

**MORTALITY OF UNIONID BIVALVES  
(MOLLUSCA) ASSOCIATED WITH DREISSENID  
MUSSELS (*DREISSENA POLYMORPHA* AND  
*D. BUGENSIS*) IN PRESQUE ISLE BAY, LAKE ERIE**

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**ABSTRACT** - Two exotic species of dreissenid mussels (*Dreissena polymorpha* and *D. bugensis*) began to colonize bottom substrates in Presque Isle Bay, Lake Erie in 1990. By 1991, all native unionid (Unionidae) shells were infested by dreissenids. In 1990 and 1991, about 500 individual unionids of 15 species were collected; in 1992, 246 individuals of 12 species were collected; in 1993, 64 individuals of 6 species; in 1994, three individuals of three species; and in 1995, no unionids were found. In general, infestation indices of unionids were relatively low in 1990 and 1991, increased in 1992, and decreased in 1993. Mortality of unionids associated with infestation in the bay occurred in a shorter period of time (ca. two to three years) than has been documented in other water bodies. Observations in an area of Presque Isle not included in the present study, indicate that a small remnant population of unionids exists in the presence of heavily-colonized substrates by dreissenid mussels. Since other shallow-water areas of Lake Erie support infestation-free unionids in the presence of dreissenid mussels, it is hoped that some unionids will survive in Presque Isle Bay of Lake Erie.

**INTRODUCTION**

In Europe, where dreissenid mussels (zebra mussels, *Dreissena polymorpha*, and quagga mussels, *Dreissena bugensis*) have probably infested unionids (Mollusca: Bivalvia: Unionidae) for about 100 years, no substantial impacts on unionids have been attributed to dreissenid infestation, except in Lake Balaton, Hungary, where *en masse* mortality of unionids occurred shortly after the introduction of zebra mussels in the early 1930s (Lewandowski 1976, Sebestyen 1938; reviewed in Schloesser and Kovalak 1991). Infestation of unionids may have contributed to the decline of other unionid populations in Europe, but none exhibited high mortality similar to that in Lake Balaton and North America, where dreissenid mussels invaded in the late 1980s (Arter 1989, Lewandowski 1991, Schloesser et al. 1996).

In North America, dreissenid mussels have infested unionids since at least 1988-89, when mussels were discovered and became abundant

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in the Laurentian Great Lakes (Griffiths et al. 1991, Hebert et al. 1989, Nalepa and Schloesser 1993). Since their discovery, zebra mussels and, possibly, quagga mussels have caused mortality of unionids in most of the large lakes and rivers they have invaded (Nalepa et al. 1996, Ricciardi et al. 1996, Schloesser et al. 1996, Schloesser et al. 1998, Schloesser and Kovalak 1991, Strayer and Smith 1996, Tucker 1994). In addition, infestation may also be impacting unionid populations in small rivers and inland lakes (Marangelo 1997; pers. comm., D. Garton, Indiana University, Kokomo, IN). However, data exist that indicate unionids co-exist with dreissenid mussels in a wetland bay and in a shallow seiche zone in nearshore waters of western Lake Erie (Nichols and Wilcox 1997, Schloesser et al. 1997). At present, we do not know why unionids survive longer in these shallow waters of the Great Lakes, but it may be that some habitat types or behavioral mechanisms of unionids allow them to escape heavy infestation and resulting mortality.

The present study was undertaken to determine whether infestation by dreissenid mussels would cause mortality of unionid populations in the bay habitat of Presque Isle, Lake Erie (Fig. 1). Presque Isle Bay differs from open bays of western Lake Erie, where Haag et al. (1993) caged unionids for short periods of time and discovered reduced fitness in energy reserves between infested and uninfested unionids. Presque Isle Bay is separated from Lake Erie by a relatively narrow opening at its eastern end through which water exchange is minimal, when compared to open bays in western Lake Erie. Unionid infestation within Presque Isle Bay may occur at a slower rate and with less intensity than that in open habitats of the Great Lakes, thus allowing unionids to survive like those in other small areas of near-shore waters of Lake Erie (Nichols and Wilcox 1997, Schloesser et al. 1997).

