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Biocontamination of the western Vistula Lagoon (south-eastern Baltic Sea, Poland)*

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Abstract

Non-native species exert considerable pressure on aquatic ecosystems; accordingly, they are treated as biopollutants. The Vistula Lagoon, one of the largest brackish water bodies in the Baltic, has become a part of the central corridor for hydrobionts migrating in the direction of western Europe and species expanding in inshore waters. Ten non-indigenous species of benthic invertebrates from five different biogeographical regions have been found in the western part of the Lagoon. Their considerable abundance relative to the numbers and abundance of native species testifies to the high level of biopollution there. The integrated biological

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contamination index (IBC) calculated for the macrobenthos in the western Vistula Lagoon was 4 and corresponds to the Lagoon's poor ecological status.

1. Introduction

The biodiversity of native fauna and flora in the Baltic Sea is relatively poor, with the pronounced dominance of alien species (AS) in a number of communities.

Currently, the Baltic Sea is undergoing large-scale biological reorganization. Being part of the central migration corridor, the Vistula Lagoon (VL) is a waterway by which euryhaline, freshwater and brackish water macroinvertebrates are able to invade the Baltic Sea. The first alien species (AS) turned up in VL in the 13th century, and in the 19th the rate of AS introductions accelerated, especially following the opening of canals linking the River Vistula with the Bug (Nowak 1971). According to the Baltic Sea Alien Species Database, 33 AS have been found in the brackish waters of VL, 27 of which are now firmly established (www.corpi.ku.lt/nemo/). In the context of the EU Water Framework Directive (European Community 2000), invasive AS represent a source of significant biological pressure.

The presence of AS, regardless of their negative ecological and/or socio-economic impact, can be regarded as biological contamination or biocontamination (Arbačiauskas et al. 2008, Panov et al. 2009). Five classes of biocontamination (SBCI – the site-specific biocontamination index and IBCI – the integrated biocontamination index) correspond directly to five ecological quality classes in the sense of the Common Implementation strategy for the EU Water Framework Directive (2000/60/EC) (European Community 2000) (Arbačiauskas et al. 2008).

The changes in the benthic community structure of VL during the 20th century have been studied by many authors: the western part was investigated by Żmudziński 1957, Cywińska & Różańska 1978, Różańska & Cywińska 1983, Żmudziński 1996, Pliński 2005, Ezhova et al. 2005 and Paturej et al. 2012; and the eastern part by Aristova 1965, 1973, Krylova & Ten 1992, Rudinskaja 1999, Ezhova 2000, 2002, Ezhova & Pavlenko 2001, Ezhova et al. 2004, 2005, Ezhova & Polunina 2011.

The aim of this paper was to ascertain the range of taxonomic composition changes of AS in the benthic fauna and to determine the present level of biocontamination of the western VL. The distribution ranges in VL of non-indigenous species of marine and freshwater origin are limited by the varied environmental conditions obtaining in these waters (especially the salinity); assessment of the biocontamination of particular habitats is therefore justified. In order to highlight the changes to the species diversity of zoobenthos, namely, species impoverishment along with dominance of

AS, we compare our own results with the research of Vanhffen (1917), Willer (1925) and Riech (1926), conducted after the regulation of the River Vistula, and with other current research work (Ezhova et al. 2005, Ezhova & Polunina 2011, Grabowski et al. 2005).

2. Material and methods

Samples for benthos determination were collected from the Lagoon monthly from May to November in 2006–2009 at 15 sampling stations (Nos. 1–15).

In 2006–2008, benthos samples were taken using an Ekman-Birge grab with a working area of 225 cm^2. Owing to the presence in the benthic fauna of *Marenzelleria neglecta*, whose distribution in the vertical sediment profile may reach 30 cm, a Kajak tube core sampler with a working area of 40.7 cm^2 was employed in 2009. Each sample taken from a particular site consisted of 5 subsamples. In 2009, additional quantitative samples (core tube sampler) were collected from the coastal zone at stations Nos. 16–24 deployed beyond the range of littoral plants at 1–1.5 m depth (Figure 1), and qualitative data were obtained from fishery catches (passive trap-type

