ILLINOIS NATURAL HISTORY SURVEY

Analysis of a Mussel Die-off in Pools 14 and 15 of the Upper Mississippi River

Aquatic Biology Section

Technical Report

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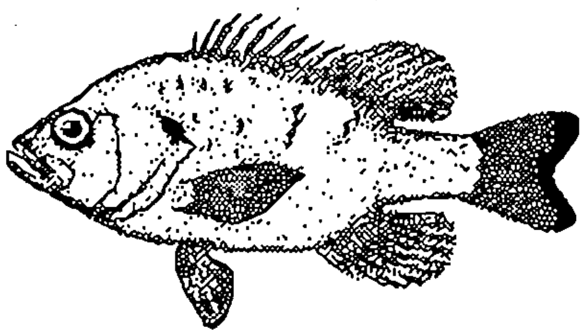

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ANALYSIS OF A MUSSEL DIE-OFF IN POOLS 14 AND 15 OF THE UPPER MISSISSIPPI RIVER

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BACKGROUND

According to Fuller (1980), early mussel surveys on the Upper Mississippi River by Tyron (1865), Pratt (1886), and Coker (1919) recorded a total of 48 species, and surveys on the Illinois River by Calkins (1874), Kelly (1899), Baker (1906), Forbes and Richardson (1913), Danglade (1914), and Richardson (1928) recorded 45 species. However, modern surveys by Fink (1966) and Fuller (1978, 1980) show a 23% decline in the number of species in the Mississippi (37 species left), and Starrett (1971) reported a 44% decline in the Illinois (25 left).

Since the 1950's, freshwater mussels have been harvested from the Mississippi drainage for use in the cultured pearl industry in Japan. In 1984, prices climbed to $800/ton of shells, stimulating exceptionally heavy harvesting; commercial shellers came from as far away as Texas and Oklahoma (Ballenger 1986). The discovery of pearls of exceptional value in Wisconsin and near Grafton, Illinois (Fritz 1986), apparently caused many commercial shellers to open every mussel they took, instead of culling undersize individuals back into the rivers (personal observation).

Since 1982, mussels in the Upper Mississippi River drainage have been affected by unexplained die-offs with the largest die-offs apparently occurring in 1982 and 1985 (Blodgett and Sparks 1987, Thiel 1987, Havlik 1987, Ballenger 1987). To date, no die-offs have been reported in the Illinois drainage, but die-offs have occurred in other major tributaries of the Mississippi River (Neves 1987).

In spring 1983, Arnold "Bill" Fritz, Commercial Fisheries Biologist, Illinois Department of Conservation, received a number of reports from commercial shellers using diving gear that there were large numbers of freshly dead and dying mussels in the Mississippi River from Pool 12 downstream to Pool 19. At his request, the Illinois Natural History Survey (INHS) sampled known mussel beds in pools 14 and 15 near Rock Island, IL, in spring 1983 to document and quantify the die-off. During summer 1985, shellers again reported finding many recently dead mussels and we resampled Pool 15 in the fall. This report analyzes data collected in 1983 and 1985 and compares results of these collections with composition and density data collected by NUS Corporation in 1978 (Oblad 1979).

METHODS

We quantitatively sampled mussels using a 24-ft pontoon boat modified to support surface-supply diving (Figure 1) and techniques developed during prior mussel research (Sparks and Blodgett 1983). Divers placed all mussels and loose substrate from 1.0-m^2 sampling frames into canvas collecting bags (Figure 2) and sent them to the surface where shells were sorted to species, measured, and categorized based on the following criteria:

Live (LI) - soft parts intact; if valves gaped, they closed when prodded.

Recently Dead (RD) - if soft parts were present, they were unable to close valves when prodded; if soft parts were gone, periostracum was intact; valves firmly joined by hinge ligament; interior nacre shiny (not the least bit chalky).

Old Dead (OD) - soft parts lacking; valves joined; periostracum incomplete; nacre chalky.

Other - not meeting the above criteria--subfossil shells, valves not joined, etc.

