Occurrence of the Quagga Mussel (*Dreissena bugensis*) and the Zebra Mussel (*Dreissena polymorpha*) in the Upper Mississippi River System

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ABSTRACT

The quagga mussel (*Dreissena bugensis)* was first found in the Ohio River and the upper Mississippi River in the mid-1990s. It has since gone unreported in the Mississippi River system possibly due in part to its phenotypic variability and close morphological resemblance to the more commonly occurring zebra mussel (*Dreissena polymorpha).* Sampling of the upper Mississippi River system during 2004-2006 revealed that the quagga mussel occurred at several localities outside its previously reported distribution in the Ohio River and upper Mississippi River. Few zebra and no quagga mussels were found in the Missouri River. Quagga mussels were not abundant in our survey, comprising less than 1% of identifiable *Dreissena* specimens.

INTRODUCTION

The zebra mussel (*Dreissena polymorpha)* and quagga mussel (*Dreissena bugensis)* are endemic to the Ponto-Caspian region in Eurasia (Starobogatov 1994, Orlova et al. 2004). Both species were discovered in the late 1980s in the Laurentian Great Lakes of North America (Vanderploeg et al. 2002). First observed in Lake St. Clair in 1988 (Hebert et al. 1989), the zebra mussel rapidly expanded its range, invading all the Great Lakes by 1990, and the Illinois River, upper Mississippi River, and Hudson River the following year (Vanderploeg et al. 2002). The quagga mussel was first collected in Lake Erie in 1989 and by 1993 had spread throughout the lower Great Lakes and the St. Lawrence River (May and Marsden 1992, Mills et al. 1993, 1996, Vanderploeg et al. 2002, USGS 2008).

Both *Dreissena* species are similar in their habitat requirements and apparently occupy a similar niche (Thorp et al. 2002, Karatayev et al. 2007). Yet, despite its dispersal abilities, the quagga mussel has become established in far fewer water bodies in North America and Eurasia than has the zebra mussel (Vanderploeg et al. 2002, Orlova et al. 2004). Several factors may limit the distribution of dreissenids (cf., Karatayev et al. 1998, Thorp et al. 2002), but the lack of quagga mussel records may be, in part, a consequence of limited sampling effort and misidentification of quagga mussel specimens as zebra mussels.

The quagga mussel was found in the Ohio River in 1994 (Brence and Miller 1994) and the upper Mississippi River in 1995 (Krumanocker 1996, USGS 2008). These findings suggested that the future colonization of these rivers by *D. bugensis* was imminent. In following years, however, the quagga mussel has apparently gone

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undetected in the upper Mississippi River basin. We made extensive benthic surveys of the upper Mississippi River, the Missouri River, and the Ohio River in 2004, 2005, and 2006. We here document the expanded distribution of the quagga mussel in the great rivers of the upper Mississippi River system. We also present data on the substrate-specific abundance of *Dreissena* species in these river relvant to aquatic ecosystem monitoring.

METHODS

Collections were made during July through September in 2004, 2005, and 2006 (Table 1). There were 447 sampling sites, and some were visited more than once. Sites were selected using a probabilistic sample design (Angradi et al. in press). Extent of sampling was similar in 2004 and 2005. In 2006, sites were located in reaches of each river considered likely to be in least disturbed condition based on landscape-scale data and professional judgment. River kilometers (rkm) refer to the actual distance along the river centerline from the mouth of the river or from the confluence with the Ohio River in the case of the upper Mississippi River. The upper Mississippi River was sampled to rkm 1402; the Missouri River to rkm 2833 (but excluding main stem reservoirs); the entire length of the Ohio River was sampled.

Samples were collected at each site by fixed-area kicking into a 500-µm mesh dip net in the main-channel littoral zone to a depth of about 0.5 m and by brushing the upper surface of a snag in the main channel into a 500-µm mesh net. Snags were typically tree trunks embedded in the river bottom and projecting into the water column. Bottom and snag surface area sampled during each site visit were about 5.7 and 0.5 m^2, respectively. Samples were preserved in 10% carbonate-buffered formalin. See Angradi (2006) for additional sampling details.

