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Short communication

Some evidence for ballast water transport being the vector of the quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) introduction into Western Europe and subsequent upstream dispersal in the River Rhine

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Abstract

Sampling in May 2008 by the author in the Main-Danube canal (Germany) as well as earlier sampling by Van der Velde and Platvoet (2007) indicated that the quagga mussel introduction into Western Europe was not the result of range expansion from its native range through the River Danube and subsequently the Main-Danube canal and River Rhine, as previously suggested.Ballast water transport and release in the Hollandsch Diep, a section of one of the distributaries in the Rhine delta (The Netherlands), is now considered the most likely vector and dispersal source.

Key words: introduction vector, Main-Danube canal, Rhine, Danube

The first observation of the quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897), in Western Europe was made in 2006 in the Hollandsch Diep, a river stretch in the Rhine delta, The Netherlands (Molloy et al. 2007). Molloy et al. (2007) suggested that range expansion via the River Danube and the Main-Danube canal was the reason for colonization of the Rhine basin, since earlier publications (Micu and Telembici 2004; Popa and Popa 2006) indicated upstream migration in the River Danube. Before 2007 several Ponto-Caspian macroinvertebrate species succeeded in colonizing the Rhine basin via this route, connecting the river basins of the Danube and Rhine (Bij de Vaate et al. 2002). Moreover, in 2007 Van der Velde and Platvoet (2007) found quagga mussels in the River Main, a tributary in the Rhine basin. However, results of *Dreissena* sampling in the Main-Danube canal in 2008, combined with the earlier observations by Van der Velde and Platvoet (2007), showed the colonization of the River Rhine by the quagga mussel in a different light: not by range expansion from the River Danube into the Rhine basin via the Main-Danube canal but the other way round with a first colonization through ballast water of sea-going vessels in the Hollandsch Diep and the subsequent dispersal towards the rivers Rhine and Main and the Main-Danube canal.

The Main-Danube canal was opened for navigation in 1992 (Bij de Vaate et al. 2002). The canal crosses the Fränkische Alb, from north to south starting at an altitude of 242 m at Bamberg, going up to a maximum altitude of 406 m in the section Hilpoltstein-Bachhausen and ending in the canalized River Altmühl (tributary of the River Danube) at an altitude of 347m at Kelheim. A longitudinal cross section of the canal is given in Figure 1. The water level in the upper section of the canal is maintained with water supplied from the Danube basin, resulting in an average discharge of Danube water into the Rhine basin of about 4.5 m^3s^{-1} (Tittizer 1997).

Dreissena species (*Dreissena polymorpha* (Pallas, 1771) and *Dreissena rostriformis bugensis* were sampled on May 24 and 25, 2008 at four locations in the canal (Table 1): two locations (Eckersmühlen and Hilpoltstein) in the Rhine basin (Rhine side) and two locations (Ottmaring and Dietfurt) in the Danube basin (Danube side). The mussels were cut from rip-rap in the littoral zone, picked up manually from a depth of 30-40 cm. All mussels collected had their shell lengths measured to the nearest mm.

The results showed a decrease in the southern direction of the Main-Danube canal in terms of relative abundance of quagga mussels in the *Dreissena* community (Table 1). Only one specimen of quagga mussels was found at the Danube side of the canal. In that part of the canal

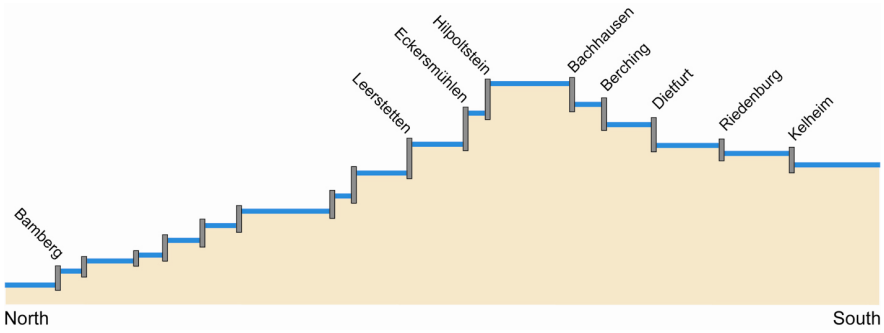

Figure 1. Longitudinal cross section of the Main-Danube canal.

Table 1. Number of zebra and quagga mussels collected in the Main-Danube canal in May 25-25, 2008.

