

# Muskrat (*Ondatra zibethicus*) Predation on Zebra Mussels (*Dreissena polymorpha*) Attached to Unionid Bivalves

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## ABSTRACT

Muskrats (*Ondatra zibethicus*) commonly prey upon unionid bivalves, discarding the empty shells in discrete piles or middens. We found large numbers of live unionids and the shell remains of zebra mussels (*Dreissena polymorpha*) in muskrat middens on the upper Ohio River and upper Mississippi River. Muskrats apparently began preying on zebra mussels that were attached to unionids following an increase in zebra mussel abundance at the study sites. Significantly fewer zebra mussels were attached to live unionids at muskrat middens than to ones collected from reference sites away from middens. We also found a group of stones with numerous zebra mussel byssal threads at an Ohio River midden, suggesting muskrats retrieved and ate the attached zebra mussels. We view this, as well as the fact that muskrats discarded live unionids, as evidence that muskrats were selectively preying on zebra mussels rather than unionids.

## INTRODUCTION

Selection of prey by predators is influenced by changes in the abundance of available prey species because generalist predators will key in on prey that is most abundant (Krebs 1994). The addition of novel prey, such as an introduced exotic species, into a predator's environment may alter a predator's feeding behavior. Abundance of an exotic species can be very high and in turn may become a predator's primary food, thereby reducing predation on native species (Kelleher et al. 1998).

The zebra mussel (*Dreissena polymorpha*) was accidentally introduced into the Great Lakes in the mid-1980's (Hebert et al. 1989, Griffiths et al. 1991), and has spread throughout much of eastern North America, primarily in lakes and large rivers (Johnson and Padilla 1996). Zebra mussels attach to almost any hard surface, including the exposed surface of native unionid mussels, and are responsible for high unionid mortality in some areas (Schloesser et al. 1996). Zebra mussels are now a readily available food source for a variety of animals that prey on mollusks and other invertebrates (Wormington and Leach 1992, Custer and Custer 1996, French and Bur 1993, Tucker et al. 1996, Boles and Lipcius 1997). Muskrats

(*Ondatra zibethicus*) introduced into Europe prey on zebra mussels (Wolk 1979, Reichhoff 1984), but they have not been reported to do so in North America. However, muskrats are well known predators of unionid mussels (Apgar 1887, Evermann and Clark 1917, Coker et al. 1921, Van Cleave 1940, Bovbjerg 1956, Schwartz and Schwartz 1981, Mumford and Whitaker 1982, Neves and Odom 1989, Watters 1993-1994) and of the Asian clam (*Corbicula fluminea*) (Neves and Odom 1989, McMahon 1991), another exotic bivalve. The conspicuous middens (shell piles), often containing hundreds of empty shells (Convey et al. 1989, Neves and Odom 1989, Watters 1993-1994), are definitive signs of muskrat activity.

We observed predation on zebra mussels by muskrats in two North American rivers and a sequence of events suggesting that muskrats switched prey selection from unionids to zebra mussels following an increase in zebra mussel abundance at our study sites on the upper Ohio River and upper Mississippi River.

## STUDY AREA

*Ohio River.* The Ohio River study site was at river km 331.4, Meigs County, Ohio. The riverbank was a narrow (1 to 15 m) sandy beach with a sparsely vegetated, steeply sloped riparian corridor of < 50 m width. Muskrat middens were in six washed out cavities, under root masses of large standing trees along a 200 m stretch of riverbank. Muskrats were not observed feeding on bivalves; however, we found fresh muskrat tracks near a midden in July 1998.

*Mississippi River.* The Mississippi River study site was at river km 349.2, Jersey County, Illinois. The site was at a gravel bar bordered by mud flats upstream and downstream. Muskrats were observed on several occasions sitting on exposed portions of stranded logs on the upstream side of the gravel bar. Shell middens were found on and near the logs used by muskrats.