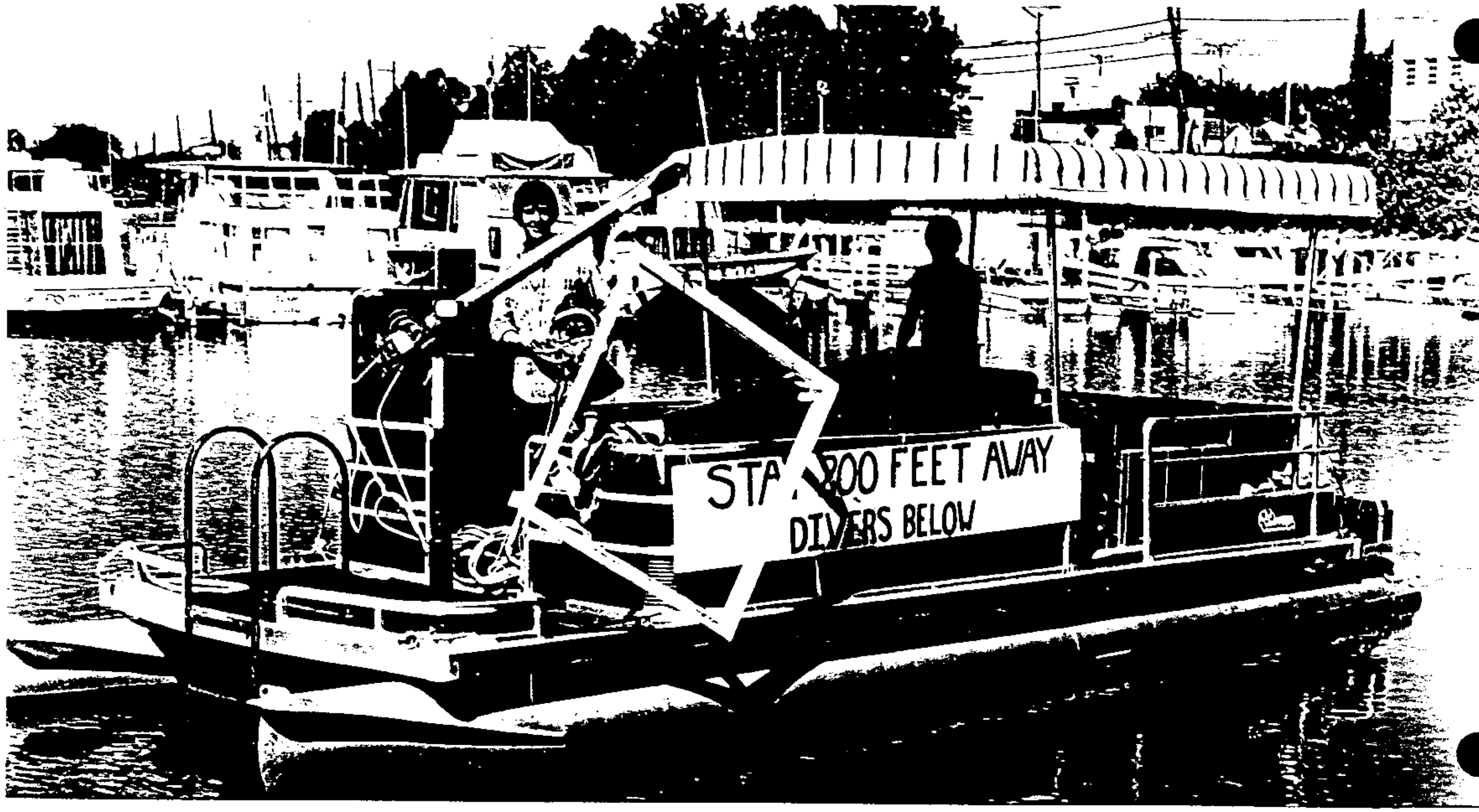


Figure 1. Illinois Natural History Survey River Diver, a 24-ft pontoon boat modified to support surface-supplied diving.

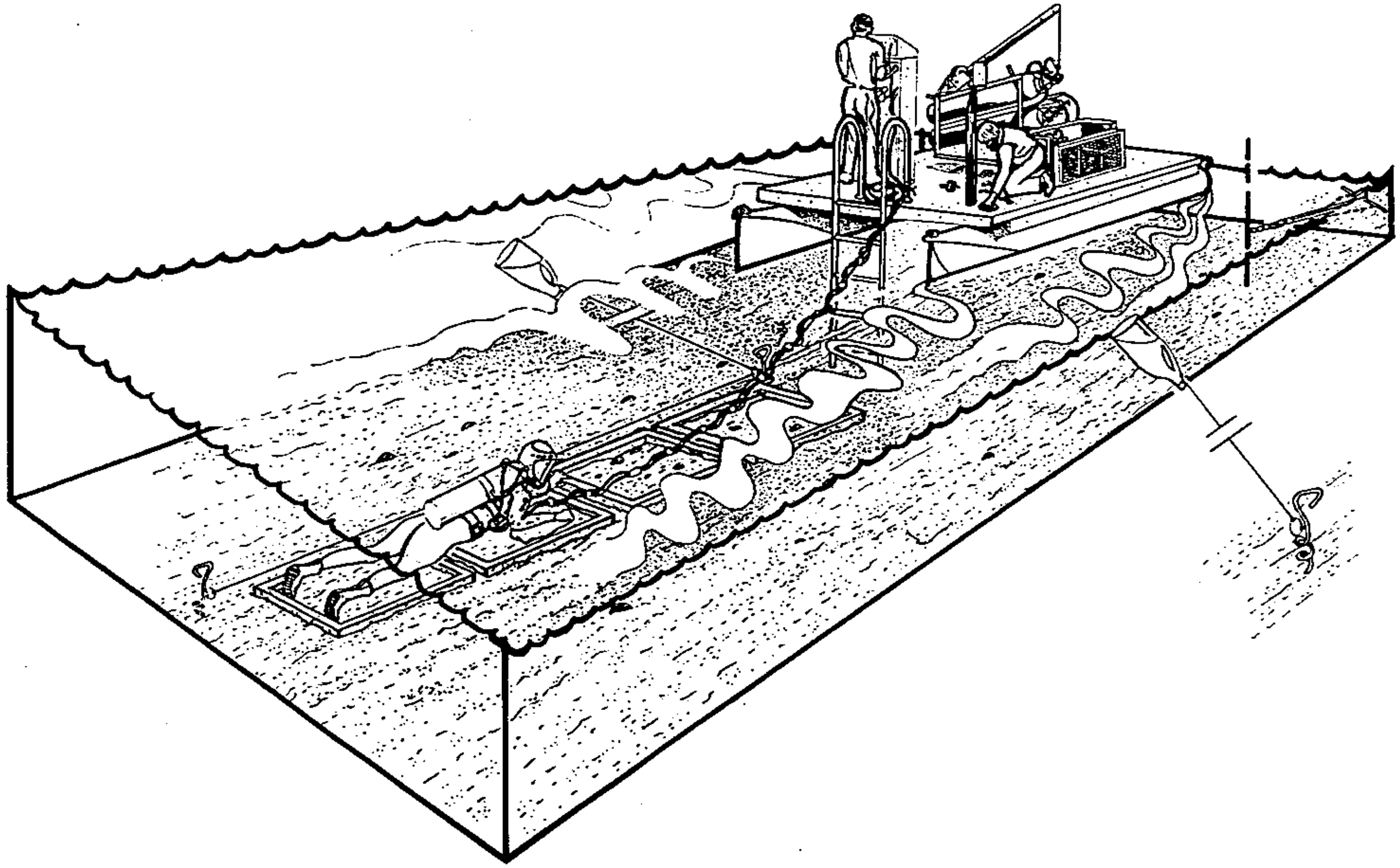


Figure 2. Schematic showing surface-supplied diving platform and a diver using sampling frames.

These criteria were developed from previous research (Sparks and Blodgett 1985) where we marked live mussels and recovered some of the shells of dead individuals 10 months later. The majority of these shells met the old dead criteria. Shellers indicated mussel soft-parts or "meats" were gone from shells a week after a die-off in Oklahoma (Zale and Suttles 1987). We are confident few if any shells we classified as recently dead had been dead more than one year; most probably had been dead less than 3-6 months.

