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Mitigation of Unionid Mortality Caused by Zebra Mussel Infestation: Cleaning of Unionids

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Abstract.—Exotic zebra mussels *Dreissena polymorpha* have infested and caused mortality of native unionids in the Great Lakes since 1986; no other such parasitism of native unionids occurs in North America. Survival of unionids threatened by zebra mussel infestation was tested by suspending uncleaned and cleaned unionids in nearshore waters of western Lake Erie. Survival was determined, and newly settled zebra mussels were removed from cleaned unionids at eight intervals that ranged from 21 d to 77 d between 5 July 1990 and 3 July 1991. After 1 year, survival rates of uncleaned and cleaned unionids were 0% and 42%, respectively. Of the 10 species examined, only individuals from 3 species (*Amblema plicata plicata*, *Fusconaia flava*, and *Quadrula quadrula*) survived 1 year. These species have relatively thick shells, which may have contributed to their survival. Removal of newly settled zebra mussels may be important to unionid survival because 98% of the zebra mussels removed after the initial cleaning were small mussels (<10 mm long) that could rapidly grow and cover unionids. At present, we do not know how zebra mussels cause mortality of unionids, but the removal of zebra mussels from unionids is the only method known that successfully reduces unionid mortality in waters colonized by zebra mussels.

Shortly after the introduction of zebra mussels *Dreissena polymorpha* into the Laurentian Great Lakes and their rapid increase in density in the mid to late 1980s, there was major concern about the effects of epizoic infestation of this taxon on native unionids (Bivalvia: Unionidae) (Hebert et al. 1989; Schloesser and Kovalak 1991) (Figure 1). This concern was warranted because zebra mussels attach to hard-bodied invertebrates and have been shown to cause mortality of unionids in lakes and rivers of North America (Tucker et al. 1993; Gillis and Mackie 1994; Nalepa 1994; Schloesser and Nalepa 1994; Tucker 1994). This infestation is unique in that no other epizoic parasite has been shown to exhibit massive encrustation of unionid shells and cause mortality. To date, the causal mechanism(s) for unionid mortality is unknown (reviewed in Schloesser and Kovalak 1991; Schloesser et al. 1996). Extirpation of unionids caused by zebra mussels in North America could not have been predicted by the European experience because these taxa have coexisted there for 200 years. Lake Balaton, Hungary, is an exception; there, mussels extirpated unionids in the early 1930s (reviewed in Schloesser and Kovalak 1991).

Translocation and propagation of unionids was first initiated in North America in the late 1800s (Coker et al. 1922). These early programs were phased out by the mid 1930s, and few studies were conducted until the mid 1970s, when translocation programs were initiated to save unionids from pollution and construction projects (Ahlstedt 1979; Sheehan et al. 1989). In the early 1990s, translocation of unionids in response to the threat posed by zebra mussels has increased (R. Neves, Virginia Polytechnic Institute and State University, personal communication). Most recent translocations are from waters colonized by zebra mussels to waters where zebra mussels are not expected to become abundant or to artificial ponds where zebra mussel colonization is improbable. However, moving unionids to waters free of zebra mussels may be difficult in some areas because zebra mussels are expected to invade, and possibly colonize, three-quarters of the surface waters in North America (Strayer 1991).

At present, there are no techniques to reduce infestations of zebra mussels on unionids in areas colonized by zebra mussels. One possible technique is the periodic removal of zebra mussels from infested unionids. This technique may allow unionids to survive in habitats where survival and reproduction has been demonstrated, thereby decreasing the need to maintain artificial habitats aimed at conserving bivalve species whose life history and propagation characteristics are not well known (Winter 1978; Newkirk 1980). This technique may also be important to preserve the genetic diversity of unionid populations during periods when zebra mussel densities are high. Unionid mortality occurs primarily at high densities of zebra mussels, and in some waters zebra mussel densities fluctuate and decline several years after their introduction (Schloesser and Kovalak 1991; Ricciardi et al. 1995; Schloesser et al. 1996).