Canal name	Canal section	Coordinates of the sampling site		Collected individuals	
		Latitude, N	Longitude, E	zebra mussels	quagga mussels
Eckersmühlen	Leerstetten-Eckersmühlen	49°12'45"	11°10'22"	502	27
Hilpoltstein	Eckersmühlen-Hilpoltstein	49°12'53"	11°12'15"	454	8
Ottmaring	Berching-Dietfurt	49°02'06"	11°33'10"	128	1
Dietfurt	Dietfurt- Riedenburg (Altmühl)	49°01'47"	11°34'16"	88	0

the *Dreissena* density at both locations sampled was substantially lower than at both locations situated in the Rhine side.

Although the total number of quagga mussels found in the *Dreissena* community was relatively low, the results may indicate that the quagga mussels colonized the canal in southern direction and not from the River Danube in northern direction. This means that most probably the quagga mussel was introduced into the Hollandsch Diep through ballast water transport of sea-going vessels. Such vessels regularly visit that river stretch since there is an important industrial zone on its left bank. Upstream migration in the River Rhine is subsequently facilitated by inland navigation vessels (Mayer et al. 2009); the river is one of the heaviest navigated rivers in the world. The quagga mussels simply attach to a ship's hull to hitch-hike in upstream direction (Haybach and Christmann 2009; Van der Velde and Platvoet 2007). In addition Van der Velde and Platvoet (2007) sampled dreissenids in the River Main, Main-Danube canal and River Danube. At that time they found quagga mussels only in the River Main including zebra mussels (*D. polymorpha*). In the Main-Danube canal and nearby River Danube only zebra mussels were found, which supports the hypothesis of dispersal from north to south of the quagga mussel towards the Main-Danube canal instead of the other way round.

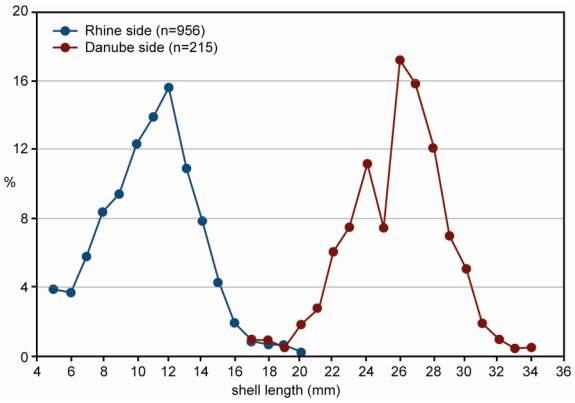

Figure 2. Length-frequency distribution of zebra mussels in the Rhine basin part of the Main-Danube canal (Rhine side) and in the Danube basin part (Danube side).

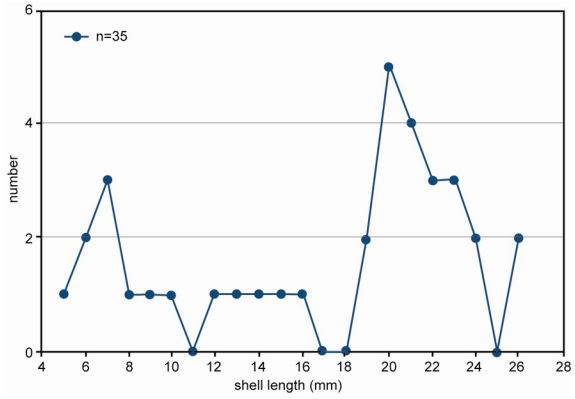

Figure 3. Length-frequency distribution of quagga mussels in the Rhine basin part of the Main-Danube canal (Rhine side).

Also range expansion of the quagga mussel from the Rhine basin into the Danube basin depends on navigation. This is in contrast to animals from the Danube basin, whose expansion in the Rhine basin is facilitated by Danube water supplied to maintain the water level in the upper section of the Main-Danube canal. The watershed supply to this canal not only led to differences in species composition of *Dreissena* species between the Rhine and Danube side but to differences in the population structure of zebra mussels as well. In terms of population structure remarkably, for both locations at the Rhine side specimens >20 mm shell length were absent, while at both sites at the Danube side specimens <17 mm were lacking (Figure 2). Based on the population structure of the quagga mussels (Figure 3) it can be concluded that the species was already present in the Main-Danube canal in 2007, assuming that the animals have about a similar growth rate as zebra mussels in the River Rhine (Smit et al. 1992). This means that quagga mussels >18 mm shell length could have been at least one year old when sampled in May 2008.

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