Differences between procedures in 1983 and 1985 were: (1) in 1985 we divided mussels into the four categories described above, in 1983 we lumped "old dead" shells with "other" and (2) shell heights and lengths were measured in 1983, but only lengths were measured in 1985. In 1985, locations of sample sites were determined using a Motorola Mini-Ranger III Radar Ranging System.

In 1983 we sampled one mussel bed in Pool 14 and one in Pool 15 (Figure 3, Table 1). The bed in Pool 14 was on the Illinois side of the Mississippi River upstream of Lock and Dam 14 and directly downstream of the US Interstate 80 highway bridge near Le Claire, Iowa. Shellers said they had worked the upstream end of the bed but not the downstream end. We collected at two sites on the downstream end of the bed; one at river mile (RM) 494.6 (4 m^2 sampled) and the other at RM 494.7 (4 m^2 sampled). Both collections were approximately 100 m from the Illinois shore. In Pool 15 we sampled approximately 50 m from the Illinois shore at RM 486.0 (4 m^2) just upstream of Arsenal Island at the entrance to Sylvan Slough, an area designated as "essential habitat" for the federally endangered Lampsilis higginsi (the Higgins' eye pearly

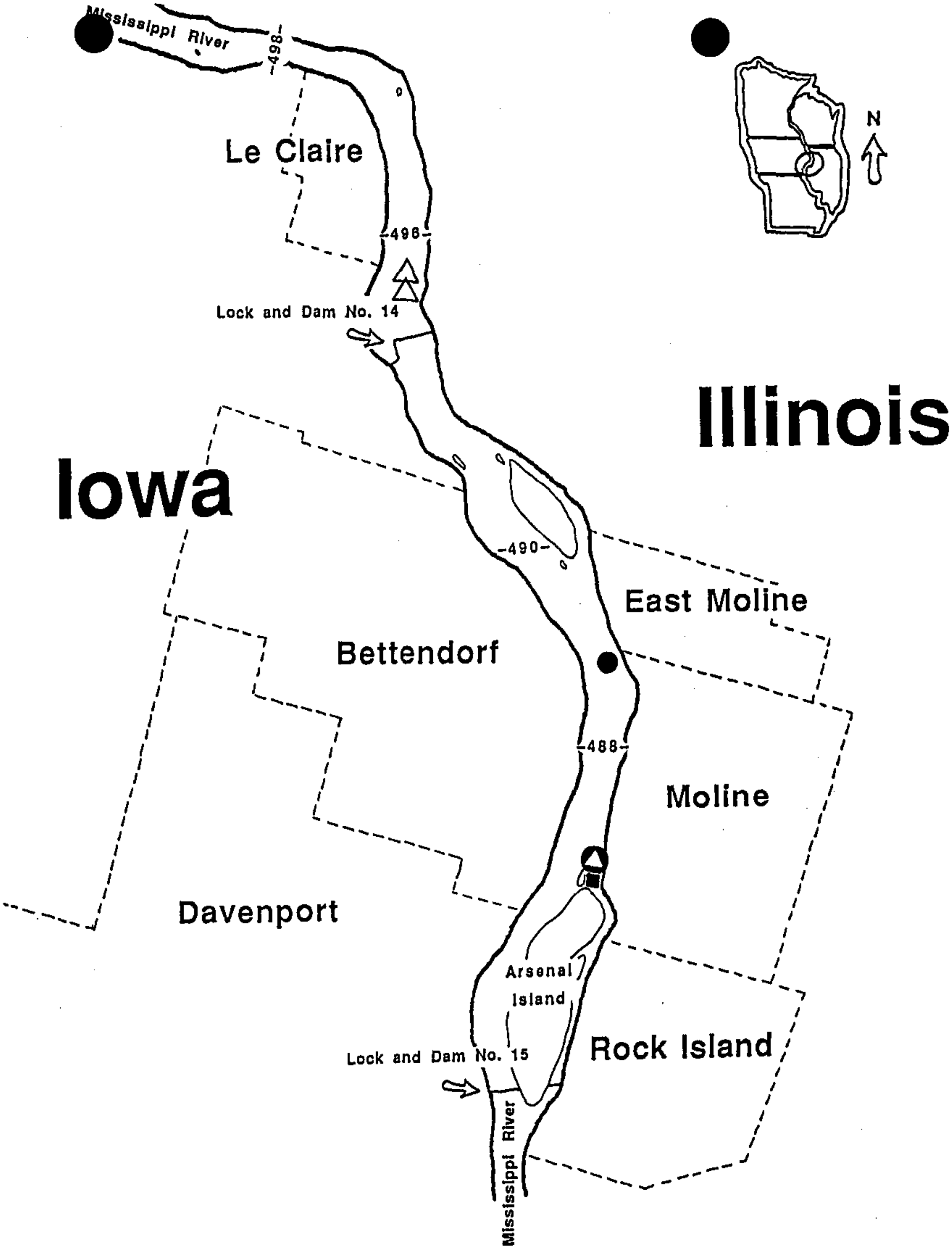


Figure 3. Map of the Upper Mississippi River near Moline, IL showing sites where mussels were quantitatively sampled by NUS Corporation in 1978 (■) and by the Illinois Natural History Survey in 1983 (△) and 1985 (●).

mussel) by the Higgins' Eye Mussel Recovery Team (Stern 1982). We saw shellers using a hand-dredge (hand-rake) just upstream of our sampling site.

We resampled Pool 15 near RM 486.0 in 1985 (8 m^2 sampled) (Table 1). A local sheller told us the area had been shelled since our previous sampling, and we found a cull pile (unsalable shells -- too small or noncommercial species) on the shore of a nearby island. We also sampled a bed (6 m^2 sampled) that the sheller thought was unharvested, about 200 m from the left bank near RM 488.6 (Figure 3, Table 1).

Table 1. Summary of INHS mussel sampling at sites on the Upper Mississippi River near Rock Island, IL.