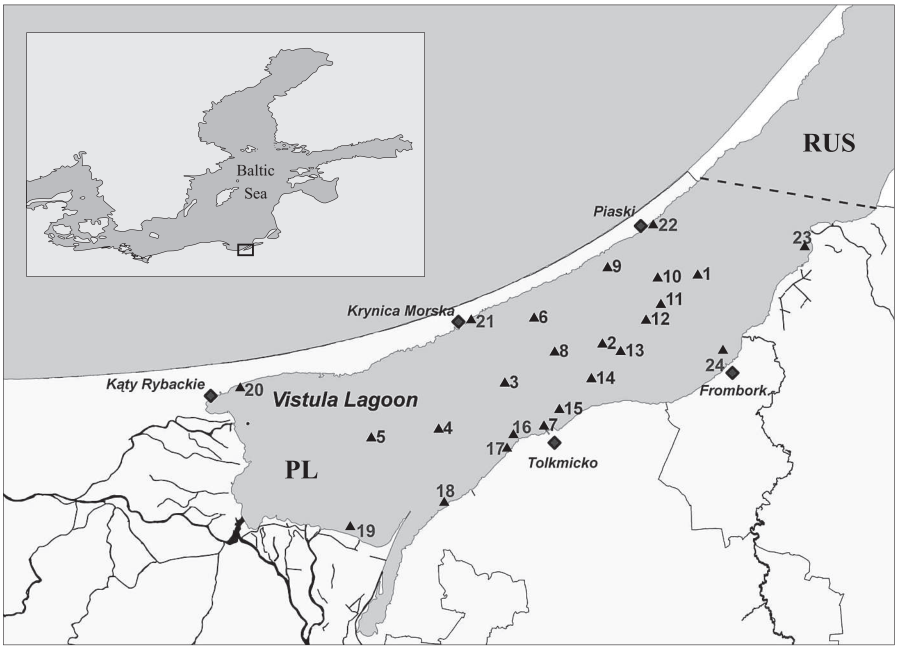

Figure 1. Localization of sampling station (1–24) in the western Vistula Lagoon

Table 1. Alien species in the benthic macrofauna of the Vistula Lagoon (VL)

Taxa	Whole lagoon 1917–1926[a]	Eastern VL 1996–2008[b]	Western VL 1988–1994[c]	Western VL 2006–2009[d]
Hydrozoa				
Cordylophora caspia (Pallas)	+	+	+	+
Polychaeta				
Marenzelleria neglecta Sikorski & Bick		+	+	+
Alkmaria rominji Korst		+		
Oligochaeta				
Potamothrix moldaviensis (Vejdovský & Mrázek)	?	+	?	+
Potamothrix bavaricus (Oschmann)	?	+	?	
Potamothrix vejdovsky (Hrabe)	?	+	?	+
Paranais ficii (Hrabe)	?	+	?	
Paranais botniensis Sperber	?	+	?	
Bivalvia				
Dreissena polymorpha (Pallas)	+	+	+	+
Mya arenaria Linnaeus	+	+		
Gastropoda				
Lithoglyphus naticoides (Pfeiffer)	+			
Potamopyrgus antipodarum (Gray)	+	+		+
Teodoxus fluviatilis (Linnaeus)	+	+		
Maxillopoda				
Amphibalanus improvisus Darwin	+	+		+
Malacostraca				
Gammarus tigrinus Sexton		+	+	+
Pontogammarus robustoides (G. O. Sars)		+	+	–[e]
Dikerogammarus haemobaphes (Eichwald)		+	+	–[e]
Obesogammarus crassus (G. O. Sars)		+	+	–[e]
Orchestia cavimana Heller		+	+	
Chelicorophium curvispinum (G. O. Sars)	+	+		
Palaemon elegans Rathke		+		+
Rhithropanopeus harrisii (Gould)		+	+	+
Eriocheir sinensis Milne-Edwards		+		+
Orconectes limosus (Rafinesque)		+		

[a]Data from Vanhöffen (1917), Willer (1925) and Riech (1926). (*Continued next page*)

(*continued*)

[b]Ezhova & Polunina (2011).

[c]Data from Ezhova et al. (2005).

[d]Authors' own data.

[e]Species recorded by Dobrzycka-Krahel et al. (2012).

? – identifiable only to class level (Oligochaeta).

gear, raised once daily on average). The sediment was sieved through a 0.5 mm mesh. The collected fauna was preserved in 4% formaldehyde and then processed in the standard way.

