilis abrupta</i>	x	x	x
	<i>Lampsilis radiata luteola</i>	x	x	x
	<i>Lampsilis ventricosa</i>	x	x	x
	<i>Lasniogona complanata</i>	x	x	x
	<i>Lasniogona costata</i>	x	x	x
	<i>Leptodea fragilis</i>	x	x	x
	<i>Ligumia recta</i>	x	w	x
OH	<i>Megalomias nervosa</i>	x	x	x
	<i>Obliquaria reflexa</i>	x	x	x
	<i>Obovaria subrotunda</i>	x	x	x
F/OH	<i>Plethobasus cincticosus</i>	x		w
OH	<i>Plethobasus cyphus</i>	x	x	x
F/OH	<i>Pleurobema clava</i>	x	w	w
OH	<i>Pleurobema cordatum</i>	x	x	x
F/OH	<i>Pleurobema plummi</i>	x	x	x
OH	<i>Pleurobema rubrum</i>	x	x	x
	<i>Pleurobema sintoxia</i>	x	x	x
	<i>Potamilius alatus</i>	x	x	x
	<i>Potamilius ohioensis</i>	x	x	x
	<i>Ptychobranchius fasciolaris</i>	x		w
OH	<i>Quadrula cylindrica cylindrica</i>	x	x	x
OH	<i>Quadrula melaneva</i>	x	x	x
	<i>Quadrula pustulosa</i>	x	x	x
	<i>Quadrula quadrula</i>	x	x	x
	<i>Simpsonaias ambigua</i>	x	x	w
	<i>Strophitus undulatus</i>	x	x	x
	<i>Toxolasma parvus</i>	x	x	x
	<i>Tritogonia verrucosa</i>	x	w	x
	<i>Truncilla donaciformis</i>	x	x	x
	<i>Truncilla truncata</i>	x	x	x
Total no. Species		25	37	40
Total no. species = 44				

w = weathered or subfossil shell only; F = Federal; OH = Ohio.

1820) (=cooperianus). Both have been extirpated from the state. Another species is Ohio endangered: *Lampsilis teres* (Rafinesque 1820). The remaining three taxa are headwater species known to occur in the Muskingum River system: *Lampsilis fasciola* Rafinesque 1820; *Lampsilis ovata* (Say 1817); and *Lasmigona compressa* (Lea 1829). Including these records, the total number of species reported from the study area is 50. At least 66% of these species still live in the area.

Comparisons of the diversity found by each of the three surveys shows that Bed 1 consistently had the lowest diversity (Fig. 2). Bed 1 also is the smallest of the beds. The diversities per bed were fairly equal for the 1983 and 1992 surveys. The 1970 study reported fewer species in each bed, although they were in the same relative proportions as in 1983 and 1992. It is not known how many man-hours were

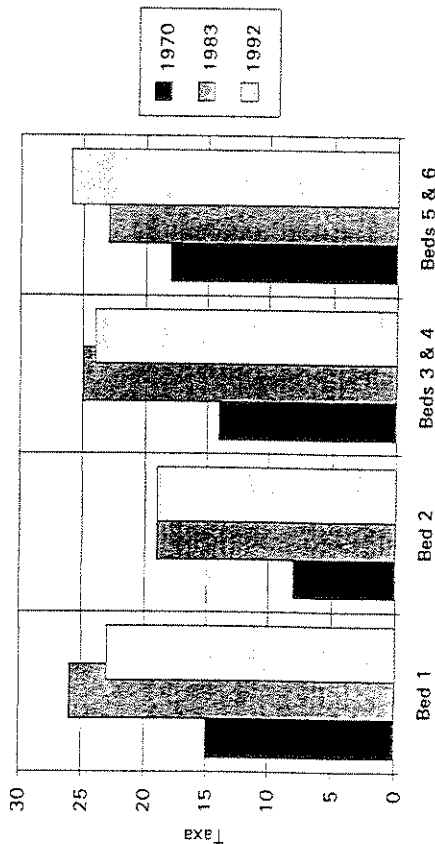


FIG. 2. Comparison of diversity of bed. 1970 - Bates (1970); 1983 - Stansbery & King (1983); 1992 - This study.

spent at each site for either Bates (1970) or Stansbery & King (1983), thus it is impossible to standardize data. We do not know if the low diversities reported by Bates were the result of shorter collecting times, his collecting methods (he did not sample muskrat middens), or if they actually reflect a depressed fauna that now is recovering.

The survey of Stansbery & King (1983) and this study reported densities for Beds 1 to 5. Stansbery and King did not recognize the presence of a sixth bed separate from Bed 5, if it existed at that time. They apparently included it with Bed 5. Fig. 3 compares the densities of these beds between 1983 and 1992. Both surveys found low densi-

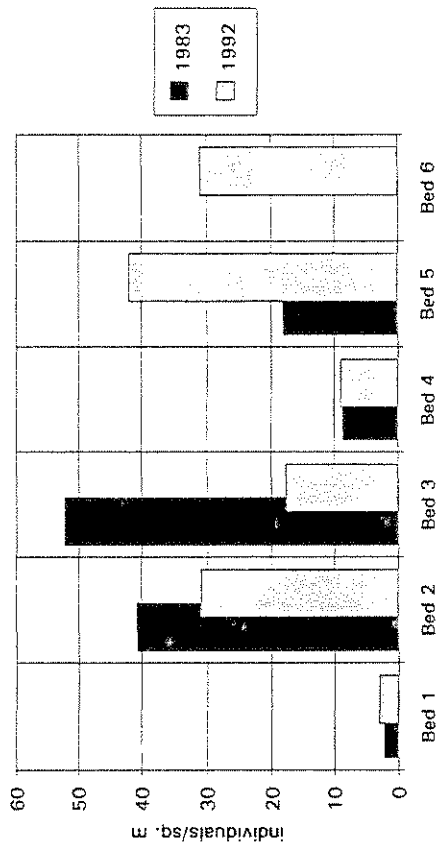


FIG. 3. Comparison of density by bed. 1983 - Stansbery & King (1983); 1992 - This study.

ties in Beds 1 and 4. However, Bed 3, below Lowell Lock & Dam, now has less than half of the density found in 1983. At that time it was the densest of all beds in the study area, whereas now it is the fourth densest. This may be due to several causes. The closure of the Beverly Lock & Dam upstream for repair, as well as the severe droughts of 1986-1989, exposed much of this shallow bed, killing untold numbers of mussels. During this study, the diver reported numerous dead shells that had begun to weather, suggesting that these were killed some years prior to 1992. The diver also found some areas devoid of mussels (live or dead) that previously had contained high densities, possibly attributable to poaching activities. A petroleum spill of 7 June 1992 just above the dam does not appear to have been responsible for this decline in density, but the bed should be monitored for any future effects.