		No. of 1-m^2 samples	
Pool	RM	May 1983	Sept. 1985
14	494.6	4	--
14	494.7	4	--
15	486.0	4	8
15	488.6	--	6
Total		12	14

If die-offs were caused by long-term accumulation of a contaminant, we would expect to see few young mussels dying. To determine whether mortality was size-selective, we made length-percent mortality histograms for five of the more numerous species, _Amblema plicata_ (three-ridge), _Megalonaias gigantea_ (washboard), _Quadrula pustulosa_ (pimple-back), _Ellipsaria lineolata_ (butterfly), and _Leptodea fragilis_ (fragile papershell).

Sample sizes of other species were too small to construct meaningful histograms.

Because sample size in the small size classes was minimal, we used shell lengths to group individuals into two groups, juveniles (nonreproductive) and adults (reproductive), based on Stein's (1973) findings that a mussel's growth rate decreases markedly at the beginning of reproductive maturity, probably because energy is diverted to reproductive products at the expense of growth. We determined the shell length of *Amblema plicata*, *Megalonaias gigantea*, and *Quadrula pustulosa* where distance between shell annuli showed an abrupt decrease. For *Amblema plicata*, the decrease occurred when the shell was between 6.5 and 7.5 cm, so we chose 7.0 cm as the threshold for the onset of reproductive maturity. Stein (1973) found reproduction in *Amblema plicata* began when shells were from 5.7 to 8.3 cm long. For *Megalonaias gigantea* we determined a threshold of 12 cm and for *Quadrula pustulosa* 5 cm.

To determine whether mean densities of live mussels differed between sites and years, we used a t-test if variances of means were equal or an approximate t-test if they were unequal (Sokal and Rohlf 1969). We used a test of the equality of two percentages (Sokal and Rohlf 1969) to determine whether percent recently dead differed: (1) between pools 14 and 15 in 1983, the only year we sampled two pools; (2) between RM 488.6 and 486.0 in Pool 15 in 1985, where the largest difference in mortality rates occurred; and (3) between adults and juveniles of the three abundant species.

RESULTS

1983

We collected 11 species of live mussels from Pool 14 and 18 species from Pool 15 in 1983. Live mussel densities/m^2 were higher ($\underline{P} < 0.01$) in Pool 15 than in Pool 14 (Table 2). The commercially important Amblema plicata and Megalonaias gigantea collectively comprised 68.3% by number of the total live mussel population in Pool 14 and 20.7% in Pool 15 (Table 3).

Table 2. Ranges, means, and standard deviations of live mussel densities from three sites on the Upper Mississippi River in spring 1983.

Pool	RM	Mean (no./m^2)	SD	Range
14	494.6	12.3	3.1	7-15
14	494.7	17.8	11.2	9-37
15	486.0	89.5	13.5	75-109

The numbers of recently dead shells collected in 1983 were alarming and verified the commercial shellers' reports (Table 3). We collected a total of 478 live and 242 recently dead mussels: 33.6%, RD/(LI + RD), of the mussels had died within the previous year, including 35.4% (34 of 96) of the A. plicata and 40.5% (64 of 158) of the M. gigantea. In Pool 14, 41.7% (86 of 206) of the mussels collected were classified as recently dead and in Pool 15, 30.4% (156 of 514). Mortality estimates may have been biased upwards because shellers were harvesting only live mussels and leaving dead shells which shell buyers would not purchase (D.E. Ballenger 1986).

Table 3. Live and recently dead mussels collected in four 1-m^2 samples from each of three sites on the Mississippi River in 1983.

	Pool 14 River mile 494.6							Pool 14 River mile 494.7							Pool 15 River mile 486.0						
	Live			Recently dead				Live			Recently dead				Live			Recently dead			
Species	Sum	$\bar{x}/m^2$	SD	Sum	$\bar{x}/m^2$	SD	%	Sum	$\bar{x}/m^2$	SD	Sum	$\bar{x}/m^2$	SD	%	Sum	$\bar{x}/m^2$	SD	Sum	$\bar{x}/m^2$	SD	%
Amblema plicata	10	2.5	0.9	8	2.0	1.2	44.4%	11	2.8	1.8	4	1.0	0.7	26.7%	41	10.2	1.1	22	5.5	4.0	34.9%
Anodonta grandis	0	0.0	0.0	0	0.0	0.0		1	0.2	0.4	1	0.2	0.4	50.0%	5	1.2	1.3	0	0.0	0.0	0.0%
Anodonta imbecillis	2	0.5	0.5	1	0.2	0.4	33.3%	1	0.2	0.4	0	0.0	0.0	0.0%	12	3.0	1.0	1	0.2	0.4	7.7%
Arcidens confragosus	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	0	0.0	0.0		1	0.2	0.4	0	0.0	0.0	0.0%
Cumberlandia monodonta	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	0	0.0	0.0		1	0.2	0.4	0	0.0	0.0	0.0%
Ellipsaria lineolata	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	2	0.5	0.9	100.0%	29	7.2	3.1	7	1.8	0.8	19.4%
Elliptio dilatata	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	1	0.2	0.4	100.0%
Fusconaia ebena	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	2	0.5	0.9	100.0%	0	0.0	0.0	0	0.0	0.0	
Fusconaia flava	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	1	0.2	0.4	100.0%	5	1.2	0.4	2	0.5	0.5	28.6%
Lampsilis ovata	1	0.2	0.4	0	0.0	0.0	0.0%	1	0.2	0.4	0	0.0	0.0	0.0%	5	1.2	1.1	1	0.2	0.4	16.7%
Leptodea fragilis	7	1.8	0.8	2	0.5	0.9	22.2%	2	0.5	0.9	2	0.5	0.9	50.0%	37	9.2	0.8	4	1.0	1.2	9.8%
Ligumia recta	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	0	0.0	0.0		3	0.8	1.3	0	0.0	0.0	0.0%
Megalonaias gigantea	16	4.0	0.7	10	2.5	1.7	38.5%	45	11.2	12.1	27	6.8	3.7	37.5%	33	8.2	3.2	27	6.8	3.4	45.0%
Obliquaria reflexa	1	0.2	0.4	1	0.2	0.4	50.0%	0	0.0	0.0	1	0.2	0.4	100.0%	15	3.8	2.4	7	1.8	0.4	31.8%
Potamilus alatus	1	0.2	0.4	0	0.0	0.0	0.0%	2	0.5	0.5	0	0.0	0.0	0.0%	16	4.0	3.2	2	0.5	0.9	11.1%
Quadrula metanevra	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	0	0.0	0.0		8	2.0	1.2	3	0.8	0.8	27.3%
Quadrula nodulata	0	0.0	0.0	1	0.2	0.4	100.0%	0	0.0	0.0	1	0.2	0.4	100.0%	0	0.0	0.0	2	0.5	0.5	100.0%
Quadrula pustulosa	4	1.0	1.2	4	1.0	0.7	50.0%	0	0.0	0.0	9	2.2	2.9	100.0%	83	20.8	5.5	50	12.5	4.7	37.6%
Quadrula quadrula	7	1.8	1.3	3	0.8	0.4	30.0%	7	1.8	0.8	0	0.0	0.0	0.0%	11	2.8	1.5	2	0.5	0.9	15.4%
Truncilla donaciformis	0	0.0	0.0	0	0.0	0.0		0	0.0	0.0	2	0.5	0.9	100.0%	13	3.2	3.3	5	1.2	1.1	27.8%
Truncilla truncata	0	0.0	0.0	1	0.2	0.4	100.0%	1	0.2	0.4	3	0.8	0.8	75.0%	40	10.0	2.3	20	5.0	3.5	33.3%
Total	49	12.2	3.1	31	7.8	2.4	38.8%	71	17.8	11.2	55	13.8	8.2	43.7%	358	89.5	13.5	156	39.0	14.2	30.4%

