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SHORT COMMUNICATION

The quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) — another Ponto-Caspian dreissenid bivalve in the southern Baltic catchment: the first record from the Szczecin Lagoon☆

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Summary In 2014, a non-indigenous dreissenid bivalve, the quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) was for the first time recorded in the Szczecin Lagoon. This was also the first record of the species in the Baltic Sea catchment. The quagga mussel was found to accompany the zebra mussel (*Dreissena polymorpha*), a non-indigenous bivalve already firmly established in the Lagoon. As indicated by the new immigrant's estimated abundance (4000.0 ± 355.44 ind. m^{-2}) and the zebra mussel to quagga mussel abundance ratio (about 60:40), the immigration of *D. rostriformis bugensis* to the Lagoon can be regarded as successful. The quagga mussel has already formed a strong and reproducing population which co-occurs with that of the zebra mussel in the area.

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1. Introduction

In addition to the zebra mussel (*Dreissena polymorpha* Pallas, 1771), the quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) is another Ponto-Caspian dreissenid bivalve which has colonised freshwater reservoirs of Europe and North America (Karatayev et al., 2015; Nalepa and Schloesser, 2013; Orlova et al., 2004, 2005; Zhulidov et al., 2010). *Dreissena rostriformis bugensis* is a species native for the entire area of the southern Bug River and Dnieper River catchment in Ukraine (Orlova et al., 2004, 2005). The bivalve began expanding its range in eastern Europe as late as post 1940, when the first dam reservoirs were built on the Dnieper River. Between 1940–1990, *D. rostriformis bugensis* was seen to expand in three major direction: to the north, along the cascade of the Dnieper River dam reservoirs; to the east, via the River Don system, and thence to the north, through the reservoirs on the Volga; and to the north-west, through the Dniester River (Mills et al., 1996; Orlova et al., 2004, 2005; Zhulidov et al., 2010). In 2004, *D. rostriformis bugensis* was recorded in the Romanian part of the Danube River system (Micu and Telembici, 2004; Popa and Popa, 2006). Concurrently, in 1989, the species was first recorded in the Laurentian Great Lakes of North America (Benson, 2013; Mills et al., 1993). The quagga mussel invasion there closely followed that of the zebra mussel so the two species have been seen to expand their range in tandem (Benson, 2013; Karatayev et al., 2015). At present, the two species continue colonising the North American waters. In most of the newly colonised areas, the two congeners co-occur, but their within-water body distributions differ (Karatayev et al., 2015; Nalepa et al., 2010). The zebra mussel seems to be a more successful coloniser of the two, the number of water bodies it has colonised being 17 times higher than the number of water bodies colonised by the quagga mussel (Karatayev et al., 2015). In western Europe, the beginning of *D. rostriformis bugensis* expansion dates to 2006 when the species was recorded in the Rhine delta, in Hollandsch Diep in the Netherlands (Molloy et al., 2007; Schonenberg and Gittenberger, 2008). Subsequently, the species colonised the rivers Rhine and Mose (Haybach and Christmann, 2009; Imo et al., 2010; Karatayev et al., 2015; Matthews et al., 2014; Van der Velde and Platvoet, 2007). In 2007, the species was spotted in the River Main, a River Rhine tributary in Germany (Martens et al., 2007; Van der Velde and Platvoet, 2007), to be found — in 2011 — in the French part of the Mosel (Bij de Vaate and Beisel, 2011). In 2014, the species was first reported from the United Kingdom (Aldridge et al., 2014). At present, the quagga is observed to be spreading rapidly in inland waters of western Europe (Karatayev et al., 2015; Matthews et al., 2014). The western European population's site closest to the Baltic Sea catchment is in the Elbe, that of the eastern European population closest to the Baltic Sea inhabiting the Prypyat River (Schoell et al., 2012).

Here, we are reporting on finding the quagga mussel in the Szczecin Lagoon (Odra River estuary, southern Baltic Sea), thus providing the first record of the species in the Baltic Sea catchment.