## STUDY AREA AND METHODS

Presque Isle Bay is surrounded by a recurved sand spit formed since the retreat of the last glacier from the area about 11 thousand years ago (Hutchinson 1957) (Fig 1). The peninsula encircling the bay to the north has formed over the past four to eight thousand years. The bay has a maximum length of 7.6 km, a maximum width of 2.3 km, a maximum depth of 9 m, average depth of 4 m, and is enclosed, except at the eastern end which is open to Lake Erie. The bay has existed in its present form for at least the past one thousand years, and it is believed this isolation from the main lake has resulted in several morphologically unique groups of fauna, including unionid mollusks that have been relatively stable for the past 70 years (Masteller et al. 1993, Ortmann 1919).

Unionids were collected annually at four sites along the north shore of Presque Isle Bay, June 12-July 28, 1990-1995 (Fig. 1). All sites were located within Presque Isle State Park. Site 1 was located just outside, and sites 2, 3, and 4 were located inside a narrow channel maintained by bulkheads and dredging for boat navigation and bay protection.

Sampling was performed by wading, swimming with snorkel, and crawling along substrates with SCUBA in water between 0.5 and 2.0 m deep. Approximately six diver hours of sampling effort were expended at each site per year to collect unionids. Unionids protruding from the substrate were located primarily by sight and tactile methods when water turbidity and macrophyte growth decreased visibility. Substrates were composed primarily of sand intermixed with gravel and rocks, visually estimated as: 25% gravel at site 1, 25% rocks at site 2, 10% gravel at site 3, and 10% gravel and 50% rocks at site 4. Unionids were removed from the substrate and taken to shore. Unionids were enumerated, identified, and returned to the substrate in a similar position and depth as that when collected.

Ten randomly selected unionids with attached dreissenid mussels were preserved in 5% formalin. In the laboratory, mussels were identified, enumerated, and measured (Schloesser and Kovalak 1991; Schloesser and Nalepa 1994). Two species of dreissenids were identified: *Dreissena polymorpha* and *D. bugensis* (Domm et al. 1993; Rosenberg and Ludyanskiy 1994). Infestation intensity (number

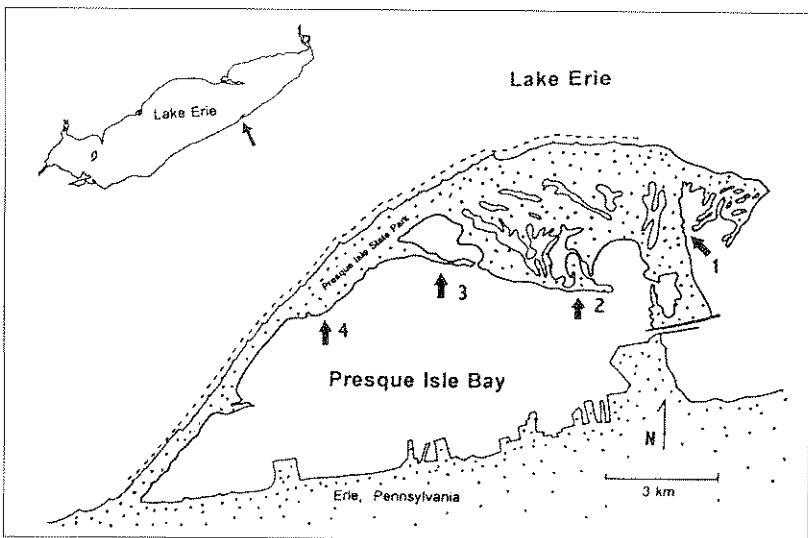


Figure 1. Location of four sampling sites along the north shore of Presque Isle Bay where unionids and dreissenid mussels (*Dreissena polymorpha* and *D. bugensis*) were collected, June-July 1990-1995.

dreissenid mussels per unionid) and infestation indices (gram dreissenid mussels per gram unionid; dry weight 104° C for 48h) of individual unionids were determined (Ricciardi et al. 1996, Schloesser et al. 1996, Schloesser et al. 1998). Designations of dreissenid cohorts (i.e., length groups) were based on the presence of relatively low numbers of mussels between modal peaks of length-frequency distributions (Griffiths et al. 1991, Schloesser and Kovalak 1991).

Unionids were identified following Masteller et al.(1993). Unionid nomenclature in the present study follows Turgeon et al. (1998), with the exception that *Lampsilis radiata radiata* (Gmelin) was combined with *Lampsilis siliquoidea* (Barnes) because shell forms intergrade in the Great Lakes (Clarke 1981).