The data presented in Fig. 3 suggest that, with the loss of density in Beds 3 and 4 below Lowell, the emphasis has shifted to Beds 5 and 6 below Devola. These beds are twice as dense now as they were in 1983, and support a higher diversity (Fig. 2). This may be due to their unobstructed connection to the Ohio River. There is some evidence that unionid and fish diversity as well as numbers are recovering in that river (W. Tolin, USFWS, personal communication; Pearson & Pearson, 1989).

For Lowell (Beds 3 & 4) and Devola (Beds 5 & 6), the beds closest to the dams had the highest densities and diversities. Stansbery & King

also found this to be the case for Beds 3 and 4 below Lowell (they recognized only one bed below Devola). This may be due to faster currents in these areas, preventing silt accumulation over substrates and mussels, higher DO levels during low flow, and fish host congregations below the dams.

Stansbery & King (1983) presented combined data for age and size classes of all commercial taxa in each bed (their figures 4 & 5). This data mixes short lived and long lived taxa, and large and small species. We do not believe this a valid comparison and have not duplicated that approach here. Both Bates (1970) and Stansbery & King (1983) published age, size, and density data only for commercially valuable species. However, the patchiness of unionid distributions does not allow for quadrat samples to be extended to individual species densities. We have preferred to rank species by relative abundance for those comparisons. Densities were determined here only for all species within a bed. Comparisons on a species by species basis are given in the next section.

Bed 1 - Luke Chute. Bates (1970) recognized three beds below the Luke Chute Lock & Dam. Neither Stansbery & King (1983) nor this study found evidence of more than one diffuse bed.

Thirty-four species have been found in this bed in the three surveys, including four federally endangered species: *Cyprogenia stegarii*; *Epioblasma torulosa torulosa* (Rafinesque 1820); *Lampsilis abrupta*; and *Pleurobema clava*. Twenty-six taxa were found in this study (Table 5). However, no federally endangered species were found as living or freshdead shells. Ten Ohio endangered species also have been recorded from the surveys. Four of these were found living in 1992: *Fusconia maculata*; *Ellipsaria lineolata*; *Pleurobema cordatum*; and *Pleurobema rubrum*.

The same five species are dominant in both the Stansbery and King study and this study. Several of these differ from those reported in Bates' study. *Oblivaria reflexa*, a dominant species in 1992, was only seventh in 1970. *Truncilla donaciformis* (Lea 1827) now fourth, was 12th in 1970. Conversely, the rare, Ohio endangered *Fusconia maculata* was the second most abundant species in 1970, but 16th and 14th in 1983 and 1992, respectively. Bates reported 93 individuals of this species in this pool, compared to four by Stansbery and King and five here. Unless his specimens were misidentified, this species has been greatly reduced in numbers since 1970. Other species common in 1970 or 1983 also have become rare: *Obovaria subrotunda* (Rafinesque 1820) and *Ptychobranchus fasciolaris*. Several have become more

common since 1970 or 1983, including the Ohio endangered *Ellipsaria lineolata*.

Bed 2 - Beverly. The bed below Beverly Lock & Dam is the smallest of the beds studied. Its downstream limit coincides with the mouth of Wolf Creek, suggesting that this creek is releasing some agent into the Muskingum River that is detrimental to unionids. This may be sediment load during flood stage, agricultural runoff, or a combination of factors. Wolf Creek should be investigated for these potential problems.

Twenty-eight species have been found in this bed in the three surveys, including the federally endangered species *Lampsilis abrupta*, which was found by Stansbery and King only as a weathered shell. Nineteen taxa were found in this study (Table 6). Six Ohio endangered species also have been recorded from the surveys, two of which were found living in 1992.

The same four species were dominant in all studies: *Amblyema plicata*; *Oblivaria reflexa*; *Quadrula pustulosa*; and *Quadrula quadrula*. The fifth most common species in 1992 was *Pleurobema cordatum*, an Ohio endangered species, and Bates found this species to be the sixth most common. Stansbery and King however ranked this taxon as 14th. Clearly, this species is much more common now than it was in 1983, and it apparently was common in 1970. This species also is more common now in the other beds than it was in 1983. Such fluctuations in a population of a long-lived species can only be detected by long term monitoring. The causes of these changes, whether they are due to limits on the mussel or on the host, and whether they are periodic, are unknown. Several other species appear more common today than in 1983: *Actinonaias ligamentina carinata* (Barnes 1823) and *Lampsilis ventricosa* (Barnes 1823). Several common headwater taxa found in 1983 were not encountered in 1992.

Beds 3 & 4 - Lowell. Bates did not recognize two beds below the Lowell Lock & Dam. Although Stansbery and King did find two beds, they combined the data to be comparable to those of Bates. Data from this study for Beds 3 and 4 also have been combined when necessary for comparison with earlier surveys. These beds are separated by the mouth of Bear Creek. As with Wolf Creek and Bed 2, this creek may be influencing beds in the Muskingum River by releasing sediment or other pollutants.

Twenty-five taxa were found in this study in Bed 3, and 21 were found in Bed 4 (Tables 7 and 8). Twenty-seven species were found in the combined beds. Thirty-two species were found in these beds in

the three surveys, including the federally endangered species *Cyprogenia stegaria* (living and freshdead) and *Lampsilis abrupta* (as a weathered shell). A third federally endangered taxa, *Pleurobema plenum*, was found in 1992 as a weathered shell. Ten Ohio endangered species also have been recorded from the surveys, seven of which were found living in 1992.