## METHODS

We sampled shell remains from muskrat middens in July or August 1993 to 1999 at the Ohio River, and July 1994 at the Mississippi River. We identified dead unionids in middens, and noted the presence of zebra mussel shells and shell fragments, but did not count all empty shells. On 11 and 18 July 1999 at the Ohio River, and 5 July 1994 at the Mississippi River, we collected live unionids in the immediate vicinity of muskrat middens. At the Ohio River, we removed all live unionids found in middens on 11 July, and sampled middens again on 18 July. We found some unionids moving away from middens in shallow (< 0.5 m) water, as evidenced by trails in the substrate. These were the only sampling periods we observed numerous live unionids at middens, although in other sampling periods (Ohio River) it was not unusual to find one to three live unionids amid the empty shells. Unionids did not normally inhabit the near-shore areas where middens were located. Unionids were concentrated several meters away from the riverbank in deeper water that was less affected by wave action.

To compare the level of zebra mussel infestation on live unionids found in muskrat middens to those not handled by muskrats, we collected unionids from a reference area 20 to 50 m away from middens at both sites. At the Ohio River, we hand collected unionids by visually searching or probing the substrate and from random 0.25 m<sup>2</sup> whole substrate samples. At the Mississippi River, unionids were collected from random 0.25 m<sup>2</sup> whole substrate samples only.

We measured the length (anterior-posterior axis) of live unionids from middens and reference areas, and counted the number of zebra mussels attached to their shells. We did not count patches of byssal threads on unionid shells to get a measure of previous zebra mussel infestation because they were often too tightly

grouped to get an accurate count, sometimes forming a single jumbled mass of threads. Also this would not account for zebra mussels that were attached to other zebra mussels and not the unionid itself. We used the Mann-Whitney test to determine if there was a difference between the number of zebra mussels attached to unionids in middens and reference areas and between study sites. Data were analyzed using SYSTAT (1992).

## RESULTS

We collected a total of 254 live unionids from muskrat middens, 175 at the Ohio River and 79 at the Mississippi River (Table 1). At the Ohio River, 105 unionids were removed from middens on 11 July, and 70 newly discarded individuals were collected on 18 July. All live unionids from middens had zebra mussel byssal threads or, in some cases, live zebra mussels attached, usually on the posterior portion of the shell. Empty zebra mussel shells and shell fragments were scattered among the unionid shells at middens at both study sites.

An estimated 80% (Ohio River) and 93% (Mississippi River) of unionids in reference area samples were colonized by zebra mussels. At both study sites significantly fewer zebra mussels were attached to unionids at middens than at reference areas (Ohio River,  $U = 6281$ ,  $df = 1$ ,  $P < 0.001$ ; Mississippi River,  $U = 6646$ ,  $df = 1$ ,  $P < 0.01$ ) (Table 1). At the Ohio River, percentage of unionids with attached zebra mussels was lower at middens than reference areas, but percentages were similar at the Mississippi River. Significantly more live zebra mussels were attached to unionids from middens at the Mississippi River than the Ohio River ( $U = 726$ ,  $df = 1$ ,  $P < 0.001$ ).

Additional evidence that muskrats were consuming zebra mussels was the presence of stones with numerous byssal threads at one Ohio River feeding site. We found 43 stones about 4 to 6 cm in diameter within a 0.25 m<sup>2</sup> area adjacent to discarded unionid shells. As with unionids, we think muskrats retrieved these stones and consumed the attached zebra mussels.

## DISCUSSION

We attribute the apparent change in muskrat prey selection from native unionids to zebra mussels to the increase in availability of zebra mussels at our study sites. We found evidence of muskrats feeding on zebra mussels the year after zebra mussels became abundant at both study sites. Neves and Odom (1989) made a similar observation on the North Fork Holston River, Virginia, where muskrats began preying more heavily on recently established Asian clams than native unionids. Apparently, muskrats learned to eat zebra mussels attached to unionids they retrieved. At least one muskrat at the Ohio River also apparently learned to retrieve rocks with attached zebra mussels, suggesting that zebra mussels were the intended prey.