In the laboratory, mussels were separated from other material under magnification, identified to species when possible, and enumerated. Identifiable specimens were assigned to *D. polymorpha* or *D. bugensis* based upon the examination of shell characters (Pathy and Mackie 1993, Claxton et al. 1997). Approximately 20 mussels with an unclear color pattern were dissected and examined for the presence of an apophysis on the myophore plate, a character present in the dark false mussel (*Mytilopsis leucophaeata*), which has been reported from the upper Mississippi River (Pathy and Mackie 1993). None was found. Representative voucher specimens of both dreissenid species were

Table 1. Summary of dreissenid collections examined for the presence of quagga mussels (*Dreissena bugensis)* and zebra mussels (*Dreissena polymorpha)* in the upper Mississippi River and Ohio River in each year of sampling. Unidentified, settled juveniles of *Dreissena* were found at two sites in the Missouri River in 2005.

River	Year	*Dreissena* collected	*Dreissena bugensis* (%)	*Dreissena polymorpha* (%)	Unidentified *Dreissena* (%)
Upper Mississippi	2004	523	0.2	50.9	49.0
	2005	996	0.3	38.6	61.1
	2006	306	3.9	77.1	19.0
Ohio	2004	488	0.6	29.5	69.9
	2005	3556	0.1	49.8	50.1
	2006	1110	0	35.0	65.0

deposited into the Field Museum of Natural History, Chicago, Illinois.

RESULTS AND DISCUSSION

Both dreissenid species were collected in the upper Mississippi River system. We examined 6990 *Dreissena* individuals, of which >45% were identified as zebra mussels and <1% as quagga mussels (Table 1). We confirmed the identity of one quagga mussel specimen previously identified by shell characters using the mitochondrial DNA sequencing method described by Stepien et al. (2005). The remaining (54%) mussels were too small or were damaged and could not reliably be identified to species.

We found quagga mussels in all years (2004-2006) in the upper Mississippi River (Fig. 1). Sixteen individuals (<13 mm long) were collected (Table 2). Fourteen *D. bugensis* were found attached to main channel snags sampled at five sites in four navigation pools between rkm 1052 and 1264. These records extend upriver the previously reported upper Mississippi River distribution for this species (Fig. 1), which was heretofore known only from below rkm 750 (Krumanocker 1996, USGS 2008).

In the Ohio River, three specimens of *D. bugensis* were collected at rkm 750 in 2004 and two individuals were found in the lower river (at rkm 168 and 448) in 2005. All collected individuals were <12 mm long, and the maximum density was 9 mussels m^{-2}.

Despite a much greater sampled area (5.7 vs. 0.5 m^2 at each site), only six (29%) quagga mussels were found in benthic samples, with the other 15 collected from the surfaces of snags (Table 2). *Dreissena bugensis* occurred at a low population density with