This study was conducted to determine the feasibility of cleaning zebra mussels from unionids as a Mussel

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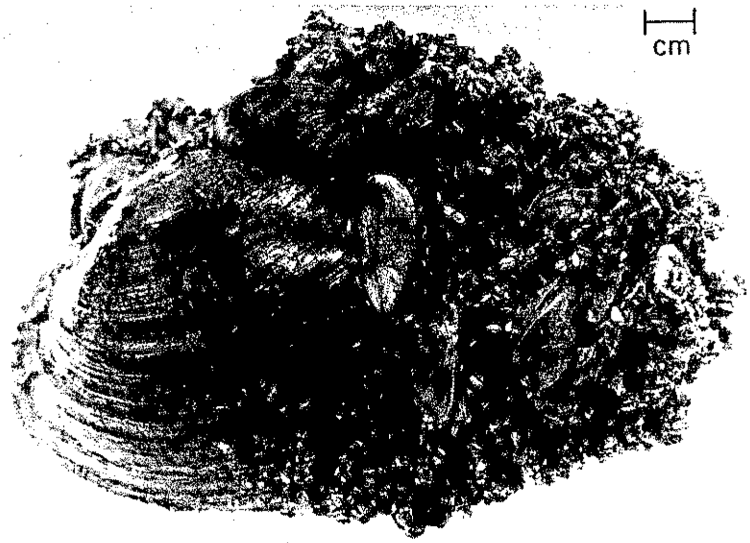

FIGURE 1.—Zebra mussels infesting a unionid mollusk (*Pyganodon grandis*).

a procedure for reducing mortality of infested unionids in waters where zebra mussels are abundant. Cleaning may become necessary for management of unionids as zebra mussels spread and threaten unionids in waters throughout North America.

Methods

Unionids and infesting zebra mussels and sediments were collected (approximately 3-m water depth) by scuba divers and suspended in cages (approximately 2.5-m water depth) in the forebay of a power plant intake canal in nearshore waters of western Lake Erie, 5 July 1990–3 July 1991 (Schloesser and Kovalak 1991). Unionids were randomly divided into two treatment groups: uncleaned and cleaned of zebra mussels by scraping with a knife. Two unionids of each treatment group were placed in each of 12 cages. No selection of unionids based on species or length was done because massive infestation prevented species identification and measurement. Each cage (22 cm in diameter × 40 cm high; 5-mm-mesh screen) was lined with a plastic bag on the bottom to hold about 25 cm of Lake Erie sediments (primarily sand).

During the 365-d study period, cages were suspended and lifted on eight sampling dates to determine survival of unionids and remove zebra mussels from treatment unionids. Zebra mussels from 10 cleaned unionids collected 5 July 1990 and from live unionids on the eight sampling dates were collected and preserved in 5% buffered ($CaCO_3$) formalin for laboratory analysis. No zebra mussels were collected from uncleaned and dead unionids because decaying unionids caused zebra mussels to release and die.

In the laboratory, zebra mussels were washed over a U.S. Standard number 60 sieve (0.25-mm-mesh opening), counted, and measured for length to the nearest millimeter. Zebra mussels smaller than 1 mm long were recorded as 1-mm individuals. Length-frequency distributions of zebra mussels removed from unionids were constructed from a randomly selected subsample (between 850 and 3,000 individuals) of zebra mussels 6 mm or less and from all zebra mussels 7 mm or longer for each sampling date. Distributions of unmeasured zebra mussels 6 mm or less were based on proportions of measured zebra mussels 6 mm or less in each 1-mm length-group. Total dry weights (nearest 0.1 g) of zebra mussels were determined by desiccation at 105°C for 48 h.

Unionids were identified and measured when the study was completed (3 July 1991). Unionid nomenclature follows Williams et al. (1993), with the exception that the eastern lampmussel *Lampsilis radiata radiata* was combined with the fatmucket *Lampsilis siliquoidea* because the geographical ranges of these two species overlap and they have been shown to interbreed in the Great Lakes (Clarke 1981).

Results

Survival of uncleaned unionids (0%; 0 of 24 specimens) was lower than that of cleaned unio-