## RESULTS

A total of 1282 unionids of 15 species were collected in Presque Isle Bay, June-July, 1990-1995 (Table 1). A total of 500 individuals of 13 species were collected in 1990, 469 individuals of 15 species in 1991, 246 individuals of 12 species in 1992, 64 individuals of 6 species in 1993, 3 individuals of 3 species in 1994, and 0 individuals in 1995.

In general, numbers of unionids decreased between successive sampling periods at all four sites (Table 2). At site 1, unionids decreased two-fold between 1990 and 1991, ten-fold between 1991 and 1992, then

Table 1. Numbers of unionids collected at four sites in Presque Isle Bay, Erie, Pennsylvania, June-July 1990-1995.

Taxa	1990	1991	1992	1993	1994	1995	1990-1995
<i>Amblema plicata</i>	36	47	44	19	1		147
<i>Elliptio dilatata</i>	12	7	1				20
<i>Fusconaia flava</i>	19	26	36	7			88
<i>Lampsilis cardium</i>	11	9	12	1			33
<i>Lampsilis siliquoidea</i>	191	210	110	27	1		539
<i>Lasmigona costata</i>	3	1					4
<i>Leptodea fragilis</i>	65	73	7				145
<i>Ligumia nasuta</i>	21	8	5				34
<i>Ligumia recta</i>	2	4					6
<i>Potamilus alatus</i>	59	48	9	8			124
<i>Pyganodon grandis</i>	71	8	1				80
<i>Prychobranchnus fasciolaris</i>		1					1
<i>Quadrula p. pustulosa</i>		1	1				2
<i>Quadrula quadrula</i>	2	10	13	2	1		28
<i>Truncilla truncata</i>	8	16	7				31
Total	500	469	246	64	3	0	1282
Number of species	13	15	12	6	3	0	15

were absent from collections in 1993-1995. At sites 2 and 3, unionids decreased about two-fold between 1990 and 1992, then decreased substantially between 1992 and 1993 before being absent from collections in either 1994 or 1995. At site 4, relatively few unionids were found before dreissenid mussels in 1990; numbers remained relatively stable through 1992, then decreased until no individuals were found in 1995.

Infestation indices of infested unionids were relatively low in 1990 and 1991, highest in 1992, and moderately high in 1993 (Fig. 2). Although *Dreissena bugensis* was first found at site 1 in 1991 and at

Table 2. Numbers of unionids collected at four sites in Presque Isle Bay, Erie, Pennsylvania, June-July 1990-1995.

Taxa	Site 1					Site 2						
	1990	1991	1992	1993	1994	1995	1990	1991	1992	1993	1994	1995
<i>Amblema plicata</i>	4	3					22	28	23	4		
<i>Elliptio dilatata</i>	1	1					6	1				
<i>Fusconaia flava</i>	14	10					1	5	18	1		
<i>Lampsilis cardium</i>	6						3	6	4			
<i>Lampsilis siliquoidea</i>	20	19	2				36	100	35	1		
<i>Lasmigona costata</i>												
<i>Leptodea fragilis</i>	22	14	1				11	30				
<i>Ligumia nasuta</i>		1					16	1	1			
<i>Ligumia recta</i>								3				
<i>Potamilus alatus</i>	36	16	3				12	15			3	
<i>Pyganodon grandis</i>	25	1					33	1				
<i>Ptychobranthus fasciolaris</i>		1										
<i>Quadrula p. pustulosa</i>								1				
<i>Quadrula quadrula</i>							2	10	12	2	1	
<i>Truncilla truncata</i>		1					4	12	1			
Total	128	67	6	0	0	0	146	213	94	11	1	0
Number of species	8	10	3	0	0	0	11	13	7	5	1	0

Taxa	Site 3					Site 4						
	1990	1991	1992	1993	1994	1995	1990	1991	1992	1993	1994	1995
<i>Amblema plicata</i>	4	15	12	9			6	1	9	6	1	
<i>Elliptio dilatata</i>	5	1	1					4				
<i>Fusconaia flava</i>	4	8	17	5				3	1	1		
<i>Lampsilis cardium</i>	2	1	7					2	1	1		
<i>Lampsilis siliquoidea</i>	101	82	36	13			34	9	37	13	1	
<i>Lasmigona costata</i>	1	1						2				
<i>Leptodea fragilis</i>	26	25					6	4	6			
<i>Ligumia nasuta</i>	1	5					4	1	4			
<i>Ligumia recta</i>		1						2				
<i>Potamilus alatus</i>	10	15	1				1	2	5	5		
<i>Pyganodon grandis</i>	11	6					2		1			
<i>Ptychobranthus fasciolaris</i>												
<i>Quadrula p. pustulosa</i>			1									
<i>Quadrula quadrula</i>									1			
<i>Truncilla truncata</i>	4	2	2					1	4			
Total	169	162	77	27	0	0	57	27	69	26	2	0
Number of species	11	12	8	3	0	0	8	9	10	5	2	0

