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Aquatic Invasions Records

First records of *Dreissena rostriformis bugensis* (Andrusov, 1897) in the Meuse River

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Abstract

The aim of this paper is to present the first data on the colonization of the Meuse River by the quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897). During our study, the quagga mussel was found at several locations in the Dutch and Belgian section. Both quagga and zebra mussels (*Dreissena polymorpha* Pallas, 1771) were sampled and the species identity was confirmed by morphological analysis. Plausible dispersion patterns and colonization routes of *D.r. bugensis* in the Meuse River are suggested.

Key words: Molluscs, Bivalves, *Dreissena*, invasive species, Meuse River

Introduction

River basins are conducive to invasions because they form corridors that facilitate rapid spread of introduced species. The reinforced river bank and the whole river bed are disturbed habitats considered as most favourable to the invasion (Beisel and Lévêque 2010). The Meuse River is particularly vulnerable to invasive species; firstly because the river has been highly altered by anthropogenic pressures (e.g. artificial banks, construction of weirs, dense navigation) and secondly it is connected through the Meuse-Waal Canal in The Netherlands and the Albert Canal in Belgium to the major European rivers Rhine and Danube and to European main ports (Rotterdam and Antwerp). Invasive macro-invertebrates not only impact on both aquatic ecosystems and biodiversity, but in addition biofouling invaders are able to negatively influence industrial activities (Mack et al. 2000; Schmidlin and Baur 2007). The best-known example is the invasion of Western Europe and North America by the zebra mussel, *Dreissena polymorpha* (Pallas, 1771) (e.g. Nalepa and Schloesser 1992; Van der Velde et al. 2010 and literature therein), which is present in the Meuse River as well. In the meantime, a second dreissenid species, the quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) (Figure 1) recently became invasive in both the Old and New World (Mills et al. 1996; Son 2007 and literature therein).

The quagga mussel is native to the Dnieper delta (Son 2007). Since 1930, the species extended its distribution range, first into the Ponto-Azov basin and Volga River (Romania, Moldavia, Ukraine, Russia) (Orlova et al. 2004; Zhulidov et al. 2005) and then into Eastern European Rivers (Zhulidov et al. 2010). The species apparently reached the Danube River in 2004 (Popa and Popa 2006), the Rhine River in 2006 (Molloy et al. 2007) and was found in its tributaries, the Main River in 2007 (Van der Velde and Platvoet 2007) and the Moselle River in 2010 (Bij de Vaate and Beisel 2011). In 2008 it was also reported from the Main-Danube Canal (Bij de Vaate 2010; Imo et al. 2010). Furthermore, the quagga mussel was found in Lake Erie in the US in 1989 and rapidly spread across all the Great Lakes, the Fingers Lakes and the rivers St. Lawrence, Ohio and Mississippi (Mills et al. 1996; Stokstad 2007; Grigorovich et al. 2008). Although both *Dreissena* species were

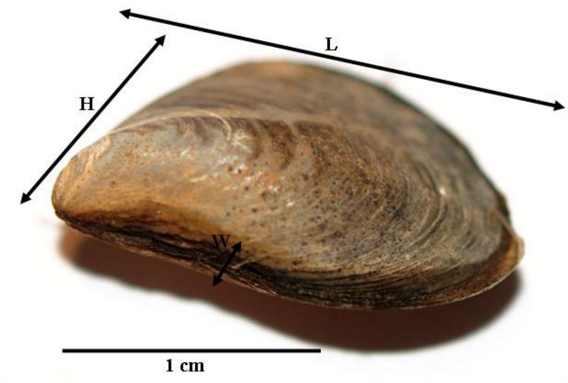

Figure 1. External view of the shell of *Dreissena rostriformis bugensis* (shell measurements: Length, Width and Height) (Photograph by J.Marescaux).

introduced to North America in the 1980s (Mills et al. 1993; Carlton 2008) spreading steadily outwards from the Great Lakes (USGS 2012), they were not reported in the Western United States until the new millennium. Quagga mussels were discovered in Lake Mead, Nevada in January 2007 (reviewed in Wong and Gerstenberger 2011) and zebra mussels were reported from San Justo Reservoir in central California in 2008 (USGS 2012). The first observation of the quagga mussel in Western Europe was made in 2006 in the Hollandsch Diep, a river stretch in the Rhine delta in the Netherlands (Molloy et al. 2007). Outside the Rhine basin, the quagga mussel was recently also found in the Meuse River (this study) and in the Albert Canal in Belgium (Sablon et al. 2010).

The first aim of this paper is to present the first data on the colonization of the Meuse River by the quagga mussel. The second aim is to compare quagga and zebra mussels in terms of shell morphology.