1985

We collected 21 species of live mussels from Pool 15 in 1985. The mean density of live mussels/m^2 from the bed at RM 486.0 in 1985 was 100.1 (SD = 21.6, range = 69-132) (Table 4). The percent recently dead for all species combined was 17.9% (175 of 976). Mortality was 22.8% (23 of 101) for A. plicata and 21.9% (30 of 137) for M. gigantea. Mortality probably was not biased upwards by shellers because they could sell recently dead shells in 1985 (D.E. Ballenger 1986).

The site at RM 488.6 had the highest average density of live mussels we had ever observed (139.3/m^2, Table 4). One 1-m^2 frame contained 216 live mussels, another 213, and we discarded a sample with even more when both the diver and sampling frame were accidentally pulled away from the sample plot before completion of sampling. Distribution of live mussels between 1-m^2 samples was uneven, as can be seen from the range of 62-216 and the standard deviation of 62.1.

COMPARISONS BETWEEN SITES AND YEARS

Oblad (1979) reported that SCUBA diving collections by NUS corporation in 1978 produced 25 live mussel species and a mean density of 13.6/m^2 in two 12.2 x 21.4 m plots (522.2 m^2 sampled) in Sylvan Slough near river mile 485.8 (Table 5). INHS sampling at the mouth of Sylvan Slough (RM 486.0) in both 1983 and 1985 produced fewer species but higher densities (Table 5). Differences in densities between the study by NUS and INHS could be attributed to patchy distributions of mussels within the bed. The area sampled in 1978 by NUS may have been in a less dense part of the bed.

Table 4. Live and recently dead mussels collected from two sites in Pool 15, Mississippi River in 1985.

	River mile 486.0 (8 1-m^2 samples)							River mile 488.6 (6 1-m^2 samples)						
	Live			Recently dead				Live			Recently dead			
Species	Sum	$\bar{x}/m^2$	SD	Sum	$\bar{x}/m^2$	SD	%	Sum	$\bar{x}/m^2$	SD	Sum	$\bar{x}/m^2$	SD	%
Amblema plicata	78	9.8	2.6	23	2.9	2.8	22.8%	98	16.3	7.3	17	2.8	1.9	14.8%
Anodonta grandis	7	0.9	0.6	0	0.0	0.0	0.0%	0	0.0	0.0	0	0.0	0.0	
Anodonta imbecillis	33	4.1	1.8	4	0.5	0.7	10.8%	16	2.7	4.0	0	0.0	0.0	0.0%
Arcidens confragosus	2	0.2	0.4	0	0.0	0.0	0.0%	2	0.3	0.5	0	0.0	0.0	0.0%
Ellipsaria lineolata	42	5.2	2.8	3	0.4	0.7	6.7%	93	15.5	8.0	1	0.2	0.4	1.1%
Fusconaia flava	4	0.5	0.5	1	0.1	0.3	20.0%	4	0.7	0.8	0	0.0	0.0	0.0%
Lampsilis ovata	7	0.9	0.9	0	0.0	0.0	0.0%	7	1.2	1.1	0	0.0	0.0	0.0%
Leptodea fragilis	81	10.1	2.9	10	1.2	1.0	11.0%	121	20.2	10.8	6	1.0	1.2	4.7%
Ligumia recta	2	0.2	0.4	1	0.1	0.3	33.3%	2	0.3	0.5	0	0.0	0.0	0.0%
Megalonaias gigantea	107	13.4	4.7	30	3.8	4.2	21.9%	16	2.7	2.2	6	1.0	1.8	27.3%
Obliquaria reflexa	33	4.1	2.0	8	1.0	1.1	19.5%	25	4.2	2.0	1	0.2	0.4	3.8%
Obovaria olivaria	1	0.1	0.3	1	0.1	0.3	50.0%	2	0.3	0.5	0	0.0	0.0	0.0%
Plethobasus cyphyus	1	0.1	0.3	0	0.0	0.0	0.0%	0	0.0	0.0	0	0.0	0.0	
Potamilus alatus	18	2.2	0.7	1	0.1	0.3	5.3%	37	6.2	4.7	0	0.0	0.0	0.0%
Potamilus laevissima	6	0.8	0.7	0	0.0	0.0	0.0%	4	0.7	1.1	0	0.0	0.0	0.0%
Quadrula metanevra	53	6.6	4.1	1	0.1	0.3	1.8%	2	0.3	0.5	0	0.0	0.0	0.0%
Quadrula nodulata	1	0.1	0.3	0	0.0	0.0	0.0%	3	0.5	0.5	0	0.0	0.0	0.0%
Quadrula pustulosa	158	19.8	6.2	55	6.9	4.1	25.8%	136	22.7	14.8	11	1.8	1.7	7.5%
Quadrula quadrula	14	1.8	0.8	3	0.4	0.7	17.6%	17	2.8	2.0	1	0.2	0.4	5.6%
Truncilla donaciformis	52	6.5	4.7	21	2.6	1.2	28.8%	44	7.3	4.3	12	2.0	2.9	21.4%
Truncilla truncata	101	12.6	4.3	13	1.6	1.6	11.4%	206	34.3	15.2	1	0.2	0.4	0.5%
Unidentified	0	0.0	0.0	0	0.0	0.0		1	0.2	0.4	0	0.0	0.0	0.0%
Total	801	100.1	21.6	175	21.9	7.8	17.9%	836	139.3	62.1	56	9.3	6.8	6.3%