The same six species were dominant in 1992 and 1983, and five of these were dominant in 1970. *Quadrula pustulosa* was the dominant species in 1983 and 1992. The sixth most common species in 1992, and fifth in 1983, was not found in 1970: *Leptodea fragilis* (Rafinesque 1820). Both *Ellipsaria lineolata* and *Truncilla donaciformis* were more common in 1992 than in previous studies. Several species have become less common, such as *Anodonta grandis* Say 1829, *Lampsilis ventricosa*, and *Potamilus ohioensis* (Rafinesque 1820). This may reflect a different emphasis on collecting techniques between 1983 and 1992 than on any biological cause. Those species often are found in slackwater outside the main stem. In 1992 collecting was most intensive in the main stem beds and species in slackwater may not be well represented in the data.

Beds 5 & 6 - Devola. Neither Bates nor Stansbery and King recognized two beds below the Devola Lock & Dam. This study found two beds and data from Beds 5 and 6 have been combined when necessary for comparison with earlier surveys.

Thirty-four taxa were found in this study in Bed 5, and 18 were found in Bed 6 (Tables 9 and 10). Thirty-four species were found in the combined beds. The three surveys combined yielded 39 species in these beds, including the federally endangered species *Cyprogenia stegaria* (living and freshdead), and *Lampsilis abrupta*, *Plethobasus cicatricosus*, *Pleurobema clava*, *Pleurobema plenum*, were found in 1992 as weathered shells. Fourteen Ohio endangered species also have been recorded from the surveys, eight of which were found living in 1992, including *Pleurobema rubrum*.

Four of the five most dominant species in 1992 were also the most dominant in previous surveys. *Obliquaria reflexa* was the most abundant species in 1992, although it had been ranked third and fourth in 1970 and 1983, respectively. *Pleurobema cordatum*, an Ohio endangered species, was the second most abundant taxa in 1992, moving up from sixth in 1983 and 1970. *Ellipsaria lineolata* and *Quadrula metancora*, both Ohio endangered, also were more common in 1992. The commercially valuable *Amblyema plicata* was only the fifth most common species in 1992, falling from first and second places in 1970

and 1983.

Commercially valuable species accounts.

Stansbery & King (1983) listed five species as being the most commercially valuable of the Muskingum River mussels: *Amblyema plicata*; *Megalomias nervosa*; *Obliquaria reflexa*; *Quadrula pustulosa*; and *Quadrula quadrula*. These species currently account for 77.5% of the individuals found in the study area. Four of them are the four most common species in the study. Only *Megalomias nervosa* is uncommon in this area.

Bates (1970) reported on the commercial harvest of the Luke Chute and Beverly beds in 1967. From Beverly, 6.8 tons of shells were removed, while from Luke Chute, approximately 30.6 tons were taken. Bates described the Luke Chute bed: "the greatest percentage of the total catch of the season came from this area" (1970: 96). Originally described as three rich beds, this is now the least dense area of those studied, having an average density of only 3/m². Only one diffuse bed could be located in 1983 and 1992. Between 1967 and 1970, approximately 1,258 tons of shells commercially were removed from the Muskingum River, much of it from the study beds. It is likely that the low densities found today in the Luke Chute bed (and probably other sites as well) are at least partially attributable to overharvesting.

Amblyema plicata (Say 1817). Although this species is less common now than in 1970 and 1983 in most of the study area, still it comprises 13.5% of the total fauna, and there is ample evidence that it is reproducing, particularly in the Devola beds. A comparison of age classes between the three studies (all beds combined) shows strong recruitment in 1970 and 1992, but a single peak of 10-12 year olds in 1983 (Fig. 4; see also Appendix A). A bed by bed comparison of 1992 data shows good recruitment in Beds 5 and 6. Less recruitment was observed in Beds 1 and 2, and little or no recruitment was found in Beds 3 and 4. The average age in Bed 4 is 18.3 years, but only 11.7 years in Bed 6. In addition, large numbers of 1 to 3 year olds were present in beds 5 and 6.

Megalomias nervosa (Rafinesque 1820). Neither Bates nor Stansbery and King found sufficient numbers of this Ohio endangered species to warrant age comparisons. In 1992, ages ranged from seven to 34 years old, indicative of a constant recruitment (Appendix A). Most of this recruitment occurs in Beds 5 and 6. These beds are open to the

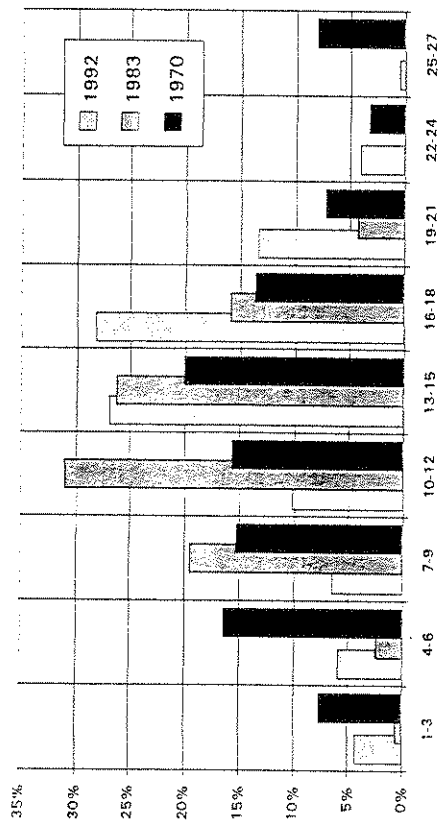


FIG. 4. Age distribution for *Amblyema plicata* from three surveys. 1970 - Bates (1970); 1983 - Stansbery & King (1983); 1992 - This study.

Ohio River where this species is common. This species appears to be increasing in numbers in the study area, but currently makes up only 0.4% of the total fauna.

Obliquaria reflexa Rafinesque 1820. Within the study area, this species has increased its numbers in the past decade and is reproducing in most areas. It is most common in beds immediately below the dams, and currently comprises 27.6% of the total fauna - the most common species in the study area. A comparison of age classes found in the three studies for all beds combined shows recruitment in all three studies (Fig. 5; see also Appendix A). A much younger size group was found in 1992 than in other study years. A bed by bed comparison of 1992 data shows recruitment prevalent in Beds 1, 3, and 6, but less prevalent in Beds 2, 4, and 5. Young individuals are preyed upon heavily by muskrats.

Quadrula pustulosa (Lea 1831). Like *Obliquaria reflexa*, *Quadrula pustulosa* is thriving in the Muskingum River. A comparison of age classes between studies (all beds combined) shows recruitment in all three studies (Fig. 6; see also Appendix A). A bed by bed comparison of 1992 data shows recruitment in all beds except for Bed 4. Except for the Devola beds, it is the second most common species in the study area, comprising 24.9% of the total fauna, and has remained abundant for the past two decades. It is reproducing in most areas and is most common in beds immediately below the dams.