The Szczecin Lagoon (Fig. 1), divided into two parts: the Small Lagoon (Kleines Haff) located almost entirely within Germany and the Great Lagoon (Wielki Zalew) on the Polish side of the Polish-German border bisecting the Lagoon, forms a major part of the River Odra estuarine system. Fed by the Odra River from the south and connecting with the Pomeranian Bay (southern Baltic Sea) in the north, the Lagoon is a typical brackish transitional water body the hydrographic regime of which is shaped by an interplay of fresh water discharged by the Odra River and the periodic intrusions of about 7 PSU sea water from the Baltic Sea. As a result, the Lagoon's salinity ranges from 0.3 to 4–5 PSU and averages 1.4 PSU (Radziejewska and Schernewski, 2008). The Lagoon's mean and maximum natural depths are 3.8 and 8.5 m, respectively, a channel dredged along the length of the Great Lagoon being deeper (up to 10.5 m). The bottom in the central part of the Great Lagoon is covered by mud, usually found at depths of 4.5–5.5 m; the muddy parts are surrounded by a belt of sandy shallows 1–1.5 m deep which slope steeply towards the muddy bottom (Wolnomiejski and Witek, 2013). The shallows themselves, and their slopes in particular, support dense aggregations of the zebra mussel (*D. polymorpha*), one of the most important component of the Great Lagoon biota (Radziejewska and Schernewski, 2008; Wiktor, 1969; Wolnomiejski and Witek, 2013). There is no information on the timing of the zebra mussel's original settlement in the Szczecin Lagoon. The very first scientific publication about Lagoon's biota (Brandt, 1896) mentions only the “very dense aggregations” of the bivalve.

The Lagoon has been exposed to a heavy anthropogenic pressure manifested through a high level of eutrophication of the main basins, with all the negative consequences of the

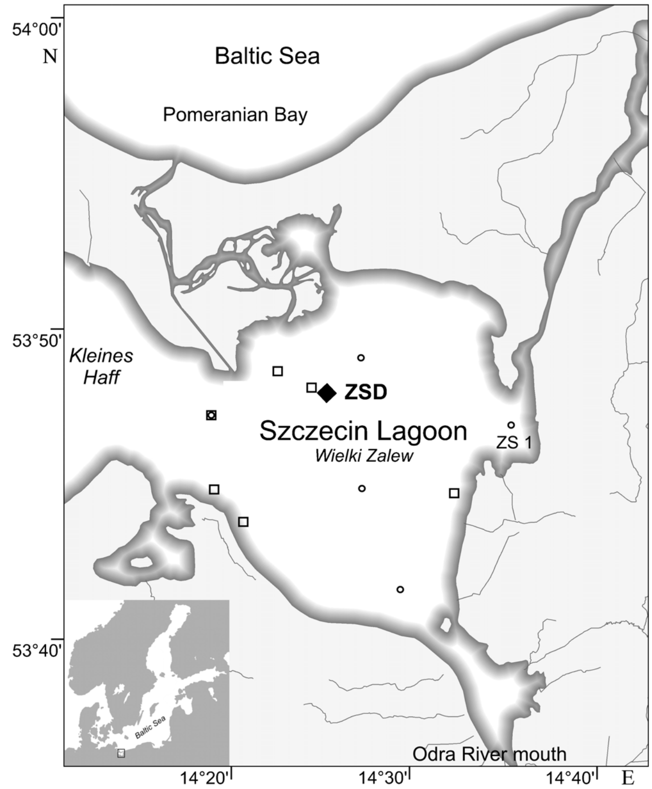

Figure 1 The study area and location of sampling sites. (□) sites of dredge and Van Veen grab sample collection on 10 October 2014; (○) sites sampled monthly within the project framework; (◆) Station ZSD, the site of the November 2014 sample.

process (Radziejewska and Schernewski, 2008). It is also an area of intensive ships' traffic, the ships using two large ports in Świnoujście and Szczecin (the latter accessed via the channel mentioned). The Odra River and a network of canals connect the Lagoon with the system of European waterways, including catchments of the rivers Vistula and Elbe and, indirectly, with those of the rivers Rhine and Danube. The consequence of the Lagoon's location and heavy ships' traffic is a high proportion of non-indigenous species in the biota (Gruszka, 1999; Radziejewska and Schernewski, 2008; Wawrzyniak-Wydrowska and Gruszka, 2005; Wolnomiejski and Witek, 2013; Woźniczka et al., 2011) which use the Lagoon as a gateway to the Baltic Sea basin (Gruszka, 1999).