Methods and methods

Dreissena samples were collected in the Meuse River at 10 Dutch, 10 Belgian and 2 French locations (Table 1; Figure 2). The mussels were collected in the littoral zone of the reinforced river bank from solid substrates which were picked up manually from a depth of 30-40 cm. Individuals were preserved in absolute ethanol. Both *Dreissena* species, quagga and zebra mussels, were identified based on shell characteristics (Pathy and Mackie 1993; Mills et al. 1996; Sablon et al. 2010). Twenty individuals from each species and from each sampling site had their shell (Length, Width and Height) measured to the nearest mm (except for the French locations where we did not sample enough mussels). The results of these measurements were used to carry out a Principal Component Analysis (PCA) with R software (2.11.1) and the package ade-4 (University Lyon I, France) (Dray and Dufour 2007) in order to confirm the visual identification.

Results and discussion

Dreissenids were found at all sampling sites (Table 1; Figure 2). They were mainly attached to rip-rap but also to dead branches, and to *Corbicula* and Unionid shells. At all collected sites zebra mussels were present; which is not surprising given the fact that this species was discovered in the Meuse River, in the vicinity of the Belgian-Dutch border, in 1822 (Van Beneden 1835) and hence the population there is long established. Quagga mussels were collected for the first time at Sambeek in 2007 (site 6), in 2008 further upstream at Linne (site 9) and the species reached the town of Maastricht (site 10) in 2010. Sampling of the Belgian section in 2011 revealed the presence of quagga mussels at all sites investigated. Despite the sampling efforts at two locations in the French section of the river, only 2 and 11 dreissenids were found, respectively, at Givet and Ham-sur-Meuse, and all were zebra mussels. This is in line with the relatively low abundance (<10%) of quagga mussels at the most upstream site in the Belgian section (Waulsort, site 20).

The mean lengths of *D. polymorpha* (n=2248) and *D.r. bugensis* (n=1471) are 13.2 mm and 14.5 mm respectively. Despite high phenotypic plasticity, shell characteristics are often used to discriminate mollusc species. Both *Dreissena* species found in the Meuse River could be distinguished by a Principal Component Analysis (PCA) conducted on the shell length and on two morphometric ratios (length/height and length/ width) (Figure 1). The results indicate a near absence of overlap between quagga and zebra mussels suggesting a well-marked morphological distinction (Figure 3). Only five individuals presented discordance between our visual identification and the PCA result. These discordances are dependant on axis 2 corresponding to the ratio length/height (Figure 3). A Principal

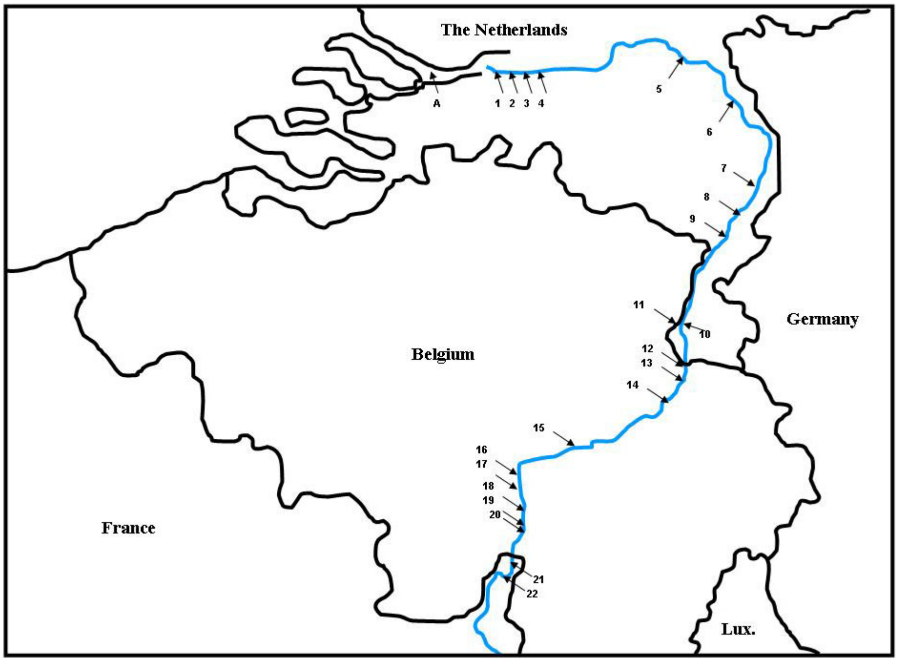

Figure 2. Expansion of *Dreissena rostriformis bugensis* in the Meuse River. Arrows indicate our sampling sites (1 to 22). The arrow A is the first record of the quagga mussel in Western Europe (Hollandsch Diep). See Table 1 for coordinates.