The site-specific biocontamination (SBC) index of each locality was determined from the proportion of AS in the taxonomic composition (RC – ratio of the number of alien taxonomic orders to the total number of orders in the community) and in the total abundance of the macrozoobenthos community (AC – ratio of the abundance of alien taxa specimens to the total abundance of the community) (Arbačiauskas et al. 2008, Panov et al. 2009) – Table 1. In the same way the integrated biological contamination (IBC) index of the assessment unit (the western VL) was estimated by averaging AC and RC of the study sites (Arbačiauskas et al. 2008, Panov et al. 2009). The integrated biological pollution risk index (IBPR) is calculated taking into account AS abundance and their potential invasiveness. The listing procedure (white, grey and black lists) and the list of alien species according to their potential invasiveness was taken from Panov et al. (2009). IBPR = 0 if no AS are present in the assessment unit; IBPR = 1 if the proportion of the abundance of AS from the white or grey list is $< 20\%$ of the total abundance of the community; and IBPR = 2 if the proportion of the abundance of AS from the grey or white list is $> 20\%$ of the total abundance of the community. Where AS from the black list are present in the community, IBPR = 3 if the proportion of their abundance is $< 20\%$ of the total abundance of alien and native species in the community, or = 4 if the proportion of their abundance is $> 20\%$ of the total abundance of alien and native species in the community.

The number of newly recorded AS in the western VL per reporting period was determined as the biological contamination rate (BCR) (Panov et al. 2009).

Study area

The Vistula Lagoon (VL) is one of the largest coastal water bodies in the southern Baltic; it is divided administratively into two parts (western and eastern) by the Polish-Russian border. Its total area is 838 km^2, 388 km^2 of which belong to Poland (Lazarenko & Majewski 1971). VL is a shallow (mean depth 2.7 m), brackish water body with salinity ranging from ca 1 PSU near the Nogat mouth to about 5 PSU in the Baltijsk Strait (the entrance from the Baltic Sea). The annual water temperature dynamics is driven by solar heating. Active wind mixing results in a mostly homogeneous temperature structure in VL (Chubarenko 2008).

The hydrochemical characteristics of VL vary significantly from year to year as they are strongly dependent on the pollution load. The Lagoon is considered a eutrophic water body (Senin et al. 2004, Paturej & Kruk 2011, Kruk et al. 2012) because of the high concentration of chlorophyll in its waters (Nawrocka & Kobos 2011). The average annual primary production estimated at 303.8 g Cm^{-2} $year^{-1}$ (Renk et al. 2001).

3. Results

During this faunistic research work in the western of VL, a total of 12 alien benthic species were found representing 7 classes of invertebrates: Hydrozoa, Maxillopoda, Malacostraca, Polychaeta, Oligochaeta, Gastropoda and Bivalvia (Table 1).

These taxa originate from 5 areas: North America (*Marenzelleria neglecta* Sikorski and Bick 2004, *Rhithropanopeus harrisii* (Gould 1841), *Amphibalanus improvisus* (Darwin 1854), *Gammarus tigrinus* Sexton 1939, *Orconectes limosus* (Rafinesque 1817)); the Ponto-Caspian Region (*Dreissena polymorpha* (Pallas 1771), *Cordylophora caspia* (Pallas 1771), *Potamothrix moldaviensis* Vejdovský & Mrázek, 1903 and *P. vejdovsky* (Hrabe)); the Pacific (*Potamopyrgus antipodarum* (Gray 1843)); the China Sea (*Eriocheir sinensis* (Milne-Edwards 1854)); the Atlantic coast of western Europe (*Palaemon elegans* (Rathke 1837)). Malacostraca is the class most numerously represented by AS in of VL; Hydrozoa are represented by just one species.

The ranges of distribution of the particular taxa varied widely. *A. improvisus* and *C. caspia* were found at single localities. The bay barnacle was found only at the easternmost stations in the Polish part of VL, whereas the brackish-water hydroid *C. caspia*, like the invasive freshwater North American crayfish *O. limosus*, were recorded in the western VL. These species, along with *P. elegans* and *E. sinensis*, were restricted to the coastal zone, and data on their occurrence came mainly from fishery catches. *P. antipodarum* (96%) and *M. neglecta* (83%) were ever-present in the samples. The distribution of the species is given in Table 2.

The SBC indices of particular areas of VL place them in classes 3 and 4 (Table 2), which are indicative of high and severe biological contamination. The integrated biological contamination (IBC) index for that part of VL subjected to assessment was 4, which classifies this water body as being highly contaminated. The integrated biological pollution risk (IBPR) level was 4.

