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Size structure and body condition of Ponto-Caspian gammarids in the Vistula estuary (Poland)

by

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Abstract

Over the past few decades, Ponto-Caspian gammarids *Pontogammarus robustoides, Obesogammarus crassus* and *Dikerogammarus haemobaphes* have colonized the European inland and coastal brackish waters. Previous experimental studies of *P. robustoides*, *O. crassus* and *D. haemobaphes* indicated that the salinity optimum for the species is about 7 PSU. We examined whether salinities below 5 PSU in the Vistula estuary – the Vistula Lagoon and the Vistula Delta, create a favorable environment and have a positive effect on Ponto-Caspian gammarids. The objective of this work was to determine the population parameters (size structure) and biological indicators (condition) of the studied gammarid species at a low salinity level. Length–weight relationships can be considered as their body condition in the environment. These relationships were calculated for each gammarid species according to the exponential equation $y = ax^b$, where: y – wet weight, x – total length, a – intercept, b – slope. The results clearly show responses of Ponto-Caspian gammarids to the low salinity habitat and indicate that such environment provides excellent conditions. The results of analysis show that the condition of gammarids is good. The optimal strategy of the examined alien gammarids may help them to maintain a strong competitive position in the environment and affect the colonization process in non-native waters with low salinity.

Key words: *Pontogammarus robustoides*, *Obesogammarus crassus*, *Dikerogammarus haemobaphes*, adaptations, biological indicator, alien species, gammarids

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Introduction

Human activities have greatly facilitated the range expansion of aquatic organisms (Carlton 1985; Carlton & Geller 1993; Konopacka 2004), for example Ponto-Caspian gammarids (Crustacea: Pontogammaridae, Amphipoda): *Pontogammarus robustoides* (G. O. Sars, 1894), *Obesogammarus crassus* (G. O. Sars, 1894) and *Dikerogammarus haemobaphes* (Eichwald, 1841). Over the past few decades, they have colonized the European inland and coastal brackish waters (e.g. Bij de Vaate et al. 2002; Grabowski et al. 2009).

At present, the issues related to migrations of gammarids are well recognized (Bij de Vaate et al. 2002; Panov et al. 2009). Although the gammarid species examined in this study come from habitats with a wide temporal or spatial salinity range, they are mainly known as invaders of freshwater ecosystems in non-native areas (Dodd et al. 2014; Guerlet et al. 2008; Kinzler et al. 2009; Dobrzycka-Krahel et al. 2013; Jermacz et al. 2015), where they are successful colonizers (Grabowski et al. 2007; Jermacz et al. 2015). There are numerous publications on the distribution, biology and ecology of invasive gammarid species in freshwater reservoirs (e.g. Dodd et al. 2014; Grabowski et al. 2009; Kinzler et al. 2009), but their status in coastal brackish waters is less known. Based on the previous laboratory studies (Dobrzycka-Krahel & Surowiec 2011; Dobrzycka-Krahel & Graca 2014; Dobrzycka-Krahel & Graca 2018), we can conclude that low salinities below 5 PSU are suboptimal for these species. Results of these experimental studies on *P. robustoides*, *O. crassus* and *D. haemobaphes* indicated that the salinity optimum for these species is about 7 PSU (in the salinity range from freshwater to 7 PSU) and the condition of these species in the Gulf of Gdańsk (salinity above 5 PSU) is good (Dobrzycka-Krahel et al. 2016). Due to these facts, the objective of the presented work was to determine whether population parameters (size structure) and biological indicators (condition) of Ponto-Caspian gammarid species, considered as their status (Jakob et al. 1996; Nalepa et al. 2000), are good in salinities below 5 PSU. The status of alien gammarids in a suboptimal habitat may show phenotypic plasticity and invasive potential of the species.