The methods muskrats use to open and consume bivalves can vary. They may forcefully pry shells open (Lee 1886, Evermann and Clark 1917) or they may break the shell of thin-shelled species (Convey et al. 1989, Hanson et al. 1989, Zahner-Meike and Hanson 2001). Large, thick-shelled unionids are generally too heavy to carry or too tightly closed to open (Evermann and Clark 1917, Watters 1993-1994, Tyrrell and Hornbach 1998). Zebra mussels may be easier to open and consume than unionids. We found zebra mussel shells in middens that had been pried open, as well as ones that were broken, similar to empty unionid shells. The fact that muskrats did not consume unionids after zebra mussels were removed, at least the ones we observed alive, supports the hypothesis that they were selecting zebra mussels over unionids.

Table 1. Zebra mussel infestation of live unionids collected at muskrat middens and reference areas on the upper Ohio River and upper Mississippi River.

Species	Ohio River									
	Midden					Reference				
	n	Mean	SD	Unionid length (mm)	Zebra mussels / unionid	n	Mean	SD	Unionid length (mm)	Zebra mussels / unionid
<i>Amblyma plicata</i>	105	85.8	13.6	13.6	0.1	0.3	82.9	16.7	22.8	20.2
<i>Ellipsaria lineolata</i>							65.0	----	0.0	----
<i>Lampsilis cardium</i>							104.5	6.4	27.5	38.9
<i>Lampsilis siliquoidea</i>	5	110.0	6.2	6.2	0.2	0.4				
<i>Lasmigona complanata</i>	2	129.5	4.9	4.9	0.0	0.0	120.0	4.2	9.0	12.7
<i>Ligumia recta</i>	1	123.0	----	----	0.0	----	142.0	----	10.0	----
<i>Obliquaria reflexa</i>	14	49.2	8.3	8.3	0.0	0.0				
<i>Potamilius alatus</i>	24	105.8	17.4	17.4	0.0	0.0	95.7	27.0	20.7	41.4
<i>Pyganodon grandis</i>	1	86.0	----	----	0.0	----				
<i>Quadrula metanevra</i>	11	62.4	12.6	12.6	0.0	0.0				
<i>Quadrula pustulosa</i>	8	47.1	6.0	6.0	0.0	0.0	50.3	4.5	14.2	13.6
<i>Quadrula quadrula</i>	4	70.8	5.8	5.8	0.6	1.3				
Total	175	73.3	26.2	26.2	<0.1	0.3	85.4	28.1	19.7	25.3
% of unionids with zebra mussels					2.3					80.0
Min - Max zebra mussels / unionid					0 - 3					0 - 130

## Mississippi River

Species	Midden						Reference					
	Unionid length (mm)			Zebra mussels / unionid			Unionid length (mm)			Zebra mussels / unionid		
	n	Mean	SD	Mean	SD	n	Mean	SD	Mean	SD	Mean	SD
<i>Ambelma plicata</i>	68	62.9	13.8	13.2	10.6	100	75.8	16.3	18.8	12.6		
<i>Arcidens confragosus</i>						2	105.0	2.8	21.5	19.1		
<i>Lampsilis cardium</i>						4	123.3	9.9	32.5	13.5		
<i>Lampsilis teres</i>	1	105.0	----	44.0	----	4	91.8	30.7	13.0	9.9		
<i>Lasmigona complanata</i>						2	115.5	10.6	47.5	33.2		
<i>Leptodea fragilis</i>	1	74.0	----	13.0	----	4	89.3	12.1	1.8	3.5		
<i>Megalonaia nervosa</i>	2	163.5	12.0	7.0	5.7	2	102.0	89.1	28.0	28.3		
<i>Obliquaria reflexa</i>	2	48.0	11.3	16.0	9.9	3	48.3	4.0	22.0	16.5		
<i>Potamilius alatus</i>						1	91.0	----	11.0	----		
<i>Potamilius ohioensis</i>						1	47.0	----	1.0	----		
<i>Pyganodon grandis</i>	4	109.3	59.7	17.0	19.7	5	160.4	19.6	47.4	50.8		
<i>Quadrula nodulata</i>						1	85.0	----	13.0	----		
<i>Quadrula pustulosa</i>						1	42.0	----	32.0	----		
<i>Quadrula quadrula</i>	1	74.0	----	2.0	----	5	44.4	16.4	13.2	4.4		
<i>Truncilla truncata</i>						2	45.5	3.5	0.0	0.0		
<i>Utterbackia imbecillis</i>						1	42.0	----	0.0	----		
Total	79	68.2	26.0	13.6	11.3	138	79.7	27.5	19.5	17.0		
% of unionids with zebra mussels				89.9					92.8			
Min - Max zebra mussels / unionid				0 - 47					0 - 131			