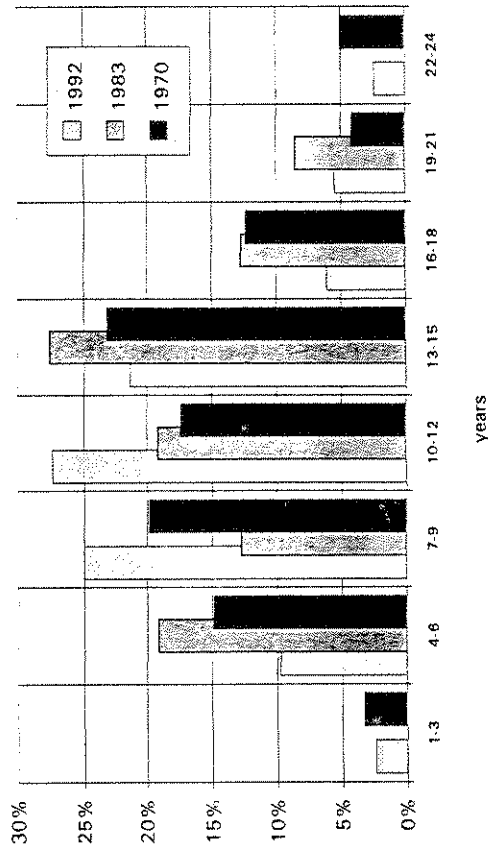


FIG. 5. Age distribution for *Obliquaria reflexa* from three surveys. 1970 - Bates (1970); 1983 - Stansbery & King (1983); 1992 - This study.

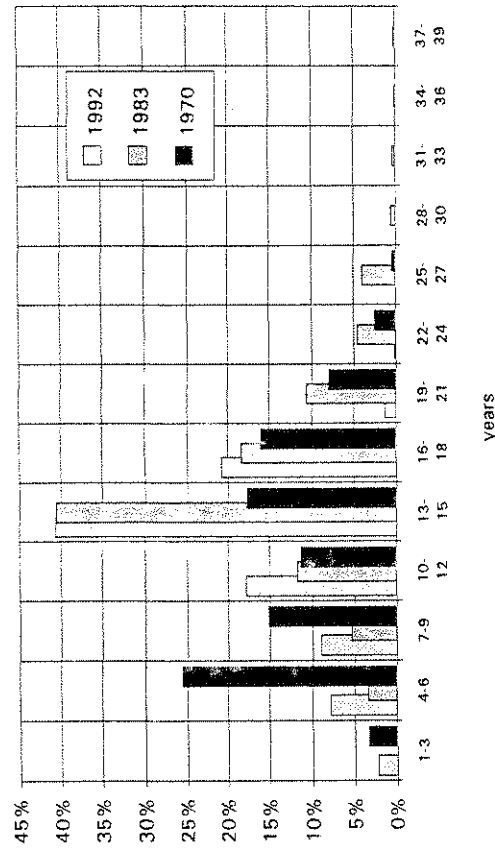


FIG. 6. Age distribution for *Quadrula pustulosa* from three surveys. 1970 - Bates (1970); 1983 - Stansbery & King (1983); 1992 - This study.

Quadrula quadrula (Rafinesque 1820). Although this species has declined in abundance, recruitment has remained fairly constant. A comparison of age classes between studies (all beds combined) shows

recruitment in all three studies (Fig. 7; see also Appendix A). Data for 1992 show that recruitment is prevalent in all beds except for Beds 1, 3, and 4. It is the most common species in Bed 6. This is not surprising given the commonness of this species in the Ohio River. It has remained abundant for the past two decades, comprising 11.2% of the total fauna, and is reproducing in most areas.

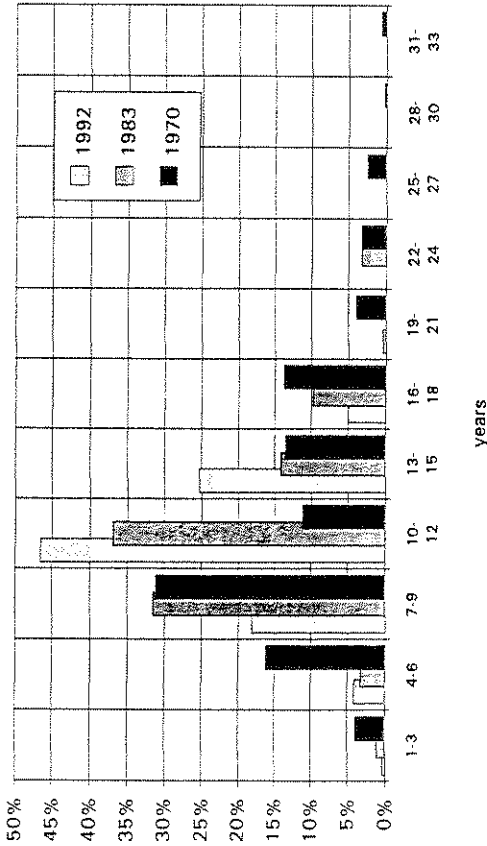


FIG. 7. Age distribution for *Quadrula quadrata* from three surveys. 1970 - Bates (1970). 1983 - Stansbery & King (1983). 1992 - This study.

Non-commercial species accounts

Actinonaias ligamentina carinata (Barnes 1823). This was a rare species in the study area, comprising only 0.32% of the total fauna, and was equally rare in the surveys of 1970 and 1983. It was most common in Bed 1, but was not encountered there living. Its distribution in Ohio is unusual in that this species is often absent or rare in areas otherwise diverse in unionids. Conversely, it is often abundant at other sites. Although common in the Ohio River, it was not common in the Devola beds closest to that river. However, the only evidence of recruitment was found in Bed 6.

Alasmidonta marginata Say 1818. Only a single weathered shell at Bed 5 was found in this study. Similarly, Stansbery and King found only a single individual in the Lowell beds in 1983. This species typically is found in clear, fast water in large creeks, conditions that are not met in the study area.