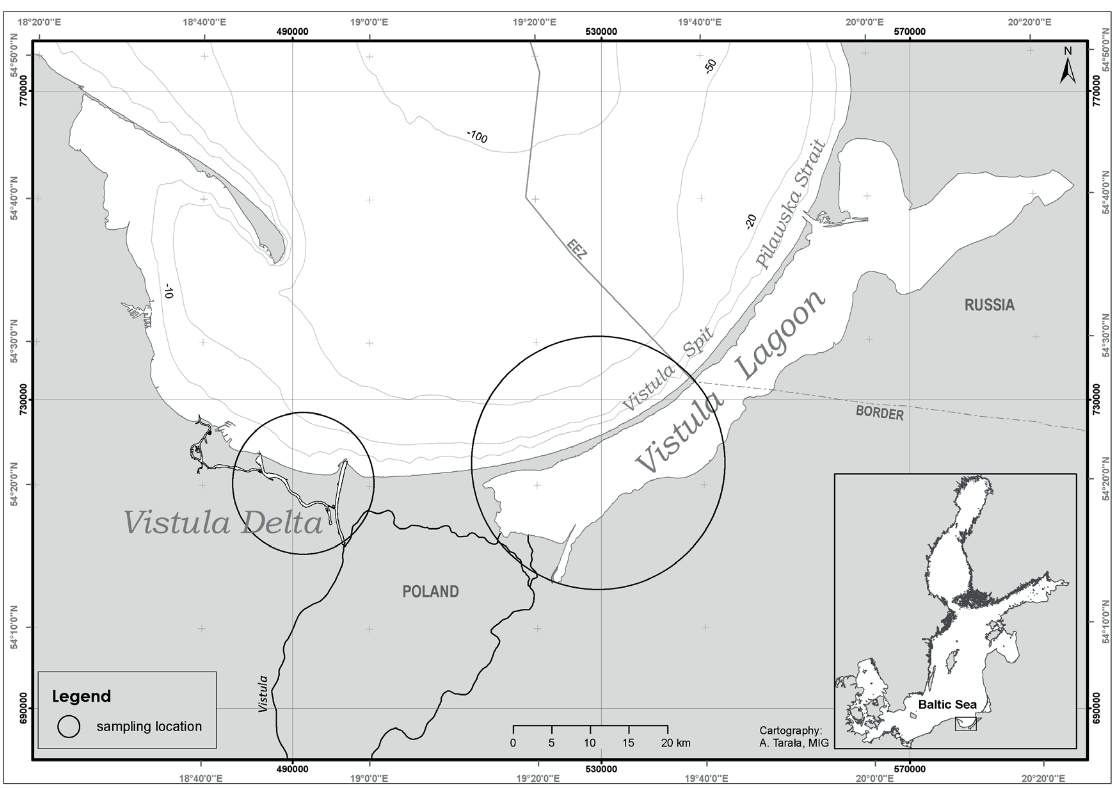

Figure 1

Sampling locations of Ponto-Caspian gammarids in the Vistula estuary: the Vistula Lagoon (VL) and the Vistula Delta (VD)

Materials and methods

Study area

The Vistula estuary (Fig. 1) is one of the largest estuaries in the southern Baltic Sea. Sometimes referred to as Vistula Bay or Vistula Gulf, the estuary is unusual in the sense that it mostly takes the form of a lagoon, an arm-shaped, elongated body of water.

The Vistula Lagoon (VL) is a broad, elongated, brackish water body, separated from the Baltic Sea by the narrow Vistula Spit. The salinity of VL is affected by the connection with the brackish Baltic Sea with an average annual salinity of up to 3.5 PSU (Chubarenko & Tchepikova 2001).

The Vistula Delta (VD) is an arm-shaped body of water. It has a number of branches. The western branch, the Dead Vistula (Martwa Wisła), carries brackish waters into the Baltic Sea using two connections. One passes through the port of Gdańsk, the other, known as the Brave Vistula (Wisła Śmiała), is responsible for the elevated salinity of the Dead Vistula. An artificial channel and the mouth of the Vistula is called Przekop (Klekot 1972, 1973). The mean salinity at the Vistula Delta is only 0.3 PSU (Pruszak et al. 2005).

The studies were carried out in the Vistula estuary: the Vistula Lagoon and the Vistula Delta (the transitional zone with salinity below 5 PSU). The studied gammarids were recorded for the first time in this area in 1998–2000 (Jażdżewski & Konopacka 2000; Jażdżewski et al. 2002; Jażdżewski et al. 2004).