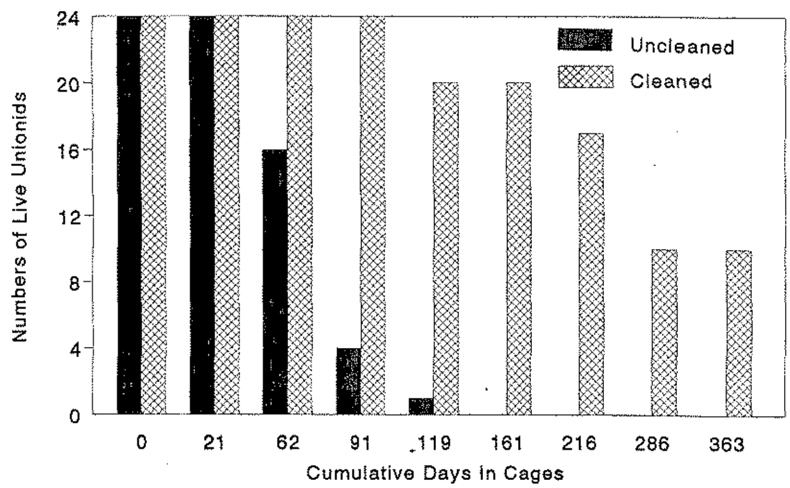

FIGURE 2.—Numbers of live uncleaned (i.e., with attached zebra mussels) and cleaned (i.e., without attached zebra mussels) unionids in cages suspended in nearshore waters of western Lake Erie from 5 July 1990 to 3 July 1991.

nids (42%; 10 of 24 specimens) (Figure 2). Thirty-three percent of the uncleaned unionids (8 of 24 specimens) died within the first 62 d of the study; 83% (20 of 24 specimens) died within 91 d; and by 13 December (161 d), no uncleaned unionids were alive. In contrast, 100% of cleaned unionids were alive within the first 91 d of the study, 83% (20 of 24 specimens) within 161 d, 71% (17 of 24 specimens) within 216 d, and 42% (10 of 24 specimens) survived 363 d.

Three species—the threeridge *Amblema plicata plicata,* Wabash pigtoe *Fusconaia flava,* and mapleleaf *Quadrula quadrula*—survived longer than seven other species—*Lampsilis siliquoidea,* pimpleback *Quadrula pustolosa pustulosa,* spike *Elliptio dilatata,* pink heelsplitter *Potamilus alatus,* fragile papershell *Leptodea fragilis,* threehorn wartybark *Obliquaria reflexa,* and giant floater *Pyganodon grandis.* Ten of 22 individuals (45%) survived 363 d, whereas none of the other 26 individuals of seven taxa survived. Of the 10 uncleaned species, only *A. p. plicata* and *F. flava* were alive 91 d after being caged. The last uncleaned specimen that died between 1 November and 13 December was an *A. p. plicata.* Of the 6 cleaned species, 5 were alive 216 d and 3 (*A. p. plicata, F. flava,* and *O. quadrula*) were alive 363 d after being suspended in cages.

In general, numbers, weights, and lengths of zebra mussels removed from cleaned unionids suspended in cages were less than those attached to the specimens at the beginning of the study (Table 1). Unionids removed from nearshore waters of western Lake Erie on 5 July 1990 were infested by an average of 614 zebra mussels/unionid (17.3 g/unionid). Numbers and weights of zebra mussels removed from cleaned unionids increased between 26 July and 4 October 1990. Substantial decreases occurred between 4 October 1990 and 6 February 1991, but there was an increase between 6 February and 3 July 1991. About 98% of all zebra mussels (N = 4,706) removed from cleaned unionids between 26 July 1990 and 3 July 1991 were 10 mm or less in length; 1% were 11–15 mm long, and only 17 (<1%) were longer than 15 mm.

Discussion

Removal of zebra mussels from infested unionids increased survival of unionids in waters colonized by zebra mussels. No uncleaned unionids survived. In addition, near total mortality of unionids occurred throughout most of western Lake Erie and in the area where unionids were collected for this study (Schloesser and Nalepa 1994).

Individual unionid species appear to have varying susceptibility to the effects of zebra mussel infestation (Haag et al. 1993; Gillis and Mackie 1994; Tucker 1994). In this study and in general, species of the subfamily Amblemine were more resistant to the effects of zebra mussel infestation than species of the subfamilies Lampsilinae and Anodontinae (reviewed by Schloesser et al. 1996).

The extent to which periodic removal of zebra mussels (in contrast to a single removal) contributed to the survival of cleaned unionids in the present study is not known. Cleaned unionids be-

TABLE 1.—Length-frequen
mussels (per unionid) remov
1990 to 3 July 1991. Cumul

Length class (mm)	5 Jul (0)	26 Jul (21)
1	<1	<1
2	5	<1
3	24	<1
4	42	<1
5	62	<1
6	86	2
7	85	3
8	83	5
9	78	5
10	56	3
11	38	2
12	23	1
13	13	1
14	9	<1
15	4	
16	2	<1
17	<1	
18	<1	
19	<1	
20		
21	<1	
22		
23		
24	<1	
25		
26		
27	<1	
28	<1	
All	614	25
All	17.3	0.6

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Survival of unionids c
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TABLE 1.—Length-frequency distributions (mean number/unionid) and mean number and dry weight (g) of zebra mussels (per unionid) removed from cleaned unionids suspended in nearshore waters of western Lake Erie, from 5 July 1990 to 3 July 1991. Cumulative number of days are in parentheses below the date.