Table 1. Number of zebra and quagga mussels collected in the Meuse River during this study. The number in the first column referred to the number on Figure 1. Collector: * and ° represent respectively Bij de Vaate and Marescaux.

	Location	Coordinates of the sampling site		Collected individuals		Record date	Collector
		Latitude, N	Longitude, E	Zebra	Quagga		
1	Lage Zwaluwe (Amer River - Nl)	51° 43' 10"	04° 41' 33"	4	385	6/11/2008	*
2	Drimmelen (Amer River - Nl)	51° 42' 37"	04° 48' 25"	16	339	6/11/2008	*
3	Keizersveer (Bergsche Meuse - Nl)	51° 43' 10"	04° 58' 55"	NA	NA	2/05/2007	*
4	Dussen (Bergsche Meuse - Nl)	51° 43' 10"	04° 58' 55"	13	360	6/11/2008	*
5	Grave (Nl)	51° 45' 57"	05° 44' 13"	495	0	4/09/2007	*
	Grave (Nl)	51° 45' 55"	05° 44' 37"	156	3	11/09/2008	*
6	Sambeek	51° 38' 12"	05° 59' 24"	417	4	4/09/2007	*
7	Belfeld (Nl)	51° 18' 43"	06° 06' 24"	163	12	23/09/2008	*
	Belfeld (Nl)	51° 18' 43"	06° 06' 24"	8	327	21/10/2010	°
8	Roermond (Nl)	51° 12' 17"	05° 58' 47"	258	184	21/10/2010	°
9	Linne (Nl)	51° 10' 02"	05° 55' 11"	197	7	23/09/2008	*
	Linne (Nl)	51° 10' 02"	05° 55' 11"	172	389	6/07/2010	*
	Linne (Nl)	51° 10' 01"	05° 55' 09"	20	287	21/10/2010	°
10	Maastricht (outlet Juliana canal - Nl)	50° 52' 11"	05° 41' 58"	252	0	4/09/2007	*
	Maastricht (outlet Juliana canal - Nl)	50° 52' 11"	05° 41' 58"	380	0	23/09/2008	*
	Maastricht (outlet Juliana canal - Nl)	50° 52' 11"	05° 41' 58"	136	12	6/07/2010	*
	Maastricht (Nl)	50° 51' 50"	05° 41' 40"	5	7	21/10/2010	°
11	Lanaye (Be)	50° 47' 18"	05° 41' 45"	51	15	24/01/2011	°
12	Lixhe (Be)	50° 45' 18"	05° 41' 01"	23	17	25/01/2011	°
13	Hermalle-sous-Argenteau (Be)	50° 42' 28"	05° 40' 45"	10	27	25/01/2011	°
14	Ile Monsin (Be)	50° 39' 10"	05° 38' 17"	31	1	28/01/2011	°
15	Gives (Be)	50° 30' 21"	05° 08' 49"	34	1	17/02/2011	°
16	Tailfer (Be)	50° 24' 01"	04° 52' 59"	1272	31	9/06/2011	°
17	Rivière (Be)	50° 21' 39"	04° 52' 25"	33	15	5/07/2011	°
18	Houx (Be)	50° 17' 45"	04° 53' 49"	32	3	5/07/2011	°
19	Anseremme (Be)	50° 14' 20"	04° 54' 28"	35	10	5/07/2011	°
20	Waulsort (Be)	50° 12' 01"	04° 51' 15"	70	4	14/07/2011	°
21	Givet (Fr)	50° 08' 45"	04° 49' 59"	2	0	14/07/2011	°
22	Ham-sur-Meuse (Fr)	50° 06' 42"	04° 46' 16"	11	0	14/07/2011	°