Sampling methods

Material for the study was collected from two localities: VL and VD in warm months (26 May 2009, 22 June 2009, 7 May 2010, 1 June 2010, 2 June 2010, 30 July 2010, 20 May 2011, 31 May 2011), because the activity of the species peaks in such periods. The samples were collected from the sampling sites once a year. Water salinity and temperature were measured for all sites during each sampling event. Gammarids were sampled at each site by two people for 45 min using a 1 mm mesh size hand net (Jażdżewski et al. 2004).

Laboratory analysis

The material was preserved in 4% formaldehyde, in which the biomass of animals is similar to that obtained using fresh animals (Leuven et al. 1985; Miyasaka et al. 2008).

The composition of gammarids was determined according to taxonomic features described by Mordukhaj-Boltovskoj et al. (1969) and Konopacka (2004). Wet weight was determined after the animals were blotted on filter paper, using a Mettler Toledo XS 205 scale. Length was also determined – each individual was measured from the tip of the head to the telson base, using a binocular Nikon SMZ 800 with a measuring ocular. To determine the size frequency distribution, gammarids were divided into body classes at 1 mm intervals.

Statistical analysis

The total length and wet weight of the examined individuals were presented as means and standard deviations for each species separately. Total length–wet weight relationships for each gammarid species were calculated according to the exponential equation $y = ax^b$, ($W_w = aL_t^b$), where: y – wet weight in mg, x – total length in mm, a – intercept, b – slope. The correlation coefficient r^2 was also determined at $p = 0.05$. The significance of differences in the length–weight relationships between species living in the Vistula estuary (Vistula Lagoon and Delta) and in the Gulf of Gdańsk (based on data from the previous study by Dobrzycka-Krahel et al. 2016) were tested using analysis of covariance (ANCOVA), at $p = 0.05$. Before the analysis, the data were transformed. Both y and x data were log-transformed to linearize the relationship ($\ln y = b \times \ln x + \ln a$) to improve the normality and homoscedasticity of the data. Data analyses were performed using STATISTICA ver. 12 and Microsoft Excel 2010.

Results

Abiotic parameters

Water salinity (S) at sampling sites varied from 0.2 to 4.8, water temperature (T) – from 12.6 to 25.8°C. Mean water salinity was 1.13 PSU (3.6 ± SD) and mean water temperature was 1.06°C (20.75 ± SD).

Species composition, body length and wet weight of gammarids

Individuals of Ponto-Caspian gammarid species: *P. robustoides, O. crassus* and *D. haemobaphes* were present in the samples. A total of 1521 individuals were recorded in samples collected in 2009–2011 from the Vistula estuary: *P. robustoides* accounted for 24% (374 individuals), *O. crassus* – 41% (617 ind.), *D. haemobaphes* – 35% (530 ind.). Native gammarid species were absent in the study area, although they were present before the arrival of alien species (Grabowski et al. 2006). Mean total body lengths and mean body weights of all examined gammarids and standard deviations (± SD) are presented in Table 1.

Size structure of gammarids

The data show variations in length of individuals of each examined species. Despite similarly small lengths of the examined alien gammarids, the ranges of length are different for each species in the study area and varied from 2.9 to 21.4 mm for *P. robustoides*, from 2.0 to 12.0 mm for *O. crassus* and from 2.0 to 15.25 mm for *D. haemobaphes* (Fig. 2). Variations in sizes (length frequency) indicated that the examined individuals ranged from immature specimens to fully mature ones. The length–frequency distribution (size structure) showed a higher frequency of 4–7 mm individuals representing *O. crassus*, 5–9 mm individuals representing *P. robustoides*, and 7–10 mm individuals representing *D. haemobaphes*, due to differences in body length of particular gammarid species.

Body condition of gammarids

The relationships between wet weight and total length of individuals representing *P. robustoides* were described as $y = 0.0107x^{3.1317}$ ($r^2 = 0.8107$, n = 374), *O. crassus* – as $y = 0.0041x^{3.5461}$ ($r^2 = 0.8175$, n = 617) and *D. haemobaphes* – as $y = 0.141x^{2.0896}$ ($r^2 = 0.8243$, n = 530; Fig. 3). Individuals of all examined species showed an increase in weight with increasing L_t. The calculated slope "b" in the total length–wet weight relationships was high for: *P. robustoides* (b = 3.1317), *O. crassus* (b = 3.5461) and *D. haemobaphes* (b = 2.0896). Statistical analysis revealed no significant differences in length–weight relationships between species living in the Vistula estuary (Vistula Lagoon and Vistula Delta) and the Gulf of Gdańsk (ANCOVA, $p > 0.05$, $p = 0.71$), indicating a similarity between the samples.