sites 2, 3, and 4 in 1992, it accounted for a relatively small proportion of the total number and weights of infesting dreissenid mussels (i.e., 0-9%). In 1990, zebra mussels and infestation of unionids occurred only at site 1. By 1991, dreissenid mussels were found at all four sites, and mean infestation indices were very similar. Between 1991 and 1992, infestation declined at site 1 and increased at sites 2-4. By 1993, infestation was not found at site 1 where no unionids occurred, remained about the same at site 2, and declined substantially at sites 3 and 4. Numbers of individual indices that exceeded 1.0 include: 1 at site 2 in 1991; 1 at site 2, 7 at site 3, and 2 at site 4 in 1992; and, 3 at site 2 and 3 at site 4 in 1993.

Length-frequency distributions of dreissenid mussels infesting unionids indicate that mussels invaded site 1 in spring before sampling occurred and sites 2-4 after sampling occurred annually (Table 3). In 1990, an extensive survey of nearshore waters in Lake Erie and Presque Isle Bay indicated that dreissenid mussels, all 1 to 2 mm long, were present only at site 1 (Masteller et al. 1993). Relatively large numbers of small mussels (i.e., 589 mussels 1-mm long) also occurred at site 1 in 1991. The possible presence of three cohorts at site 1 in 1991 indicates that a spring and fall recruitment period occurred before and after sampling in 1990, and before sampling in 1991. However, at the

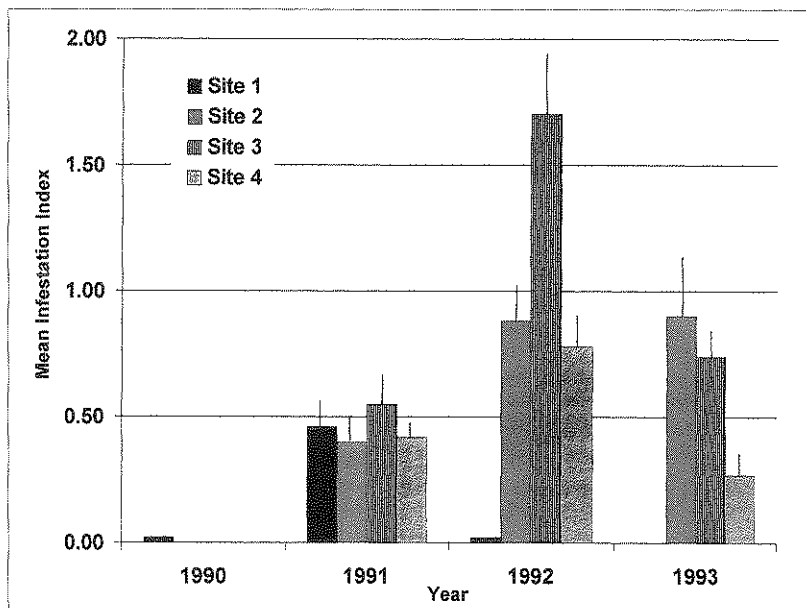


Figure 2. Mean ( $\pm$  s.e.) infestation indices (g dreissenid mussels per unionid) of unionids infested by dreissenid mussels (*Dreissena polymorpha* and *D. bugensis*) at four sites (Fig. 1) in Presque Isle Bay, June-July 1990-1993.

other three sites, relatively large numbers of small dreissenid mussels were not found, indicating little to no spring recruitment before sampling in June-July. Presence of two cohorts at sites 2-4 in 1992 and 1993 also indicates that limited dreissenid recruitment occurred in the inner bay before sampling.

Table 3. Length-frequency distributions of dreissenid mussels (*Dreissena polymorpha* and *D. bugensis*) infesting unionids (n=10/site/date) in Presque Isle Bay, Erie, Pennsylvania, June-July 1990-1993. Lines in columns separate possible cohort/year-class groups based on visual inspection.