Unionids from Mississippi River middens had more zebra mussels attached than those at the Ohio River. Because of their small size (<5 mm), we think most zebra mussels at Mississippi River middens had settled on discarded unionids after muskrats had initially removed zebra mussels. Alternatively, muskrats may not have eaten these small zebra mussels because they provided little benefit. At the Ohio River middens, many unionids were discarded shortly before we collected them, thus insufficient time had elapsed for zebra mussels to resettle on the shells.

The observation of similar feeding patterns by muskrats at sites so far removed from one another suggests muskrat predation on zebra mussels may be a relatively common occurrence. Empty zebra mussel shells were observed at a midden on the Ohio River, at Lawrenceburg, Indiana (river km 793.6) in 1994 (B. Sietman pers. obs), but discarded live unionids were not noted.

While we believe our interpretations are the most logical, there are other hypotheses that may also explain our observations. It is possible that zebra mussels were torn off unionids while being gathered by muskrats, zebra mussels may have voluntarily detached (Eckroat et al. 1993) from unionids after they were retrieved, or muskrats may have selected and retrieved unionids with fewer zebra mussels attached to them. Any of these could explain why we found fewer zebra mussels attached to unionids in middens than reference areas, but if muskrats were not retrieving unionids to eat the attached zebra mussels then why did they not eat the unionids? Muskrats actively forage throughout the year and only occasionally store food, primarily plant material (Errington 1963, Schwartz and Schwartz 1981), and we are unaware of any documentation that muskrats store live unionids in dens or abandon large numbers of live unionids in middens. Thus we think muskrats were indeed retrieving unionids and rocks to consume the attached zebra mussels. The empty and fragmented zebra mussel shells in middens are reasonably sufficient evidence that muskrats were eating them, as similarly empty unionid or Asian clam shells have been in other studies (Neves and Odom 1989, Watters 1993-1994, Tyrrell and Hornbach 1998).

Our observations raise two questions. First, can muskrats become significant predators on zebra mussels? At our study sites, muskrat predation, while notable, seemed to be of minor consequence given the large zebra mussel population. However, in areas where muskrat densities are high, muskrats may well add to the overall predation pressure on zebra mussels, along with other predators such as fish (Tucker et al. 1996, Mitchell et al. 2000), decapod crustaceans (Boles and Lipcius 1997, Perry et al. 1997), and waterfowl (Hamilton et al. 1994, Custer and Custer 1996, Mitchell et al. 2000).

Second, will removal of zebra mussels by muskrats reduce the negative impact of zebra mussels on native unionids? Hart et al. (2001) found that one-time removal of zebra mussels had no effect on unionid survival when zebra mussel infestation is heavy because unionids are eventually recolonized. However, unionids that have zebra mussels removed repeatedly maintain higher glycogen stores (Hallac and Marsden 2001) and show increased survival (Schloesser 1996, Hallac and Marsden 2001). If muskrat predation on zebra mussels is recurrent on individual unionids, it could have a positive impact on unionid survival, assuming that unionids are discarded in suitable habitat, and are not eventually eaten by muskrats. Nonetheless, the muskrat's apparent preference for zebra mussels over native unionids may effectively reduce muskrat predation on unionids when zebra mussels are numerous.

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