Table 1

Descriptive statistics of body length (L) and wet weight (W) of gammarid species from the Vistula Lagoon and the Vistula Delta in 2009–2011

Species	N	%	L (mm) ± SD	W (g) ± SD
P. robustoides	374	24	8.55 ± 4.02	0.019 ± 0.047
O. crassus	617	41	5.93 ± 1.82	0.003 ± 0.004
D. haemobaphes	530	35	7.73 ± 2.65	0.012 ± 0.011

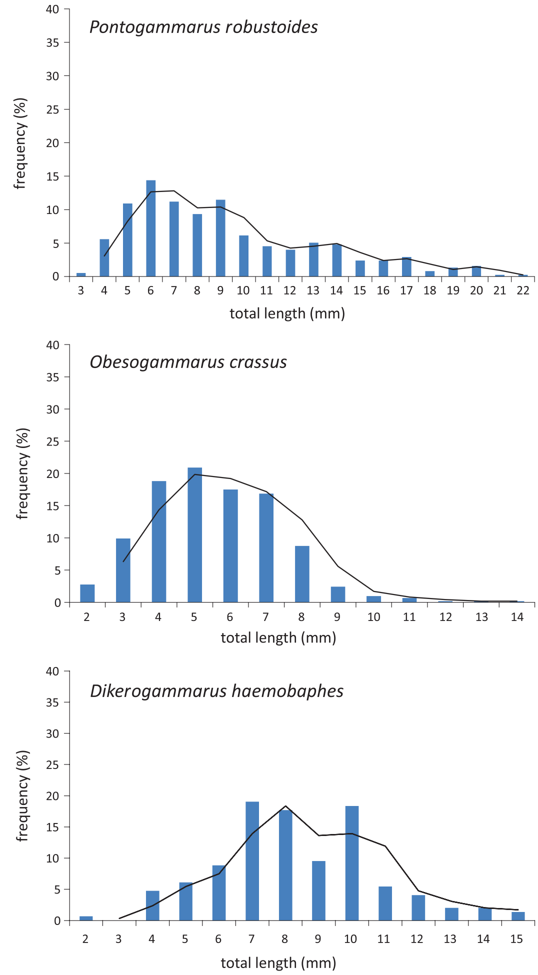

Figure 2

Length–frequency distribution of Ponto-Caspian gammarids in the Vistula estuary in warm months of 2009–2011

Discussion

Similarities in body length and weight of the analyzed invasive gammarid species were observed. The results also show a high proportion of juveniles (characterized by a fast growth rate) in the case of *P. robustoides* and *O. crassus*, and therefore good condition of these species, as the growth rate of animals is higher in younger individuals than in the older ones (Pauly 1979; 2010). In the case of *D. haemobaphes*, the lowest value of slope "b" was determined due to a smaller proportion of immature individuals. If rapid growth provides a selective advantage and growth varies as a function of habitat, we should also expect individuals to choose habitats with the optimal growth potential (Sogard 1992).