Length (mm)	1990	1991				1992			1993		
	Site 1	Site 1	Site 2	Site 3	Site 4	Site 2	Site 3	Site 4	Site 2	Site 3	Site 4
1	733	589						2			
2	6	<u>36</u>						1			
3		128	8	3	2			1		1	
4		126	6	9				2			
5		342	63	14				27	1	2	
6		359	77	20	1			61	1	3	
7		488	120	43	3	2	71	3	7	3	
8		510	177	47	6	18	128	11	21	3	1
9		291	139	87	8	18	184	14	36	14	
10		355	418	217	11	36	331	37	55	35	
11		99	170	165	7	38	273	44	69	34	
12		72	207	292	17	137	482	64	92	62	2
13		22	157	279	19	161	365	103	54	49	4
14		11	68	271	41	175	323	194	50	63	5
15		5	57	299	103	177	393	252	29	89	3
16		<u>2</u>	15	151	72	97	186	206	<u>23</u>	51	6
17		2	3	72	98	<u>72</u>	146	188	26	<u>68</u>	3
18		4	2	39	95	76	82	137	50	64	5
19		3		7	50	85	80	90	82	56	6
20		20	1	2	43	132	69	43	99	68	7
21		4		3	21	94	<u>54</u>	17	114	77	14
22		11			16	74	51	15	97	98	<u>2</u>
23		10			5	44	74	<u>7</u>	83	81	7
24		3				32	61	7	75	90	14
25		4				17	91	15	68	79	18
26						5	44	11	26	39	13
27			1			1	32	16	16	32	20
28						1	17	14	6	20	18
29							5	10	3	15	12
30							1	10	2	5	19
31							1	3		5	9
32											8
33											2
34								1	1	1	1
35											1
Number/unionid											
Small group											
	74	344	169	202	62	56	326	143	44	47	6
Large group											
	0	6	0	0	0	93	38	9	75	73	14
Total	74	350	169	202	62	149	364	152	119	120	20

## DISCUSSION

Infestation of unionids by dreissenid mussels resulted in total mortality of unionids in Presque Isle Bay of Lake Erie between 1990 and 1995. This is similar to results of most studies in North America where unionid mortality associated with zebra mussels has been documented (Gillis and Mackie 1994, Nalepa et al. 1996, Ricciardi et al. 1996, Schloesser et al. 1996, Schloesser et al. 1998, Schloesser and Kovalak 1991, Schloesser and Nalepa 1994, Strayer and Smith 1996, Tucker 1994). In Europe, only one study (Sebestyen 1938) documented *en masse* infestation and associated mortality of unionids by zebra mussels (reviewed in Schloesser and Kovalak 1991).

Decline in unionid abundance in Presque Isle Bay after invasion by dreissenid mussels occurred in a shorter period of time than in other waters of North America. Near-total mortality of unionids within Presque Isle Bay occurred within two years of dreissenid invasion at sites 1 and 2, and three years at sites 3 and 4. In general, near-total mortality of unionids occurs between four and eight years after invasion by mussels (reviewed in Ricciardi et al. 1998 and Schloesser et al. 1996). The most intensively studied area where infestation-induced mortality has occurred is the Lake Huron-Lake Erie corridor of the Great Lakes (Schloesser and Kovalak 1991, Schloesser and Nalepa 1995, Schloesser et al. 1996, Schloesser et al. 1998). Mussels invaded the corridor in 1986, became abundant in 1989, and killed most unionids by 1994, except for small unionid populations in a wetland bay and a shallow water seiche habitat (Nichols and Wilcox 1997, Schloesser et al. 1997).