Anodonta grandis Say 1829. *Anodonta grandis* was a rare species in this study, comprising only 0.13% of the total fauna, although Stansbery and King found more examples than did this survey. This species is common in backwater areas of rivers and impoundments. This study may not have addressed those areas as thoroughly as did the study of Stansbery and King.

Anodonta imbecillis Say 1829. Like *Anodonta grandis*, this species is most often found in backwaters and impoundments. It was not well represented in this study, although it is often locally common in the proper habitat. Only two individuals were found in this survey.

Cyclonaias tuberculata (Rafinesque 1820). This species was found only in Bed 1 in 1983 and 1992 and does not appear to be reproducing. Six individuals were found in 1992, all 15 years or older. It is a species of sandy substrates in large creeks or rivers.

Cyprogenia stegaria (Rafinesque 1820). This federally endangered species was found living in Beds 5 and 6, and freshdead in Beds 4 and 5. Two of these dead specimens were found in muskrat middens along Bed 5. A weathered shell was found in Bed 1. All living individuals were found among other species in packed sand and gravel. This species comprised 0.09% of the fauna; 19 other species were rarer, or as rare as, *Cyprogenia stegaria*. Bates found a single individual below Devola, and Stansbery and King found two below Lowell and one below Devola. Ages of the 1992 specimens ranged from nine to 17 years, although one freshdead individual was seven years old. Thus there was no evidence that this species was reproducing in the study area. However, this does not preclude the possibility that undetected juveniles exist, or that the adults found will not reproduce in the future. This species is not known to live anywhere else in the state, and now occurs in less than half of a dozen sites in the world.

Ellipsaria lineolata (Rafinesque 1820). This Ohio endangered species was found living or freshdead in every bed in the study area. A total of 224 individuals was found, comprising 2% of the total population, making it the sixth most common species in the study. It was most abundant in Bed 5, where it represented 3.2% of the fauna, and is reproducing below Devola in Beds 5 and 6. In all beds it is now as common, or more common, than in either 1983 or 1970. The only known population of this species in Ohio is in the lower Muskingum River.

Elliptio crassidens (Lamarck 1819). Only a single weathered shell was found within the study beds, at Bed 1. Another weathered shell was found downstream of Bed 2. Bates did not find this species, and

Stansbery and King found only weathered shells. This Ohio endangered species occurs only sporadically within the state's waters, although locally abundant in the Ohio River. Its absence in the lower beds of the Muskingum River is a mystery.

Elliptio dilatata (Rafinesque 1820). Only two living specimens were collected in this study, both in Bed 1. This species typically inhabits smaller rivers and creeks where it may be abundant. It occurs in this bed along with a few other smaller river species that were either absent or very rare in other beds. These specimens may have been introduced from neighboring tributaries. It also was very rare in previous surveys.

Fusconia flava (Rafinesque 1820). Like *Elliptio dilatata*, this species is common in smaller creeks in the state, but was very rare in the study area. Only four specimens were found in the study, two of these were from Bed 1. Bates did not find this species, and it was rare in the study of Stansbery and King.

Fusconia maculata maculata (Rafinesque 1820). This Ohio endangered species was found in all beds except Bed 2. However, a single specimen was found living some miles below that bed. It comprises 0.18% of the total fauna of the study area. This also was a rare species in 1983, but Bates reported 93 specimens in 1970 from Bed 1 where it was the second most abundant species. By contrast, it was 16th in 1983 and 14th in the present study. This species has some commercial value, and if Bates' figures are correct, this species may have been over-harvested in that bed. Most specimens found in 1992 were old individuals, the youngest being a seven year old specimen in Bed 6. This is a rare species in the Ohio River, and the Muskingum River population may be the only remaining one within the state boundary.

This taxon also may be listed as *Fusconia subrotunda* (Lea 1831). *Lampsilis abrupta* (Say 1831). This federally endangered species was found in 1983 and 1992 only as weathered shells. There is no evidence that is still living in the study area, although recent records from the Ohio River are known.

Lampsilis radiata luteola (Lamarck 1819). This species is the most common unionid in Ohio, but is rare in big rivers. The Muskingum River is no exception and only three specimens were found in the study. Bates found only a single specimen, and Stansbery and King, only five. This species also may be listed as *Lampsilis siliquoides* (Barnes, 1823).

Lampsilis ventricosa (Barnes 1823). This species comprised 0.25% of the total fauna and was found in all beds. It was most common in

Bed 1, where it may be reproducing. This taxon is more common in smaller rivers and creeks. It was equally uncommon in previous studies. This species also may be listed as *Lampsilis cardium* (Rafinesque 1820).

Lasmigona complanata (Barnes 1823). This species was found in all beds except Bed 6, although most specimens came from Bed 5, where it probably is reproducing. It comprised 0.28% of the total fauna. It was much rarer in 1970, but about equal numbers were found in 1983 and 1992. Its habitat ranges from creeks to large rivers, but it is only locally common.

Lasmigona costata (Rafinesque 1820). This is a creek or small river species that is rare in the Ohio and Muskingum Rivers. Only five specimens were found in this study, and it was equally rare in 1970 and 1983. All specimens in 1992 were old individuals.

Leptodea fragilis (Rafinesque 1820). This species was uncommon, although found in all beds. It comprised 1.43% of the total fauna, and was the eighth most common species. Although Bates did not find this species in 1970, it was present in 1983 in the same numbers as today. It appears to be reproducing in all beds, and the histograms for age (Appendix A) show two recruitment events centered about 3-4 and 7-8 years ago. These pulses may be linked to fish migration.

Ligumia recta (Lamarck 1819). This otherwise common species is surprisingly rare from the Muskingum River. Bates (1970) found a single specimen, and Stansbery & King (1983) recorded only subfossil fragments. In this study, a single freshdead juvenile was found in a midden adjacent to Bed 5.

Obovaria subrotunda (Rafinesque 1820). This species rarely is common in Ohio, although it occurs from creeks to rivers. In the study area it accounted for only 0.43% of the total fauna. Although much more common in 1970, comparison of its relative abundance between studies shows that it has steadily declined in abundance since then. All specimens in 1992 were old individuals, and there was no indication that this species is reproducing in the study area.

Plethobasus cicatricosus (Say 1829). This very rare, federally endangered mussel was found as a weathered shell fragment adjacent to Bed 5. This represents the first authenticated record of this species for the Muskingum River. The Ohio State University Museum of Zoology (OSUMZ) record of Hildreth in 1830 probably is based on an erroneous locality record (D.H. Stansbery, OSUMZ, personal communication). There is no evidence that it still lives in the study area.