2. Material and methods

Individuals identified as *D. rostriformis bugensis* were first encountered on 10 October 2014 in a sample of bivalves collected from the Lagoon to resolve doubts regarding the identity of unusual, non-typical zebra mussel-like individuals, found in earlier benthos samples from locations with bottoms covered by the zebra mussel and in fish trawls (B. Wawrzyniak-Wydrowska, A. Woźniczka, pers. obs.). Subsequently, qualitative samples were collected with a bottom dredge, quantitative samples being retrieved with an 0.1 m^2 Van Veen grab from areas known for the abundant presence of *D. polymorpha* (Fig. 1). The study was subsequently extended to include samples collected in the framework of a research project aimed at investigating historical and contemporary aspects of the Lagoon's sedimentary communities dynamics under the influence of intensive deposition of phytal organic material from the water column (Radziejewska et al., in prep.). The project involved monthly (April—November 2010—2014) sediment sampling at 5 stations located throughout the Lagoon (Fig. 1), differing in their hydrographic regime. In November 2014, additional samples were collected from Station ZSD (Fig. 1) in the northern part of the Lagoon to obtain enough material with which to check the earlier identification of *D. rostriformis bugensis*. Those samples were collected with a 625 cm^2 Van Veen grab. Contents of all grabs were sieved on an 0.5 mm mesh size sieve; the sieve residue was preserved in buffered 10% formalin and sorted in the laboratory. The quagga mussel individuals found were measured to 1 mm with a calliper.

3. Results

The individuals first identified as representing *D. rostriformis bugensis* were collected on 10 October 2014 in the northern part of the Szczecin Lagoon (sites denoted with squares in Fig. 1). They were present in all the samples and co-occurred there with the zebra mussel (*D. polymorpha*) to form mixed aggregations.

The identification of *D. rostriformis bugensis* was based on examination of shell characters (May and Marsden, 1992; Mills et al., 1996; Pathy and Mackie, 1993). The following features were regarded as diagnostic (cf. Fig. 2): the shell triangular in outline; distal part of the shell rounded; a rounded triangular carina between the ventral and dorsal surfaces; ventral side of the shell convex, without any sharp ventro-lateral ridge; dorsal side flat, also with a rounded margin, frequently with an ala-like distension; the two shells distinctly asymmetric; the proximal part of the right shell curved mid-ventrally; umbone (the thickest and oldest part of the shell) pointed and directed downward; byssus grove on the lower part of the shell very fine, located close to the