Table 5. Species and mean densities of live mussels collected near the mouth of Sylvan Slough, Pool 15, Mississippi River, in 1978 by NUS Corporation (RM 485.8) and in 1983 and 1985 by the Illinois Natural History Survey (RM 486.0).

	NUS 1978	INHS 1983	INHS 1985
Actinonaias ligamentina	P	A	A
Amblema plicata	P	P	P
Anodonta grandis	P	P	P
Anodonta imbecillis	A[a]	P	P
Arcidens confragosus	P	P	P
Cumberlandia monodonta	P	P	A
Ellipsaria lineolata	P	P	P
Elliptio dilatata	A	A[a]	A
Fusconaia ebena	A[a]	A	A
Fusconaia flava	P	P	P
Lampsilis higginsi	P	A	A
Lampsilis radiata	A[a]	A	A
Lampsilis teres	A[a]	A	A
Lampsilis ventricosa	P	P	P
Lasmigona complanata	P	A	A
Leptodea fragilis	P	P	P
Ligumia recta	P	P	P
Megalonaias gigantea	P	P	P
Obliquaria reflexa	P	P	P
Obovaria olivaria	P	A	P
Plethobasus cyphyus	P	A	P
Potamilus alatus	P	P	P
Potamilus laevissima	A[a]	A	P
Quadrula metanevra	P	P	P
Quadrula nodulata	P	A[a]	P
Quadrula pustulosa	P	P	P
Quadrula quadrula	P	P	P
Strophitus undulatus	P	A	A
Tritogonia verrucosa	A[a]	A	A
Truncilla donaciformis	P	P	P
Truncilla truncata	P	P	P
Number of species[b]	24	18	21
Mean density (no./m^2)	13.6	89.5	100.1

P = present

A = absent

[a] recently dead collected, however no live specimens observed

[b] total number of live species = 26

In 1983, there were no significant differences in live mussel densities or mortalities between the two sites (RM 494.6 and RM 494.7) in Pool 14. However, Pool 14 had a significantly lower density of live mussels ($\underline{P} = 0.01$) and significantly higher mortality ($\underline{P} = 0.004$) than Pool 15 (Table 3).

The mortality of 6.3% (56 of 892) at RM 488.6 was significantly lower ($\underline{P} < 0.001$) than at 486.0 (17.9%, 175 of 976) in 1985 (Table 4). Densities of live mussels were not significantly different. Site 488.6 was nearer the main channel where higher current velocities may have scoured away more recently and old dead shells than at the other site, perhaps depositing some downstream at RM 486.0. A less likely explanation is that the die-off was less severe in this bed than in the one just 2.6 miles downstream.

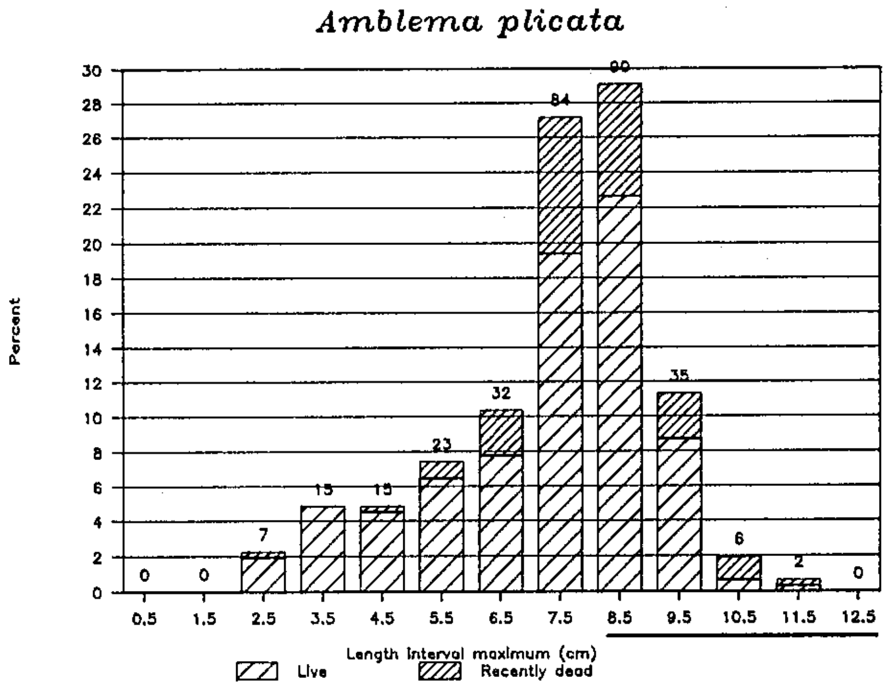
The significant difference ($\underline{P} < 0.001$) in mortality at RM 486.0 between 1983 (30.4% RD) and 1985 (17.9% RD) may be attributable to shellers leaving recently dead shells in 1983 but harvesting them in 1985. The problem of separating the effects of selective harvest from those of a die-off illustrates the need to establish mussel preserves where harvesting would not be permitted. If shelling had no effect on the proportion of recently dead shells, a second hypothesis is that susceptible mussels died in response to some causative agent in 1983 leaving behind only more resistant mussels in 1985. A third hypothesis is that the intensity of some unidentified causative agent was less in 1985 than in 1983.