Table 2. Distribution of alien species, site-specific (SBC) and integrated biological contamination (IBC) indices of the western Vistula Lagoon (2006–2009)

Taxon	Station number											
	1	2	3	4	5	6	7	8	9	10	11	12
Marenzelleria neglecta	+	+	+	+	+	+	+	+	+	+	+	
Potamothrix moldaviensis	+			+	+	+	+					
Potamothrix vejdovsky	+											+
Potamopyrgus antipodarum	+	+	+	+	+	+	+	+	+	+	+	+
Dreissena polymorpha				+		+						
Gammarus tigrinus	+		+	+	+							
Rhithropanopeus harrisii		+	+	+				+				
Amphibalanus improvisus												
Cordylophora caspia												
Eriocheir sinensis						+						
Orconectes limosus												
Palaemon elegans												
RC [%]	57.0	28.6	50.0	60.0	71.0	66.0	66.0	40.0	50.0	40.0	40.0	60.0
AC [%]	10.3	13.7	16.9	13.7	13.8	37.1	9.3	15.0	13.0	13.8	8.2	7.4
SBC	4	3	3	4	4	4	4	3	3	3	3	4

Taxon	Station number												
	13	14	15	16	17	18	19	20	21	22	23	24	IBC
Marenzelleria neglecta	+		+		+	+	+	+		+		+	
Potamothrix moldaviensis													
Potamothrix vejdovsky													
Potamopyrgus antipodarum	+	+	+		+	+	+	+	+	+	+	+	
Dreissena polymorpha				+				+					
Gammarus tigrinus				+						+			
Rhithropanopeus harrisii			+	+						+		+	
Amphibalanus improvisus										+			
Cordylophora caspia								+					
Eriocheir sinensis													
Orconectes limosus				+									
Palaemon elegans				+						+		+	
RC [%]	40.0	25.0	50.0	83.0	40.0	40.0	28.6	40.0	25.0	50.0	50.0	75.0	53.0
AC [%]	2.7	9.1	48.9	85.0	50.0	7.3	3.9	23.5	14.3	30.0	62.5	98.3	18.9
SBC	3	3	3	4	3	3	3	3	3	3	4	4	4

With reference to literature data, and taking the presence of *P. antipodarum* and *A. improvisus* in the western VL in the 20th century into account, the BCR for 1994–2009 was defined as 5.

4. Discussion

In the 20th century significant changes occurred in the composition of the benthic fauna of VL. At the beginning of the last century, native species made up the main share of the macrozoobenthos species composition in VL, alongside which at least 8 representatives of alien benthic macroinvertebrates species were found – Oligochaeta indet. (Vanhöffen 1917, Willer 1925, Riech 1926). By the end of that century there were already 14 non-native species, 9 of them in the western part (Ezhova et al. 2005). In 2006–2009 the number of AS recorded in the benthic fauna of the western VL rose to 12. These changes are the consequence of new species appearing and also of shifts in the distribution ranges of species recorded in VL.

Amphibalanus improvisus was observed in the western and eastern VL up to the 1950s. By the 1980s it was no longer recorded in the western part of the basin although it was still present in the eastern (Russian) VL (Ezhova et al. 2005). During the current research, however, this species was again recorded in the western (Polish) VL.

The distribution changes of the New Zealand mud snail *P. antipodarum* were similar, its presence in VL having been confirmed at the beginning of the 20th century. The species inhabited the bottom of the whole VL until the 1950s. According to Ezhova et al. (2005), it was not recorded in the western (Polish) part towards the end of the 20th century, but remained abundant in the eastern part (loc. cit.). This is especially noteworthy, as there are no ecological or geographical barriers that could restrict its occurrence. The present research confirmed the resurgence in the population of this mud snail in the western VL.

According to the literature (Ezhova 2000, Grabowski et al. 2006), there are now fewer gammarid species in the benthic fauna of the central VL. Samples taken there contained individuals of only one such species – *G. tigrinus*. Six taxa were found in the western VL at the turn of the century (Grabowski et al. 2006), *G. tigrinus* being markedly dominant. Its significance in the gammarid community continued to increase between 1998 and 2004 (Grabowski et al. 2006). In the littoral nearshore zone in 2008–2010, Dobrzycka-Krahel et al. (2012) were still able to find three of the four non-indigenous gammarid species recorded by Grabowski et al. (2006), again with the pronounced dominance of *G. tigrinus*. Perhaps the finding of only this taxon during sampling in the central VL is a further consequence of the expansion of this invasive North American gammarid which, according to Grabowski et al. (2006) is favoured by the ongoing eutrophication and pollution of this water body.