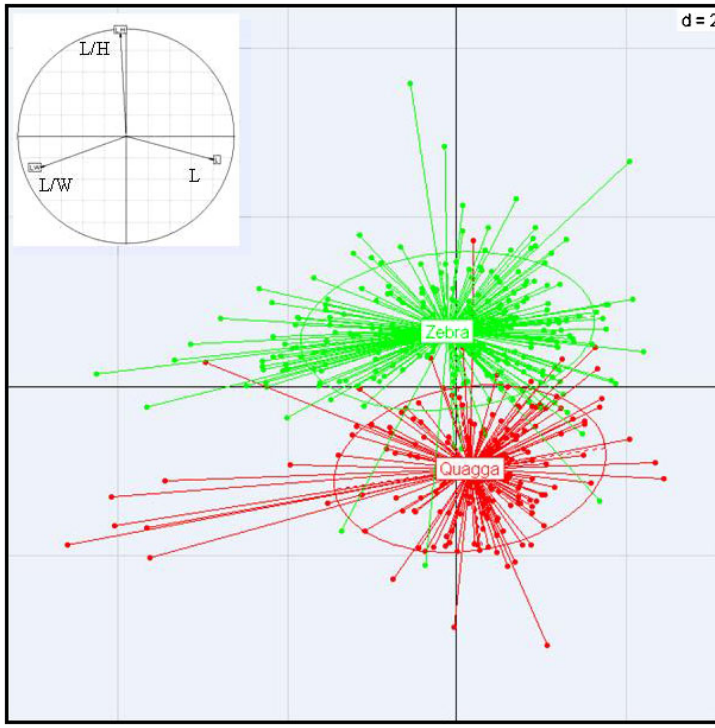

Figure 3. Relationship between scores on Axis 1 and Axis 2 for the Principal Component Analysis for shell measurements on 263 individuals (zebra (n=249) in green and quagga (n=177) in red).

Component Analysis has already been used to distinguish the lineages within *Corbicula* clams and between both *Dreissena* species (Claxton et al. 1998; Pigneur et al. 2011). The method allows a distinct separation of species with nearly similar morphologies. Moreover, the large size of some quagga mussels sampled (maximum 26.9 mm) suggests that the species was present in the Belgian part of the river for at least three years. Indeed, *D.r. bugensis* has an average life span of 3-5 years reaching sizes up to 4 cm (Benson et al. 2011).

We highlight here the co-distribution of the two dreissenid species and the rapid colonization of the Meuse River by the quagga mussel in upstream direction. The invasion of this species seemed to start in the Hollandsch Diep in 2006 (Molloy et al. 2007) in which the Meuse River discharges, and since its discovery it has colonised this river approximately 400km in an upstream direction. The downstream dispersal rate of the quagga mussels in the Volga River is estimated at nearly 700km/year (Orlova et al. 2004), much higher than that reported in the Laurentian Great Lakes (USA) (Mills et al. 1996). In the US, the zebra mussel spread through a combination of passive larval drift and "jump" dispersal (Johnson and Padilla 1996; Johnson et al. 2001). An explanation for the upstream dispersion in the Meuse River is that *D. r. bugensis* presents a "jump" dispersion pattern. Biological features (high phenotypic plasticity, high larvae dispersal rate, high fecundit) could not explain the rapid upstream dispersal of *D. r. bugensis* in Meuse River and we therefore suppose that human activities, such as commercial and recreational navigation, are playing a great role in the propagation of this species.

Following the recent distributional observations of the quagga mussel in Europe, two plausible colonisation routes have been proposed for this invasive species. The first hypothesis is that the quagga mussel invaded Western Europe through a southern corridor formed by the Danube River, Main-Danube Canal and Rhine River (Bij de Vaate et al. 2002). Since the opening of the Main-Danube Canal in 1992, this corridor has been a pathway for the westerly spread of several Ponto-Caspian macro-invertebrate species (Bij de Vaate 2002). Observations on colonization of the Danube River in an upstream direction underlines this hypothesis (Molloy et al. 2007 and literature therein). The gap between the most upstream location where the species was found around

2004 and the Rhine basin could have been overcome by jump dispersal. The second hypothesis highlights the species introduction in the Hollandsch Diep (Figure 1) followed by upstream range expansion in both the Rhine and Meuse basin (Bij de Vaate 2010). Both invasion corridors could be plausible colonisation routes of *D. r. bugensis* in the Meuse River. Although it is suspected that *D. r. bugensis* entered via the Main-Danube canal, the invasion of The Netherlands and Belgium by the quagga mussel may also have been caused by discharge of ballast water from the Black Sea area or from the Great Lakes in the Rotterdam Port (Molloy et al. 2007; Van der Velde et al. 2010). In addition, we also propose a third colonisation route for the invasion of *D. r. bugensis* in the Belgian section of the Meuse River. During sampling we observed high densities of the quagga mussel in the Ham Kwaad Mechelen lock on the Albert Canal (maximum density of 45900 individuals per square meter). We therefore suspect that invasion occurred via a discharge of ballast water into the port of Antwerp with a subsequent colonization of the Albert Canal that is connected to the Meuse River at Lanaye. Genetic analysis of *D. r. bugensis* using both mitochondrial DNA and microsatellites may allow us to clarify their invasion corridor or corridors into the Meuse River. These data give a first overview of the rate of spread of quagga mussels in Western Europe and will be useful for any future monitoring of macroinvertebrates in the Meuse River.

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