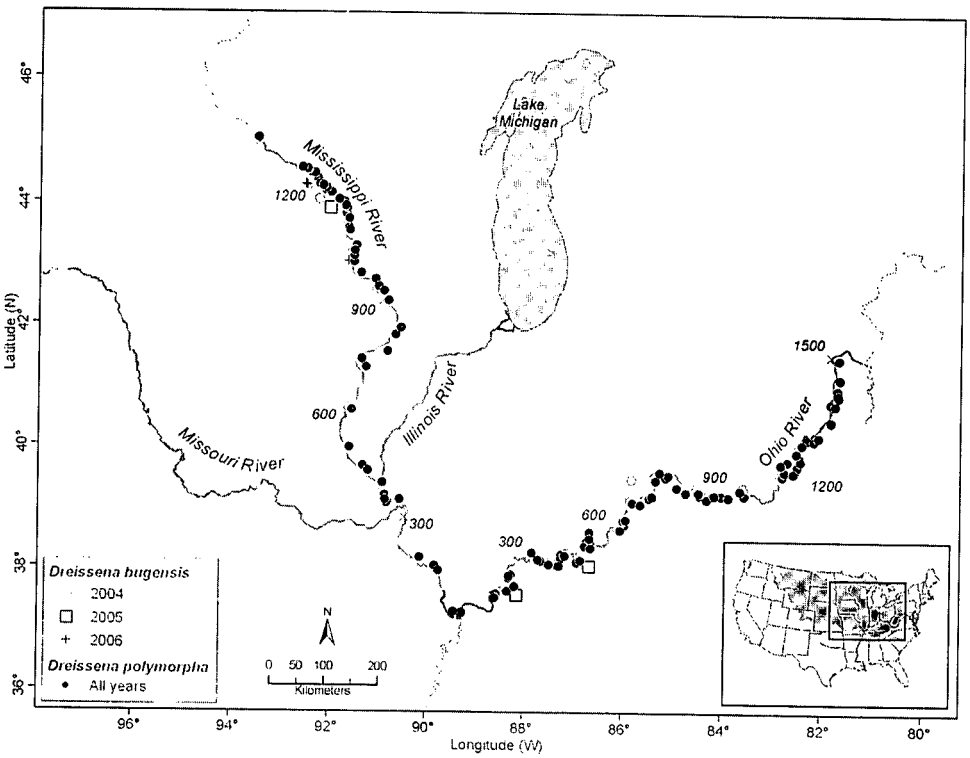

Figure 1. Collection locations of quagga mussel (*Dreissena bugensis)* and zebra mussel (*Dreissena polymorpha)* in the upper Mississippi River and Ohio River. Shaded area of inset map is drainage for the upper Mississippi River. Numbers are rkm. Only a few unidentifiable *Dreissena* specimens were collected from the Missouri River. See text for locations of Missouri River collections.

the exception of one Mississippi River snag with an estimated density of 118 mussels m^{-2} on its upper surface.

The density of *Dreissena* species was, in general, higher on snags than in the littoral benthos (Table 3). The frequency of occurrence was, however, higher in kick samples than snag samples due to the greater bottom area sampled at each site. In the littoral benthos, *Dreissena* spp. density was higher at sites dominated by coarse substratum than at sites dominated by fine substratum.

The zebra mussel was widely distributed throughout the upper Mississippi River and Ohio River (Fig. 1) but was nearly absent from the Missouri River. In 2005, we only collected eleven unidentifiable, settled juveniles of *Dreissena* in the Missouri River at sites 770 and 1111 rkm. Zebra mussels have previously only been reported from above rkm 1150 on the Missouri River in 1999 (a 24-mm adult) and 2003 (veligers) (USGS 2008).

Our estimates of zebra mussel density in the upper Mississippi River and Ohio River were lower than previously reported by Cope et al. (1997) who sampled mussels using concrete-block substrates and Payne and Miller (2002) who sampled using divers. The difference probably reflects methodological differences since our sample design and collection methods were not optimized for mussels but were designed to collect a representative semi-quantitative sample of all littoral (<0.5 m deep) and snag-surface invertebrates.

We collected large zebra mussels (15-26 mm) in the upper Mississippi River and Ohio River. We did not collect any quagga mussels in this size range. Consistent with the absence of large individuals or shells, the occurrence of quagga mussels in the main channel of the upper Mississippi and Ohio Rivers is likely the result of recruitment of propagules produced elsewhere (e.g., from tributaries or Great Lakes sources), rather than by self-sustaining local populations. The quagga mussel has been in the upper Mississippi River systems for over 10 years but apparently remains at the early colonizing stage.