The numbers of *M. neglecta* (formerly known as *M. viridis*) in VL have fallen. This taxon was first found in VL in 1988 (Żmudziński et al. 1996). In the initial period of the invasion, the abundance of this spionid was 5000–7000 indiv. m^{-2} (Żmudziński et al. 1996). During the present research, however, its abundance was much lower, from 100 to 150 indiv. m^{-2}. Presumably, the decrease in abundance is due to its entering the declining stage of invasion and a state of balance being established in the area of colonization.

The occurrence of *M. neglecta* is also restricted by the presence of another alien species, *D. polymorpha*. While no live zebra mussels were found in the central VL, large deposits of empty shells were observed there, which hinder or even prevent *M. neglecta* from burrowing into the bottom (Kotta & Kotta 1998). The lack of live individuals of *D. polymorpha* in this zone may be due to the substantial hydration of the bottom sediments (50–70%, authors' own data – unpublished). Live specimens were found in only a few coastal samples and on hydrobionts – two young zebra mussels were found on a *R. harrisii* carapace. Despite the small numbers of this species, the large quantity of dead shells found in the sediments and their good state of preservation are an indication of the mussel's great significance in the past.

These shell deposits, which on the one hand are a hindrance to the burrowing activities of *M. neglecta*, have, on the other hand, created favourable living conditions for another AS – the above-mentioned *R. harrisii*. This was very abundant in areas with a solid sandy bottom, but also occurred in the central VL, in the area of the shell deposits.

A. improvisus and *C. caspia* were found at single localities. Sedentary species like the native hydrozoan *Gonothyraea loveni*, not recorded hitherto in the Lagoon, colonize the surfaces of various objects immersed in the water, including live organisms. Their occurrence in VL is described on the basis of an examination of fishing gear. As in the case of the decapods, they are probably more widespread than the distribution range ensuing from this research.

The value of the site-specific biocontamination (SBC) index of the animal community of the western VL indicates that this area has undergone severe biological contamination.

The integrated biological contamination (IBC) index of 4 is indicative of severe biological contamination and corresponds to the bad ecological status of the researched part of VL, as assessed by Polish State Inspectorates for Environmental Protection (*Report on the state of the environment of Warmia and Mazury in 2011*).

The integrated biopollution risk (IBPR) index determined for the macrozoobenthos of the western VL and defined by Panov et al. (2009) for the whole VL takes the same value of 4. This is due to the presence of species with a high risk of dispersal, their establishment in a new environment or the high risk of adverse ecological or economic impact (according to Panov et al. 2009 – the black list of AS).

In 1997–2007 the whole VL had a biological contamination rate (BCR) of 6, as defined by Panov et al. (2009). Calculating BCR for the western VL is not an easy matter: a value of 5 was assigned to it for the years 1994–2009 (see Results). This implies the appearance of five new non-native species in that period. In comparison with the species composition given by Ezhova et al. (2000), *Potamothrix moldaviensis*, *P. vejdovsky*, *Palaemon elegans*, *Eriocheir sinensis* and *Orconectes limosus* made their appearance in the western VL.

The present research has shown that the number of AS in VL is still increasing. Towards the end of the last decade, 23 AS had been recorded in VL (Ezhova & Polunina 2011, the current work data), 14 of which were present in the whole VL (including three gammarid species, whose presence in the period under consideration was confirmed by Dobrzycka-Krahel et al. 2012).

All of them have become important components in the trophic chains, especially as regards the abundance and biomass of VL's benthic macrofauna. Frequently, however, their influence on native biota and the latter's population dynamics is obscured by the intense eutrophication of VL.

Nonetheless, the reorganization of the benthic fauna community in VL is a dynamic process, governed by many different factors. Apart from ongoing eutrophication, the changes taking place in the chemistry of the waters are not without significance. After the regulation of the River Vistula in 1916, the freshwater inflow into VL via the River Nogat (a branch of the Vistula delta) decreased more than tenfold. Since that time, VL's hydrological and sedimentation regimes have changed dramatically (Chubarenko 2008). Declining environmental quality may be one of the reasons behind the changes in distribution ranges of certain non-indigenous organisms. This is probably a factor for encouraging the development of alien species, which show great ecological valence and resistance to pollution. However, most of the abundant species present in estuaries are tolerant to natural stressors (Zettler & Daunys 2007). The difficulties in determining anthropogenic stress using benthic indicators and indices within a naturally organic-rich system is the 'paradox of estuarine quality' (Dauvin 2007).

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