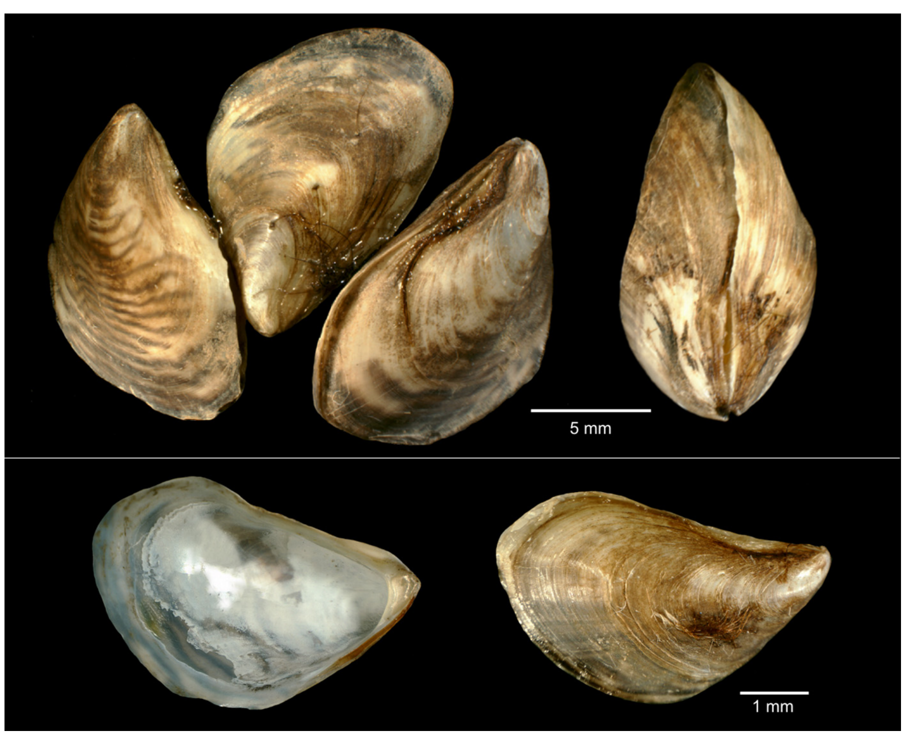

Figure 2 Quagga mussel individuals collected at Station ZSD (cf. Fig. 1) in the Szczecin Lagoon.

hinge; periostracum variously coloured (from light brown-yellow to totally black) with dark concentric rings variously shaped and sized and lighter-coloured rings found close to the hinge; shells of some individuals may differ in colouration of the latero-ventral and latero-dorsal side. The apical septum is located inside the proximal part of the shell; it serves as a myophore plate (an attachment site) for the anterior pedal retractor and the anterior shell adductor. The dorsal margin features two elongated scars left by the posterior adductor and posterior byssal retractor. In the proximal part, the shells are connected with the ligament. The hinge teeth are residual.

The samples collected in November 2014 made it possible to estimate the abundance and proportions of the two dreissenids and to determine the size structure of *D. rostriformis bugensis*. The ZSD samples yielded mixed aggregations of the dreissenids. The mean abundances of *D. polymorpha* and *D. rostriformis bugensis* in the area (+ standard deviation) were estimated at 6010.8 ± 446.05 and 4000.0 ± 355.44 ind. m^{-2}, respectively, and the zebra mussel to quagga mussel abundance ratio being estimated at about 60:40.

The *D. rostriformis bugensis* size structure was analysed on 1250 individuals collected at Station ZSD. The shell length was found to vary from 1.56–31.76 mm, 52.5% of the population being made up by small (shell length <7 mm) individuals.

4. Discussion

The data summarised above as well as observations made on other benthos samples and bivalves present in fish catches from the Lagoon allow to conclude that, at present, the quagga mussel is common and abundant throughout the Szczecin Lagoon (and the adjacent Kamieński Lagoon), and that it forms a strong, reproducing population there which co-occurs with that of *D. polymorpha*. It may be even argued that *D. rostriformis bugensis* has become a permanent component of the benthic biota in the Lagoon, and — together with *D. polymorpha* — it will play a major role in the functioning of the Lagoon's ecosystem. The high per cent contribution of *D. rostriformis bugensis* to the mixed dreissenid aggregations evidences the immigration success of the species and testifies to its being an able competitor for the stabilised zebra mussel population in the Lagoon. Interactions between the two species have been in the focus of numerous studies for some time (e.g., Karatayev et al., 2015; Nalepa et al., 2010; Quinn et al., 2014; Wilson et al., 2006). Both in the newly colonised reservoirs in North America and in the native central European locations, *D. rostriformis bugensis* has been observed to replace (in North America within a relatively short time of 5–10 years) the zebra mussel (Imo et al., 2010; Mills et al., 1996; Nalepa et al., 2010; Orlova et al., 2004; Ricciardi and Whoriskey, 2004; Zhulidov et al., 2004). A number of mechanisms have been put forth to explain the replacement in the Great Lakes. It has been suggested that one of the mechanisms involves genetic adaptations to new habitats, allowing expansion from deeper cold water to shallower, warmer habitats (Karatayev et al., 2011; Mills et al., 1996). Other authors suggest that *D. rostriformis bugensis* may begin to reproduce at temperatures lower than those needed by *D. polymorpha* to breed. Therefore breeding occurs earlier in the season, which confers a competitive advantage to the larval settlement (Claxton and Mackie, 1998; Roe and MacIsaac, 1997). Other hypotheses point to differences in filtration rates and in feeding and energy efficiency between the two species. According to Diggins (2001), *D. rostriformis bugensis* filtration rate is higher than that of *D. polymorpha*, again conferring a competitive advantage to the former, particularly when food resources are limiting. In addition, the energy efficiency of the quagga mussel is higher than that of the zebra mussel, which results in a higher growth rate at a high food concentration (Baldwin et al., 2002; Stoeckmann, 2003).