SIZE-SPECIFIC MORTALITY

Length-frequency histograms for five of the more numerous species, Amblema plicata, Megalonaias gigantea, Quadrula pustulosa, Ellipsaria lineolata, and Leptodea fragilis, were skewed to the right, indicating that there were more large individuals in the population (Figure 4). Similar skewed length frequencies have been reported from the Upper Mississippi River (Duncan and Thiel 1983; Coon et al. 1977). This skew is probably due, in part, to the fact that intervals on the right contain large, slow-growing individuals, hence multiple year classes, while intervals on the left contain small, rapidly-growing individuals, hence fewer year classes. Commercial harvesting reduces the number of large individuals of Amblema plicata and Megalonaias gigantea, so undisturbed populations of these mussels are even more skewed toward large individuals.

In future collections, we will age mussels and measure shell lengths to determine how many year classes are included in each size interval. Aging should be done routinely in mussel studies, so that recruitment and survival rates can be determined.

Larger size classes had higher mortality rates than smaller ones in most species (Figure 5). Mortality was significantly greater ($P < 0.08$) in reproductive adults than in juveniles of Amblema plicata, Quadrula pustulosa, and Megalonaias gigantea (Table 6). Mortality rates may be greater in older individuals because of stresses associated with reproduction or a greater body burden of toxicants. Again, more data on size-specific natural mortality rates and body burdens of contaminants in healthy, undisturbed mussel populations are needed for comparison.



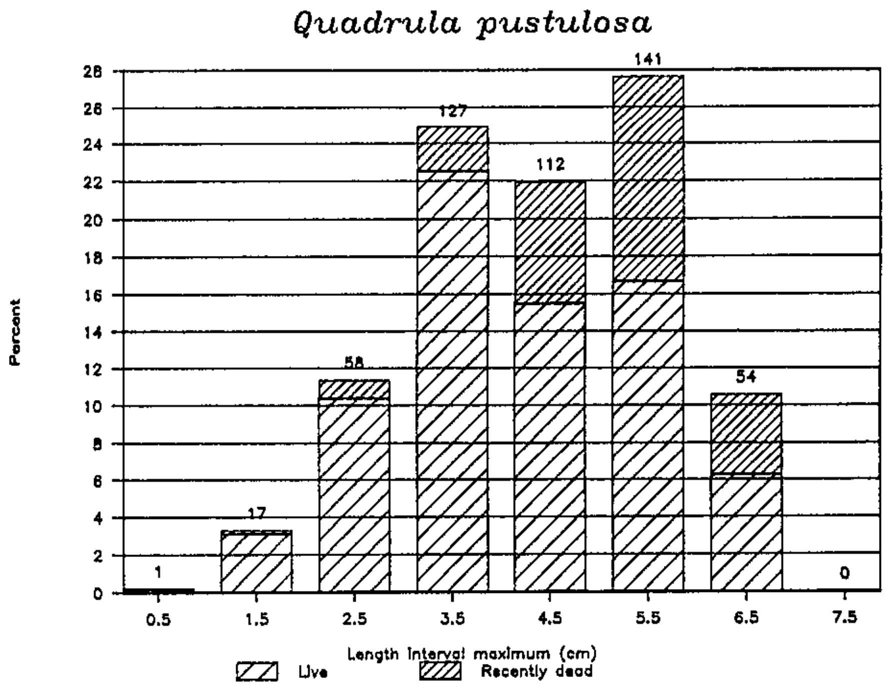
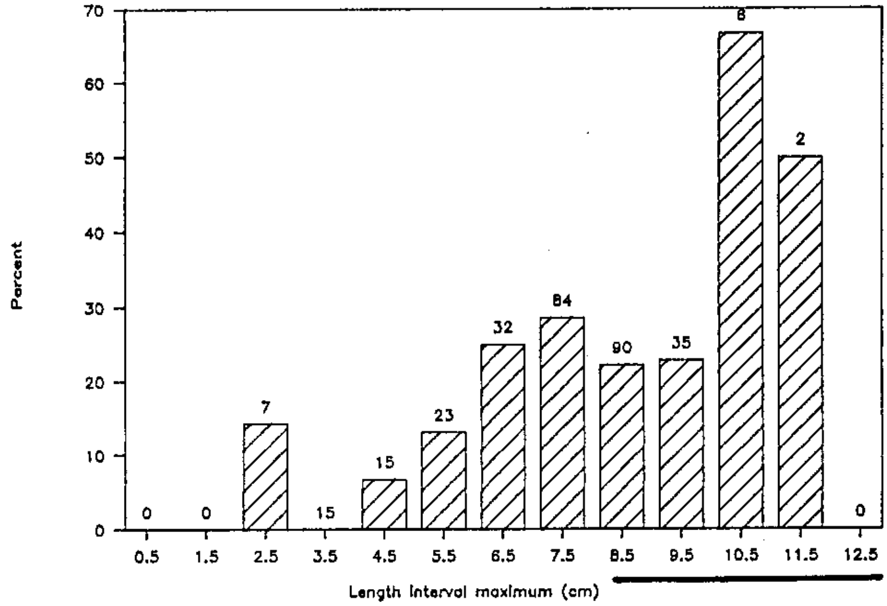


Figure 4. Length-percent live and recently dead Amblema plicata and Quadrula pustulosa collected from pools 14 and 15 of the Upper Mississippi River in 1983 and 1985. Numbers at the top of bars indicate total number of live and recently dead in that interval. Horizontal bar below x axis indicates legal size range for commercial harvest.