Length class (mm)	1990						1991		
	5 Jul (0)	26 Jul (21)	5 Sep (62)	4 Oct (91)	1 Nov (119)	13 Dec (161)	6 Feb (216)	17 Apr (286)	3 Jul (363)
	Mean number of zebra mussels per unionid								
1	<1	<1	228	262	250	42	<1	2	2,400
2	5	<1	151	165	43	18	<1	1	5
3	24	<1	56	150	47	34	<1	2	6
4	42	<1	59	108	89	31	<1	2	6
5	62	<1	44	78	56	31		3	7
6	86	2	39	24	33	15		3	5
7	85	3	5	18	8	6		3	4
8	83	5	5	11	7	8		2	3
9	78	5	6	5	6	3		1	5
10	56	3	7	1	2	1		<1	7
11	38	2	5	1	<1	<1		<1	4
12	23	1	5	<1	<1	<1		<1	6
13	13	1	5	<1				<1	4
14	9	<1	5	<1					4
15	4		6	<1	<1	<1			4
16	2	<1	1	<1	<1			<1	2
17	<1		<1	<1				<1	1
18	<1		<1	<1					1
19	<1		<1		<1			<1	
20			<1		<1				<1
21	<1								
22				<1	<1				
23									
24	<1								
25									
26									
27	<1								
28	<1								
All	614	25	624	827	544	190	1	22	2,473
	Mean weight (g) of zebra mussels per unionid								
All	17.3	0.6	1.7	2.4	2.2	1.3	<0.1	0.4	3.7

came infested by large numbers of zebra mussels on four of eight sampling dates. A large proportion of these zebra mussels were relatively small, consistently weighing less than those removed on 5 July 1990, when large zebra mussels were also over four times more abundant. If zebra mussels had not been periodically removed, they could have grown and contributed to mortality. Mortality of unionids does not occur in the first year of heavy infestation (e.g., >5,000 zebra mussels/m^2 of substrate), when most zebra mussels are small (i.e., <10 mm; Schloesser and Kovalak 1991; Masteller et al. 1993; Ricciardi et al. 1995; Schloesser et al. 1996). However, unionid mortality may be caused by the accumulative effects of several years of infestation by small zebra mussels, but at present no such circumstances have been found.

Survival of unionids cleaned of zebra mussels (42%) was within the range of published survival rates for translocation studies where zebra mussels were not present (Sheehan et al. 1989). However, published studies probably underestimated survival rates (Ahlstedt 1979; Sheehan et al. 1989). For example, in most translocation studies, unionids have not been confined, and the fate of lost specimens has not been documented, leading to inaccurate survival estimates (Sheehan et al. 1989).

Survival of cleaned unionids in this study could have been underestimated because substantial differences existed between the habitats where unionids were collected and where cages were suspended and because unionids were heavily infested for 3 years (1989–1991) before the study was begun (Schloesser and Kovalak 1991). Unionids were translocated from a lake habitat in western Lake Erie and suspended in cages in a riverine-type habitat where water flow was uniform (about 1 m/s) and unidirectional. This site was selected because waves in western Lake Erie would have destroyed the holding cages. Careful selection of the habitat to which unionids are translocated can maximize survival to about 80% for 1 year (Neves, personal communication). Unionids used in the present study were exposed to 3 years of the highest substrate densities of zebra mussels and heaviest infestation intensities ever recorded (Schloesser and Kovalak 1991; Nalepa and Schloesser 1993). Such infestations have been shown to reduce fitness (i.e., energy reserves) and increase stress (i.e., cellulase enzyme activity) of host unionids in as short a time as 120 d (Haag et al. 1993).

The present study indicates that cleaning unionids is a viable technique to reduce zebra mussel infestations and short-term (<1-year) mortality of unionids in waters containing zebra mussels. This technique may be especially useful when zebra mussels increase exponentially in the first few years after their introduction and then decline to densities that allow coexistence with unionids.

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