Plethobasus cyphus (Rafinesque 1820). Only six specimens of this

Ohio endangered species were found in the study area, where it comprised only 0.05% of the total fauna. It was absent from Beds 1, 2, and 3, but became more common with proximity to the Ohio River. It also was rare in 1970 and 1983. It probably is not found anywhere else in the state.

Pleurobema clara (Lamarck 1819). This federally endangered species was found adjacent to Bed 5 as a weathered shell. There is no evidence that it still lives in the study area, although it was once common in several Muskingum River tributaries.

Pleurobema cordatum (Rafinesque 1820). This Ohio endangered species was locally abundant in the study area. It accounted for 13% of the total fauna, and was the fourth most common species. It is more common today than in 1970 and 1983, particularly in Beds 5 and 6, where it now is the second most common species. Bates found 101 individuals in the study area; Stansbery & King (1983) found 153. This study found 1,406 specimens. Although no living individuals were found under six years of age, this species probably is reproducing in the study area. In Ohio, this species may occur only in the lower Muskingum River. Although not considered by Stansbery and King as commercially valuable, poachers have been apprehended in recent years with hundreds of specimens.

Pleurobema plenum (Lea 1840). Three weathered shells were found that may be referable to this federally endangered species. There is no indication that it still lives in Ohio. Although it has not been reported from this system, it is known from historical records in other northern tributaries of the Ohio River.

Pleurobema rubrum (Rafinesque 1820). Two living, and one weathered, individuals were found of this rare, Ohio endangered species. One living specimen was found in Bed 1, where Stansbery & King (1983) had also found a specimen. A second live specimen was found in Bed 5. Although Bates did not find this species in 1970, judging from a weathered shell at Bed 3 in 1992, this species has been a resident in the Muskingum River for many years. Both living specimens were very old, and there is no evidence of reproduction. This species is a relict in this river system, but does not occur anywhere else in the state. It also is listed as *Pleurobema pyramidalatum* (Lea 1840).

Pleurobema sintoxia (Rafinesque 1820). Although much more common in smaller rivers and creeks, this is an uncommon species in the study area, where it accounted for 0.24% of the total fauna. Bates did not find (or recognize as distinct) this species. In most beds, it is more common today than in 1983, but there was no evidence in 1992

of recruitment. It also is listed as *Pleurobema coccineum* (Conrad 1834).

Potamilius alatus (Say 1817). This usually common species represented only 0.83% of the total fauna. Although it was found in all beds, it was never common. It is less common now than in 1983, but this may reflect differences in collecting emphasis. This species is more common in backwaters, which was not the main focus of this study. Juveniles were found in the Devola beds.

Potamilius ohioensis (Rafinesque 1820). As with *Potamilius alatus*, this species was less common in 1992 than in 1983, but probably as a result of collecting emphasis. Bates did not find this species.

Ptychobranchius fasciolaris (Rafinesque 1820). This species may be abundant in smaller rivers and creeks, but is rare in many rivers. In the study area only two individuals were found. These came from Bed 1, which had several headwater species that are rare or absent in other beds. Bates also found two specimens in Bed 1 and nowhere else, and Stansbery and King did not find this species in the study area.

Quadrula cylindrica (Say 1817). A single subfossil valve was found adjacent to Bed 5. This is the first record of this Ohio endangered species from the study area.

Quadrula metanera (Rafinesque 1820). This Ohio endangered species was found in all beds except 1 and 2. It was very rare below Lowell, but much more common in the Devola beds. It accounted for 0.86% of the total fauna. Stansbery & King (1983) also found this species only below Lowell and Devola, where it was rare. Bates (1970) found only five specimens of this species only below Devola. It appears to be as rare today as it was in 1970 and 1983. Juveniles were found below Devola, where it probably is reproducing. Its greater relative abundance in Beds 5 and 6 is undoubtedly due to their proximity to the Ohio River, where this species is uncommon. This species does not occur anywhere else in the state.

Simpsoniis ambigua (Say 1825). This uncommon species is recorded from the study area for the first time from a large (52 mm in length) weathered pair of shells. It was found adjacent to Bed 5.

Strophilitus undulatus (Say 1817). Although common in creeks, this is not a big river species. Only two freshdead individuals were found in the study area, in middens along Beds 2 and 3. Bates also found this species to be very rare here. Although Stansbery & King (1983) found more specimens than did this study, it nevertheless was rare in 1983 as well. These specimens may represent stray occurrences from tributaries.

Truncilla donaciformis (Lea 1827). This was the seventh most common species in the study, comprising 1.76% of the total fauna. Most specimens were found in muskrat middens. This is a fairly short-lived species, and most evidence of reproduction was found in the beds below Lowell and Devola. Many juveniles were found attached by byssal threads to other unionids. Bates found only two specimens in 1970, but the species had become more common by 1983. It is now more abundant than in either previous study.

Truncilla truncata Rafinesque 1820. In some rivers this species may be present in large numbers, but it is rare in the Muskingum River and adjacent portions of the Ohio River. Specimens were found only in Bed 5, and it comprised only 0.1% of the total fauna. Neither Bates nor Stansbery and King found this species in the study area. However, the two live examples found were two and three years old, suggesting that this species may be reestablishing itself in the study area.

SUMMARY

This study found 11,145 specimens of 40 unionid species, including living specimens of the federally endangered *Cyprogenia stegaria*. Eight species were present only as weathered shells, including the federally endangered *Lampsilis abrupta*, *Plethobasus cicatricosus*, *Pleurobema clava*, and *Pleurobema plenum*. Fourteen Ohio endangered species were found (including federally endangered species): *Ellipsaria lineolata*; *Elliptio crassidens* (only as weathered shells); *Fusconia maculata*; *Megaloniais nervosa*; *Plethobasus cyphus*; *Pleurobema cordatum*; *Pleurobema rubrum*; *Quadrula cylindrica*; and *Quadrula metanevra*.