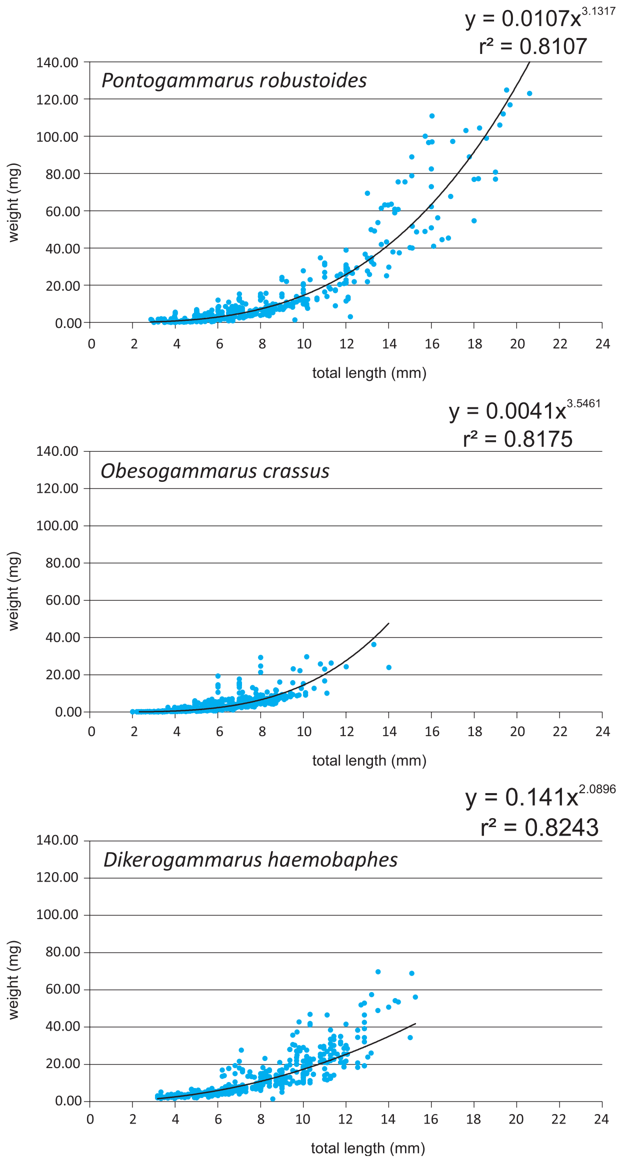

Figure 3

Relationship between total length and wet weight of Ponto-Caspian gammarids in the Vistula estuary in warm months of 2009–2011

In general, our results show that the environment of the Vistula estuary is favorable for the examined species and the relationships demonstrate good fitness of gammarids and the high body weight growth rate in relation to the length growth rate.

If we consider the importance of the body condition of organisms, we can mention examples of previous research. Many authors have examined the relationships between length and weight (e.g. Siegel 1982; 1989; Morris et al. 1988), because species differ in body weight growth in relation to length growth (Lindqvist & Lahti 1983). Factors such as resource availability (Basset & Glazier 1995) and competitive interactions among species (Basset & Rossi 1990) are known to affect the body size and body condition of individuals. The relationships between the total body length and wet weight of species may be used to assess the size and mass of species consumed by predators (Janas 2005). The Ponto-Caspian gammarid species in question may be important food components for such fishes as *Neogobius gymnotrachelus* (Kessler, 1857), *Perca fluviatilis* (Linnaeus, 1758) (Grabowska & Grabowski 2005) or *N. fluviatilis* (Pallas, 1811) (Grabowska et al. 2009).

The length–weight relationships may also indicate morphological differences in various areas (Färber-Lorda 1994). To our knowledge, data on the condition of the examined gammarid species from their original area have not yet been published. However, we have calculated intercepts (a) and slopes (b) of Ponto-Caspian gammarids from the Gulf of Gdańsk (salinity above 5 PSU) (Dobrzycka-Krahel et al. 2016). The values of the intercepts (a) and slopes (b) calculated for *P. robustoides, O. crassus* and *D. haemobaphes* in the present study (salinity below 5 PSU) were compared with the corresponding values obtained for these species from the Gulf of Gdańsk (salinity above 5 PSU). There were no statistical differences between these values. The results of the analysis show good condition of gammarids. These results contradict the scientific hypothesis of the study that salinity below 5 PSU is suboptimal for Ponto-Caspian gammarids. Field studies (Dobrzycka-Krahel & Graca 2018) also indicated that salinity within the investigated range, i.e. below 5 PSU (0.3, 3.4) and above 5 PSU (7.3 PSU), was not a key factor governing the abundance of gammarids and, consequently, their distribution pattern. We can conclude that most likely the plasticity of Ponto-Caspian gammarids (Dobrzycka-Krahel & Surowiec 2011, Dobrzycka-Krahel & Graca 2014, Dobrzycka-Krahel et al. 2015) causes that salinity in the examined range is not a key factor for Ponto-Caspian gammarids. Comparing the intercepts (a) and slopes (b) of Gammaridae living in North America of *Gammarus minus* and of *G. pseudolimnaeus* (Basset & Glazier 1995) and from the Black Sea (Rosati et al. 2012) with our gammarids, we can conclude that the species examined in our study are in similar condition (Table 2).