Amblema plicata



Quadrula pustulosa

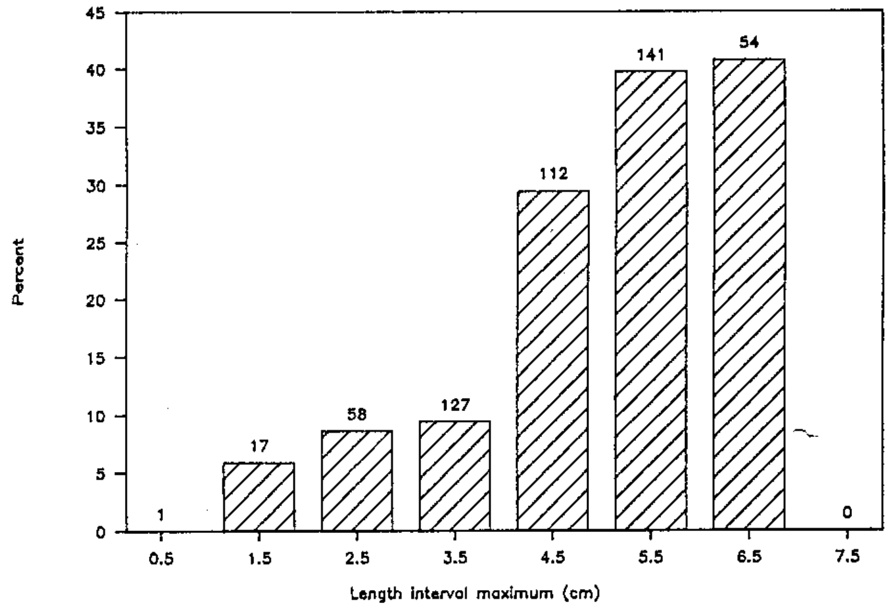


Figure 5. Percent recently dead, RD/(LI + RD), for length intervals of Amblema plicata and Quadrula pustulosa collected from pools 14 and 15 of the Upper Mississippi River in 1983 and 1985. Numbers at the top of bars indicate total number of live and recently dead in that length interval. Horizontal bar below x axis indicates legal size range for commercial harvest.

Table 6. Comparison of recently dead percentages for juvenile and adults of three mussel species from pools 14 and 15 of the Upper Mississippi River.

Species	Samples[3]	Juvenile[1] Live	Juvenile[1] Recently dead (RD)	Juvenile[1] % RD	Adult[2] Live	Adult[2] Recently dead (RD)	Adult[2] % RD	P[4]
Amblema plicata	All combined	79	13	14.1	160	57	26.3	0.014
Amblema plicata	All - RM 488.6	42	9	17.6	99	46	31.7	0.021
Megalonaias gigantea	All combined	66	18	21.4	150	69	31.5	0.073
Megalonaias gigantea	All - RM 488.6	62	17	21.5	138	64	31.7	0.081
Quadrula pustulosa	All combined	264	51	16.2	117	78	40.0	< 0.001
Quadrula pustulosa	All - RM 488.6	154	47	23.4	90	71	44.1	< 0.001
Quadrula pustulosa	1983	42	14	25.0	45	49	52.1	< 0.001

[1] Amblema plicata <7 cm
Megalonaias gigantea <12 cm
Quadrula pustulosa <5 cm

[2] Amblema plicata >7 cm
Megalonaias gigantea >12 cm
Quadrula pustulosa >5 cm

[3] All combined = individuals from all sites and both years pooled
All - 488.6 = all combined minus individuals from river mile 488.6
1983 = all individuals collected from pools 14 and 15 in 1983

[4] P = Probability that the difference in percentages between adults and juveniles results from chance -- arcsin transformation and statistic for comparison of percentages (Sokal and Rohlf 1969)

Detailed graphical or statistical analyses could not be run on the rarer species because sample sizes were too small, but a recent die-off appeared to have occurred in all species (Tables 3 and 4). Although we collected no *Lampsilis higginsi* in our routine sampling, we found one dead specimen in a sheller's cull pile on a small island near RM 486.

It is apparent that if the mortality rates we observed in 1983 and 1985 occur repeatedly and the recruitment is as low as our size distributions indicate (Figure 3), mussel populations in pools 14 and 15 are in jeopardy. The problem is more extensive than our study indicates -- papers presented at the recent workshop on mussel die-offs (Neves 1987) and reports from shellers, district fishery biologists, and other informed observers all indicate that the die-offs of 1983 and 1985 extended over a reach of the Upper Mississippi River several hundred miles long.

SUMMARY

1. In 1983, 33.6% of the mussels we collected in pools 14 and 15 of the Mississippi River had died within the year.

2. In 1985, 17.9% of the mussels collected near RM 486.0 and only 6.3% of those near RM 488.6 in Pool 15 had died recently.

3. Mortality rate estimates may have been biased upwards in 1983 because shellers were harvesting only live mussels and leaving dead unsalable shells. In 1985, shellers were able to sell recently dead shells so they probably did not bias mortality estimates.

4. If shelling had no effect on the proportion of recently dead shells, a second hypothesis is that susceptible mussels died in response to some causative agent in 1983 leaving behind only more resistant mussels in 1985. A third hypothesis is that the intensity of some unidentified causative agent was less in 1985 than in 1983.

5. Adults and juveniles of all species were affected in both years. However, mortality rates were significantly greater ($\underline{P}$ < 0.08) in reproductive adults (31.7%-44.1%) than in juveniles (17.6%-23.4%) of <u>Amblema</u> <u>plicata</u>, <u>Quadrula</u> <u>pustulosa</u>, and <u>Megalonaias</u> <u>gigantea</u>, the species for which we had the largest sample sizes. Increased mortality in adults could be associated with the stress of reproduction, or with greater accumulation of some unidentified toxic agent in older individuals.

RECOMMENDATIONS

1. Term definitions and techniques to be used in future investigations of mussel die-offs should be standardized to facilitate comparison of different die-off episodes. Terms to categorize the status of shells (live, recently dead, etc.) are defined in this report and may be useful to other investigators. Quantitative sampling using frames and divers should be standard practice, and substrate within sampling frames should be collected and transported to the surface and carefully examined for small specimens.

2. In addition to shell length, age of mussels should be determined by counting annuli if possible so that growth and recruitment rates can be determined.

3. To determine whether the causative agent for mussel die-offs in the Mississippi River is a transmittable infectious agent, healthy mussels should be exposed to moribund individuals in the laboratory.

4. Body and shell burdens of contaminants should be monitored in healthy mussel populations and in populations where die-offs occur. The effects of any contaminants found in significantly higher concentrations in populations experiencing die-offs should be determined in laboratory bioassays on healthy mussels.

5. Mussel sanctuaries should be established to provide unharvested mussel beds where scientists could study mussel ecology without the confounding effects of commercial harvest. The size distributions and recruitment, growth, and mortality rates of relatively undisturbed mussel populations should be determined for comparisons with populations subject to die-offs or harvesting. In addition, these sanctuary beds could serve as seed populations in the future.

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