Field observations and mesocosm experiments (Thorp et al. 2002) have shown that both the zebra mussel and the quagga mussels can survive in large rivers that lack infested upriver impoundments. The species are apparently similar in their habitat requirements (Karatayev et al. 2007). Thorp et al. (2002) concluded that there were probably no ecological barriers to quagga mussel establishment in habitats colonized by zebra mussels. Models of ship-mediated species introductions predicted quagga mussel dispersal from the heavily infested lower Great Lakes into the upper Mississippi River system (Allen and Ramcharan 2001). The appearance of quagga mussels at disjunct localities in the Illinois River, Ohio River, and Mississippi River (Fig. 1) implicates river shipping as the most likely mechanism of introduction.

Table 2. Collection records for quagga mussels (*Dreissena bugensis*) in the upper Mississippi River (MS) and Ohio River (OH). Number recovered is the number of quagga mussel specimens recovered in sorted subsamples from each site.

Site ID	River	Latitude N	Longitude W	Approx. river km (rkm)	Year	Navigation pool	Sample type	Number recovered	Approx. density (# m^{-2})
1006	MS	43.06741	91.17368	1052	2006	10	Snag	1	7.8
297	MS	43.88597	91.33076	1161	2004	7	Snag	1	4.6
280	MS	44.11871	91.71088	1207	2005	5	Snag	3	59.0
1005	MS	44.41298	92.11111	1261	2006	4	Snag	9	117.7
1037	MS	44.42855	92.16727	1264	2006	4	Kick	2	7.1
0084	OH	37.48551	88.06951	168	2005	Smithland	Kick	1	7.1
0091	OH	37.95282	86.51153	448	2005	Cannelton	Snag	1	9.1
0007	OH	38.90508	84.87156	750	2004	Markland	Kick	3	1.1

With the appearance of the second dreissenid species in North American waterways in the 1990s, the morphological identification of dreissenid species became more difficult. Part of the problem stems from intraspecific phenotypic variability and overlap between *D. polymorpha* and *D. bugensis* in several shell characters (Claxton et al. 1997). The application of genetic techniques can alleviate this problem (May and Marsden 1992, Claxton et al. 1997). For example, the DNA sequencing technique of Stepien et al. (1999, 2005) clearly differentiates between the species.

Cryptic colonization by quagga mussels may delay its detection. In reservoirs on the Dniester River and Volga River, the quagga mussel remained undetected or misidentified as zebra mussels for at least six years (Shevtsova and Grigorovich 1998, Orlova et al. 2004). In the Don River drainage it was overlooked for 17 years (Zhulidov et al. 2004). In some habitats in North America and eastern Europe the quagga mussel has been replacing the zebra mussel at later stages of infestation (c.f., Vanderploeg et al. 2002). Therefore, the early detection of quagga mussel invasions is necessary for understanding the aquatic community dynamics in the upper Mississippi River system.

Table 3. Mean *Dreissena* spp. density (mussels m^{-2}) by sample type and observed dominant substrate (pooled across years) at littoral kick sample locations. Frequency is the percentage of samples with *Dreissena* spp. (both species combined).

River	Year	Density (±SE) by sample type (Sample size, frequency)		Density (±SE) by dominant littoral substrate (Sample size)			
		Littoral kick	Snag surface	Fines (≤0.6 mm)	Sand (>0.6–2 mm)	Gravel (>2–64 mm)	Cobble and larger (>64 mm)
Upper Mississippi	2004	11.1±4.2 (54, 50)	3.6±0.7 (47, 23)				
	2005	8.9±3.7 (64, 51)	152.4±144.2 (71, 16)	1.5±0.5 (44)	1.4±0.4 (63)	15.9±9.3 (19)	18.2±5.9 (45)
	2006	1.7±0.07 (54, 35)	62.0±53.3 (53, 26)				
Ohio	2004	12.7±7.1 (38, 45)	14.7±5.5 (37, 50)				
	2005	65.5±27.9 (75, 57)	94.3±30.1 (75, 69)	24.7±13.4 (45)	20.8±6.2 (73)	67.6±59.1 (17)	193.9±143.8 (12)
	2006	20.6±7.4 (34, 62)	162.6±149.0 (34, 41)				

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