In general, infestation intensities (i.e., 74-350 dreissenid mussels/unionid) and infestation indices (grams dreissenid mussels/gram unionid = 0.02-1.7) of unionids and length-frequency distributions of infesting mussels in Presque Isle Bay are similar to those found in other waters of the Great Lakes where near-total mortality of unionids has occurred from dreissenid infestation (Mackie 1991, Schloesser and Kovalak 1991). High infestation intensities in excess of 10,000 mussels/unionid have been observed, but these are found only in summer/fall time periods and include dreissenid mussel recruitment from the summer time period (Gillis and Mackie 1994, Schloesser and Kovalak 1991). Recruitment of dreissenid mussels typically occurs during late-June to mid-August, but has been observed in early-May (Gillis and Mackie 1994, Mackie 1991, Mackie and Schloesser 1996). After a winter period, dreissenid mussels exhibit high mortality, and infestation intensities by larger mussels the following year are similar to those found in Presque Isle (<200/unionid) in June-July (Mackie 1991, Ricciardi et al. 1996, Schloesser and Kovalak 1991, Schloesser and Nalepa 1994). Similarly, infestation indices as high as 4 (gram dreissenid/gram unionid) have



been seen in fall sampling, but indices in early spring and summer are usually <1-2 (Schloesser and Kovalak 1991, Schloesser and Nalepa 1994). Length-frequency distributions of dreissenid mussels indicate that most individual mussels live about two years in Presque Isle. This is typical of zebra mussel populations in waters of the Great Lakes (Griffiths et al. 1991, Mackie and Schloesser 1996, Schloesser 1995).

Species composition and abundance of unionids in Presque Isle Bay is believed to have remained relatively unchanged between the turn of the century and the early 1990s (Masteller et al. 1993, Ortman 1919). In 1990-1992, the total estimated population of unionids at the four sites in the present study was 19,181 individuals of 18 species (Masteller et al. 1993). In the early 1990s, the population of unionids in Presque Isle Bay was believed to be "among the highest (currently) found in the Great Lakes" (Masteller et al. 1993). In addition, many of the unionids found at the turn of the century and in the early 1990s were morphologically distinct forms found only in Presque Isle Bay (Masteller et al. 1993, Ortman 1919).

The anticipation that infestation of unionids by dreissenid mussels would not cause substantial mortality was based on studies in nearshore waters of western Lake Erie where dreissenid mussels avoid infestation for unknown reasons (Nichols and Wilcox 1997, Schloesser et al. 1998). Unfortunately, observations by Masteller et al. (1993) shortly after dreissenid mussels became abundant indicated that heavy encrustation of unionid shells by young-of-the-year zebra mussels at site 1 occurred in 1990. Schloesser et al. (1996) stated, "the earliest warning of negative impacts of infestation on unionids appears to be the presence of heavy encrustation on exposed unionids shells." This visual method is relatively simple and has been successful in predicting unionid mortality in studies in the Great Lakes and Mississippi River, where mortality of unionids has accompanied heavy shell infestations (Gillis and Mackie 1994, Nalepa et al. 1996, Ricciardi et al. 1996, Schloesser and Nalepa 1994, and Tucker 1994; reviewed in Schloesser et al. 1996 and Schloesser et al. 1997). To date, only a few studies conducted in waters outside the Great Lakes have documented mortality of unionids comparable to the Great Lakes (Strayer and Smith 1996, Tucker 1994). However, infestation has occurred for a longer period of time in the Great Lakes than elsewhere in North America (Hebert et al. 1989, Mackie 1991, Schloesser and Kovalak 1991).

Unionids exhibited total mortality at the four sites in our study of Presque Isle Bay. However, one site in Presque Isle that was not included in the present study was observed to have unionids free of infestation, even though surrounding substrates were covered with mussels. This was a small area north of site 1, which is progressively being separated from site 1 by shallow sand-bars. At present, we do not know

whether mortality of unionids at the infestation-free site will occur. Recent data indicate that substantial mortality of unionids can occur at infestation intensities of <10/unionid (Ricciardi et al. 1996, Strayer and Smith 1996). Mortality in the absence of heavy shell infestations is believed to indicate that the causal mechanism of mortality is competition for available food rather than direct interference of unionid movement, metabolic activities, and access to substrates (Schloesser and Kovalak 1991, Strayer and Smith 1996).

## CONCLUSIONS

Clarke (1992), Masteller et al. (1993), and Tucker and Atwood (1995) have called for the establishment of managed refugia to save unionid populations that are unique and at high risk from impacts caused by dreissenid mussels. Establishment of refugia in areas where unionid populations remain infestation-free or infestation is very light could allow efficient use of active management techniques, such as that developed by Schloesser (1996) to reduce unionid mortality. Although observations indicate a possible infestation-free area for unionids outside the study area, none of the four sites intensively studied were found to remain free of dreissenid mussels, and 100% mortality of unionids occurred within 2 to 3 years after invasion in Presque Isle Bay, Lake Erie.

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