It is thus highly likely that *D. rostriformis bugensis* is well-equipped to substitute *D. polymorpha* in the Odra estuary. It is difficult to predict at present whether such replacement will in fact occur. Evidence from other areas (lakes) points to stabilisation of the co-occurrence of the two species in a lake on account of their depth-related spatial segregation (Karatayev et al., 2015). In reservoirs similar to the Szczecin Lagoon (shallow lakes and embayments) which support both species, the zebra mussel distribution is usually restricted to the littoral zone, while quagga mussel can be abundant in both the littoral and at larger depths (Karatayev et al., 2015). At the same time, the quagga mussel is known for its ability to settle on the muddy bottom, extremely inhospitable for the zebra mussel except for spots with hard elements enabling attachment (Karatayev et al., 2015). Therefore, taking into consideration the prevalence of muddy bottoms in the Szczecin Lagoon (Radziejewska and Schernewski, 2008), it may be expected that the quagga mussel will expand to the muddy bottom in the central part of the Lagoon, so far known only for occasional presence of the zebra mussel (Wiktor, 1969; Wolnomiejski and Witek, 2013). As a result, the dreissenid resources in the Szczecin Lagoon may be expected to increase, with potential consequences for the ecosystem functioning.

Observations made both in North America (Dermott et al., 2003; McMahon, 2011; Mills et al., 1993) and in Europe (Matthews et al., 2014) show that the domination of small individuals in *D. rostriformis bugensis* populations evidences an early stage of population growth. Bij de Vaate (2010) suggested individuals >18 mm found in the Rhine to have been at least 1 year old, while Imo et al. (2010) and Molloy et al. (2007) regarded the individuals they found in the Netherlands and in the Main, with shell lengths averaging 22.4 mm and reaching the maximum size of 27.5 mm, respectively, to have been at least 2 and 3 years old, respectively. As reported by Orlova et al. (2004) for the Volga River, *D. rostriformis bugensis* found in the area after it had colonised it in 1994 was represented by small (<2 mm) individuals; 4 years later (in 1996), however, the population included all the size classes up to the largest individuals with shells measuring 30 mm. As indicated by the shell length of the individuals found in the northern part of the Szczecin Lagoon (Station ZSD), they are about 3 years old, which means that the species arrived in the area at least 3 years prior to the first record. Examination of archived bivalve samples collected in 2010–2014 from the Skoszewska Cove in the eastern part of the Lagoon (Station ZS1 in Fig. 1) and stored in our laboratories revealed the presence of two quagga mussel individuals measuring 4.4 and 19.4 mm in an April 2013 sample, the November 2014 sample from that station yielding a

22.36 mm long individual. Thus, the data suggest that the bivalve is a recent immigrant in the area, the species being absent in samples collected from the Cove prior to 2013.

The vectors and mechanisms of the quagga mussel immigration into the Baltic Sea catchment are not known at present. An insight into the latter is expected from the genetic studies planned as the next step of the study. However, the most plausible is a hypothesis assuming quagga mussel dispersal from the sites it currently occupies in western Europe (Heiler et al., 2013; Matthews et al., 2014). It is also likely that the immigration proceeded via inland waterways (as was the case in *Hypania invalida*; Woźniczka et al., 2011) and from the sea, aided by ships. In the latter case, a reverse immigration from the Great Lakes cannot be ruled out (Heiler et al., 2013). Jump dispersal aided by ships operating in inland waterways and in the sea (Heiler et al., 2013) is most probable, because the nearest known sites supporting *D. rostriformis bugensis* are located in the Elbe River catchment (Heiler et al., 2013) and are beyond the potential of diffusive spread of the species. Considering the location of the Szczecin Lagoon with respect to various navigation routes, it may be assumed that the Lagoon will be a "stepping stone" for further expansion of the quagga mussel to areas populated at present by *D. polymorpha* (e.g., the Curonian Lagoon or the Neva Bay). Inland waters of central and eastern Europe may be another destination of a potential expansion. Owing to the high dispersal potential of the quagga mussel and serious effects the bivalve has produced in the water bodies it has colonised so far, including interactions with *D. polymorpha*, it seems necessary to monitor the species' progress in the Baltic Sea catchment.

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