On the one hand, the good condition of Ponto-Caspian gammarids (*P. robustoides, O. crassus* and *D. haemobaphes*), as demonstrated by the results of this study, indicate that they grow well in low salinity environments (Table 2). It is likely that the increasing salinity of European rivers facilitated the intensive spread of many alien species (Bäthe &

Table 2

Calculated intercepts (a) and slopes (b) in the total length–wet weight relationship regression models $y = ax^b$ of gammarids from different areas and for different numbers of individuals (n)

Species	Area of occurrence	intercepts (a)	slopes (b)	individuals (n)	Reference
Pontogammarus robustoides	Vistula Lagoon and Delta Europe: Poland (brackish environment)	0.0107	3.1317	374	current study
Obesogammarus crassus		0.0041	3.5461	617	
Dikerogammarus haemobaphes		0.141	2.0896	530	
Pontogammarus robustoides	Gulf of Gdańsk Europe: Poland (brackish environment)	0.0367	2.852	72	Dobrzycka-Krahel et al. 2016
Obesogammarus crassus		0.0069	3.3477	75	
Dikerogamarus haemobaphes		0.0033	3.7855	225	
Dikerogammarus villosus		0.0674	2.852	117	
Gammarus sp.	Black Sea (brackish environment)	0.0016	2.87	20	Rosati et al. 2012
Gammarus minus	North America (freshwater environment)	0.012	2.74		Basset & Glazier 1995
Gammarus pseudolimnaeus		0.0049	3.001	37	Marchant & Hynes 1981
Gammaridae	Mediterranean and Black Sea (transitional waters)	0.0046	1.2	20	Rosati et al. 2012

Coring 2011; Dobrzycka-Krahel & Graca 2014; Petruck & Stöffler 2011; Piscart et al. 2011), so we can conclude that low salinity (below 5 PSU) is not a limiting factor for Ponto-Caspian gammarids in a non-native area. According to Grabowski et al. (2009), the increased number of alien species and their abundance in Polish rivers is associated with higher water conductivity (higher salinity). Furthermore, increased salinity of the Vistula Lagoon in the 20th century (Chubarenko & Tchepikova 2001) was probably an important factor facilitating the expansion of alien species in this area. The invasive alien gammarids are considerably more tolerant to elevated ionic levels compared to native species (Piscart et al. 2011). Forecast of desalinization of the Baltic Sea (Vuarinen et al. 1998; Rajasilta et al. 2014) caused by the absence of a saline water pulse since the late 1970s and the simultaneous increase in the run-off (Malmberg & Svansson 1982; Launiainen & Vilhma 1990; Matthäus & Schinke 1994) is unlikely to affect the future dispersal of the examined gammarids in the Baltic Sea, because they are tolerant to salinity (Grabowski et al. 2009; Dobrzycka-Krahel & Surowiec 2011; Dobrzycka-Krahel & Graca 2014; Dobrzycka-Krahel et al. 2015). Also other factors apart from salinity could affect the condition of gammarids, e.g. temperature measured during this study, but it is a varying factor (even in the daytime) in the Vistula estuary and all gammarids are eurythermic species (e.g. Wijnhoven et al. 2003).

According to Calow & Forbes (1998), fitness traits help not only to define stress, but more generally to understand how environmental variables affect the distribution and abundance of organisms. Good fitness corresponds to normal responses (Jacobsen & Forbes 1997). On the other hand, good condition of alien species affects the process of invasion or colonization. Fitness of invaders increases its ability to displace residents (Peacor et al. 2006). When invasive species strays from its optimal strategy, it can no longer compete with native species (Gross 2006). The optimal strategy of invasive alien gammarids may help them maintain strong competitive position in the environment as well as affect the colonization process of the Vistula Lagoon and the Vistula Delta. Such studies may be used in aquatic habitat management as they indicate the status of invasive alien species.

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