The fauna is dominated by five species, which account for 90.2% of the total fauna: *Obliquaria reflexa* (27.6%), *Quadrula pustulosa* (24.9%), *Ambelma plicata* (13.5%), *Pleurobema cordatum* (Ohio endangered, 13%), and *Quadrula quadrula* (11.2%). With the exception of *Pleurobema cordatum*, these are all commercially valuable species. *Megaloniais nervosa*, also commercially important, is present in much lower numbers. All of these species appear to be reproducing.

Twenty-one species or 53% of the total fauna occur in relative abundances of 0.1% or less. Eighty percent of the fauna is present in relative abundances under 1%. Clearly, most of the fauna in the study area must be considered rare. This includes the federally endangered *Cyprogenia stegaria*, and the Ohio endangered *Fusconia maculata*, *Ellipsaria lineolata*, *Plethobasus cyphus*, *Pleurobema cordatum*, *Pleurobema rubrum*, and *Quadrula metanevra*, all of which probably do not occur

anywhere else in the state.

Approximately 3/5th of the species found live are reproducing, including many of the Ohio endangered taxa. Most recruitment was found in Beds 5 and 6. These beds are open to the Ohio River and probably derive their fish hosts from there. The concentration of big river unionids in these beds suggests that their hosts rarely migrate through the locks to more upstream pools. Bed 4 showed the least recruitment.

While a few species appear to be declining in numbers since 1970, such as *Ambelma plicata*, *Fusconia maculata*, and *Obliquaria subrotunda*, most species are either more common today or have not changed in rarity. Species that have increased in abundance are *Ellipsaria lineolata* (Ohio endangered), *Megaloniais nervosa* (Ohio endangered), *Obliquaria reflexa*, *Pleurobema cordatum* (Ohio endangered), *Pleurobema sintoxia*, *Truncilla donaciformis*, and *Truncilla truncata*.

Few specimens were found outside of the beds. The majority of the study area consists of long depauperate reaches between beds. This especially is true below Dams 5 and 4. However, there is ample evidence to suggest that prior to construction of the dams, the unionid fauna was widely distributed in this area. A subfossil deposit below Dam 4 at river mile 22 at Dana Island (no longer an island) reveals that this fauna consisted of species that are now rare or extirpated.

Average densities within the beds ranged from 3 to 42 individuals/m². The most diffuse bed was Bed 1. Bates (1970) reported that this was the most dense commercially harvested bed on the Muskingum River. In 1967 alone, 30.6 tons of shells were taken from that bed. It may be no coincidence that this bed now is the least dense of those studied. The densest bed was Bed 5 below Devola Lock & Dam, where one quadrat contained 124 individuals/m². Ohio legislation banned commercial harvesting of mussels before clambers began harvesting from this bed. It is interesting that the beds found by Stansbery and King in 1983 still exist in approximately the same locations, and cover the same amount of river. Clearly, if left alone, beds may persist for decades or longer, and become self-maintaining.

Although these Muskingum River beds represent the largest mussel beds in Ohio, their survival is precarious. The beds are located in a 34 mile stretch of a single river, and contain rare and endangered species that do not occur anywhere else in the state. It is foreseeable that a single major environmental accident upstream, such as an oil or pesticide spill, could irreparably damage or even eliminate this fauna. One such spill, although apparently minor and well contained,

occurred in 1992. All agencies should be especially vigilant in maintaining the health of this river.

For these same reasons any work on the existing Lock and Dam system must be undertaken with caution. Sediment samples revealed that silt and detritus have accumulated against the upstream side of the dams. The release of this material would be disastrous to the beds below. Since most of the beds are immediately below the dams, and most of the mussel populations are in these beds, any construction would jeopardize them. Removal of the dams such as these must be accompanied by prior removal of the sediment. Similarly, dredging activities must be closely monitored. No dredging on existing beds should be permitted unless the mussels are relocated. Dredging above beds should be done so as to minimize sediment release.

There is little doubt that harvesting pressure has long term effects on animals that have a low turnover rate. Recruitment in mussels is sporadic and mortality is high. Survival rates for a glochidium to metamorphosis range from 0.000001% (Young & Williams, 1984) to 0.0001% (Jansen & Hanson, 1991), not including predation after metamorphosis. Successful recruitment may depend on a critical number of individuals in proximity, plus the proper host. Any efforts that kill or remove large numbers of individuals from a bed reduce the chance of successful reproduction. The Muskingum River may be the only Ohio river containing beds with sufficient density to be commercially important in Ohio. These beds contain numerous endangered species, hence commercial harvesting should remain closed in Ohio. These beds, occurring in such a small area, are the last of their kind in Ohio and cannot endure the removal of tons of living individuals. Ultimately, the study section should be made into a mussel sanctuary similar to sanctuaries in other states, such as the Clinch River in Tennessee.

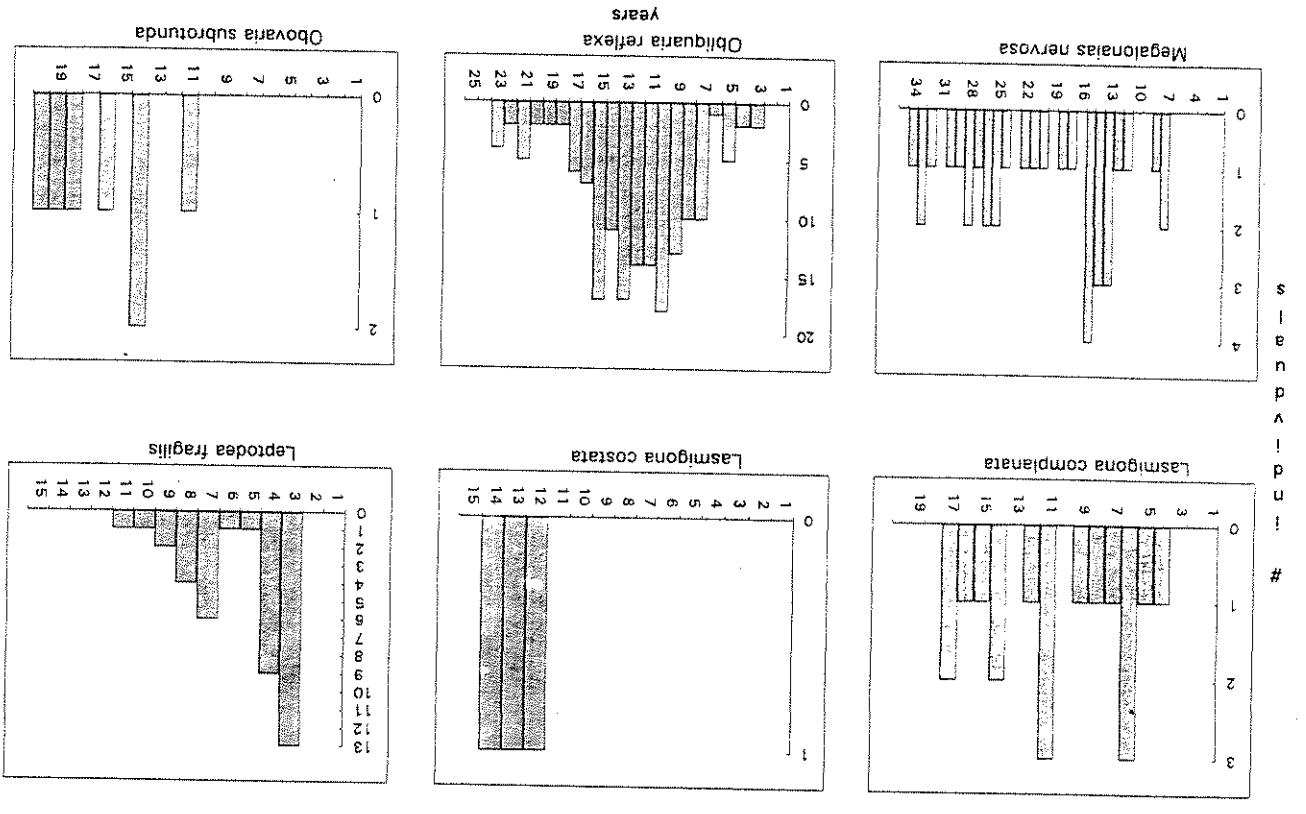
ACKNOWLEDGMENTS

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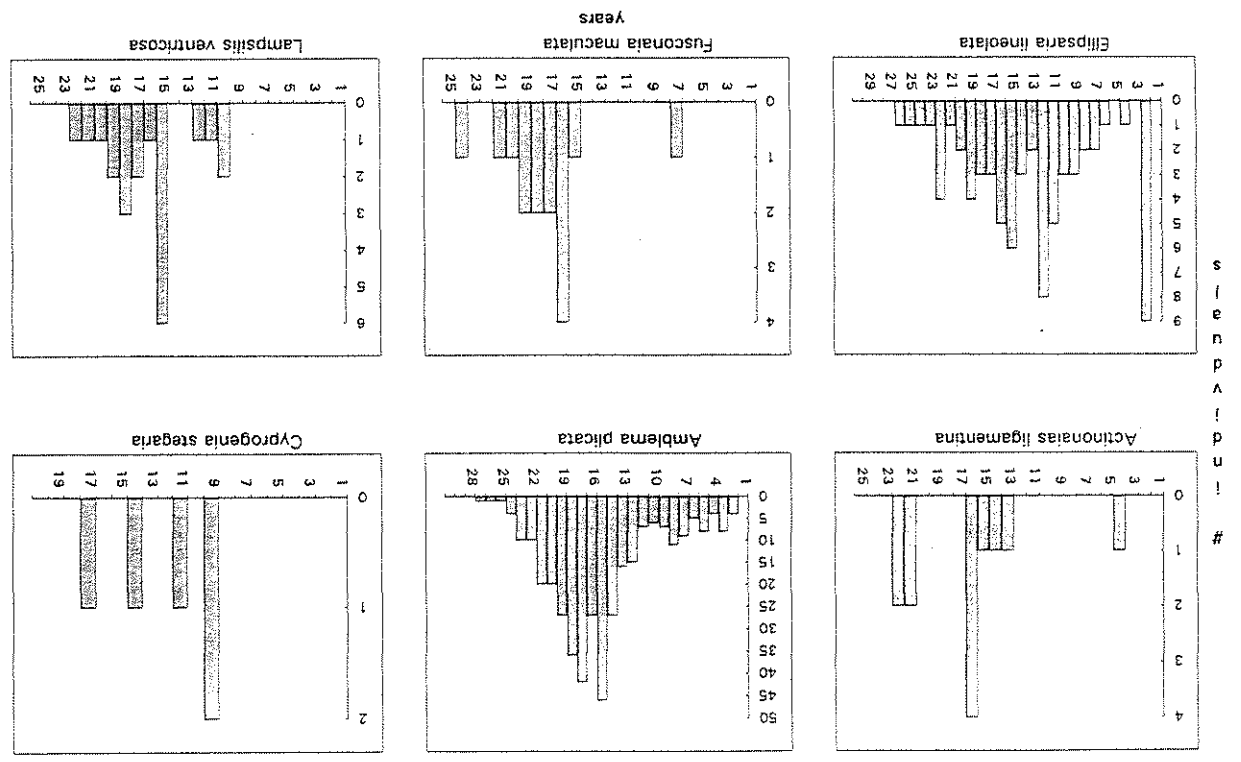
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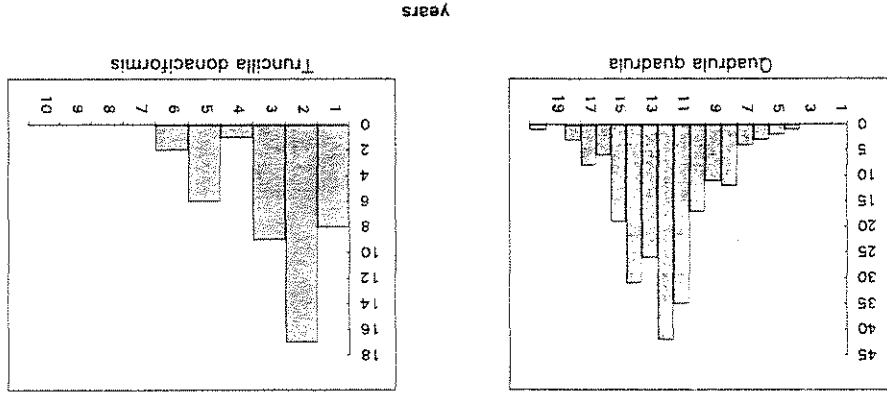


APPENDIX A.

Age distributions for species found in two or more beds. All beds combined.



Unionidae of the Lower Muskingum River



Watters and Dunn

