Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 48, Issue 1, March 2019

pages (66-75)

ISSN 1730-413X

eISSN 1897-3191

Distribution and abundance of Talitridae in the southern Baltic Sea – twelve years after the first record of *Platorchestia platensis* (Krøyer, 1845) in 2005

by

Marta B. Tykarska*, Urszula Janas, Radosław Brzana

DOI: **10.2478/ohs-2019-0007**

Category: **Original research paper**

Received: **July 04, 2018**

Accepted: **September 13, 2018**

University of Gdańsk, Faculty of Oceanography and Geography, Institute of Oceanography, Department of Experimental Ecology of Marine Organisms, Al. M. Piłsudskiego 46, 81-378 Gdynia, Poland

* Corresponding author: *marta.tykarska@phdstud.ug.edu.pl*

Abstract

Four Talitridae species have been recorded in the southern Baltic Sea, including two indigenous species – *Talitrus saltator*, *Deshayesorchestia deshayesii*, and two presumably non-indigenous ones – *Cryptorchestia garbinii*, *Platorchestia platensis*. It has been twelve years since *Platorchestia platensis* was recorded for the first time. The distribution and abundance of talitrids have not been studied since the 1990s. Therefore, the main objective of this research was to document the occurrence in Talitridae in the region in order to determine whether non-indigenous *P. platensis* has spread and whether it co-occurs with indigenous species. Talitrids were recorded at 20 out of 43 sampling sites. *T. saltator* occurred both along the coast of the open sea and in the Gulf of Gdańsk. The remaining species were found only around the gulf. *P. platensis* was more abundant than other species and its density was positively correlated with wrack biomass. Our studies have shown that the area of *T. saltator* occurrence has decreased during the last two decades. Non-indigenous species *P. platensis* co-occurred with all other Talitridae species, whereas *C. garbinii* co-occurred only with *P. platensis*.

Key words: non-indigenous species, sandhopper, beach flea, *Talitrus saltator*, *Deshayesorchestia deshayesii*, *Cryptorchestia garbinii*, *Platorchestia platensis*, Baltic Sea

DE GRUYTER

The *Oceanological and Hydrobiological Studies* is online at www.oandhs.pl

Introduction

The family Talitridae currently consists of 80 genera and 512 species occurring all over the world (Horton et al. 2018). They include beach fleas and sandhoppers, which are semiterrestrial bimodal breathers (Spicer & Taylor 1987) – they either bury themselves in moist sand or live among stranded decaying algae (Backlund 1945; Zettler & Zettler 2017). Cryptic species are discovered and described every year, suggesting that the taxonomy of Talitridae is at an early stage of development (e.g. Wildish 2017). So far, four species of Talitridae have been recorded in the southern Baltic Sea: two indigenous species – *Talitrus saltator* (Montagu, 1808) and *Deshayesorchestia deshayesii* (Audouin, 1826) and two presumably non-indigenous species – *Cryptorchestia garbinii* (Ruffo, Tarocco & Latella, 2014) and *Platorchestia platensis* (Krøyer, 1845) (Ojaveer et al. 2017). In addition to these four species, two other species of Talitridae, *Orchestia gammarellus* (Pallas, 1766) and *Britorchestia brito* (Stebbing, 1891), occur in the catchment area of the Baltic Sea and adjacent territories (Zettler & Zettler 2017).

The indigenous talitrids, *T. saltator* and *D. deshayesii*, inhabit supralittoral sandy beaches in the southern and western Baltic Sea. During the day, they hide in burrows close to a high water mark to avoid desiccation stress (Williams 1983) and emerge at night to feed on nearby stranded macrophytes (Bulheim & Scholl 1986; Fallaci et al. 1999; Ayari-Akkari et al. 2014). *T. saltator* and *D. deshayesii* often co-occur (Drzycimski & Nawodzińska 1965). *D. deshayesii* was first recorded in the study area by Drzycimski and Nawodzińska (1965), who found it only on the Hel Peninsula (Puck Bay).

It has been suggested that the populations of *T. saltator* and *D. deshayesii* have declined in the Baltic Sea area (HELCOM 2013a,b). According to the HELCOM Red List, *T. saltator* can be classified into the "data deficient" category and *D. deshayesii* – into the "vulnerable" category. In Poland, *T. saltator* is legally protected[1], whereas *D. deshayesii* is not protected by law. Studies on the distribution and abundance of *T. saltator* and *D. deshayesii* (as *Talorchestia deshayesii*) on the southern Baltic Sea coast were carried out in 1961–1963 (Drzycimski & Nawodzińska 1965). After that, research on *T. saltator* was carried out in 1997 (Węsławski et al. 2000a).

C. garbinii is presumably a non-indigenous species in the Baltic Sea (Ojaveer et al. 2017). According to recent molecular studies, *C. garbinii* is closely related to other species from the genus Cryptorchestia inhabiting the eastern Mediterranean regions. The evolution of *C. garbinii* could have been a pattern of recent east-to-west dispersal, with a more recent northward expansion (Davolos et al. 2004; 2018). The information about the arrival and invasion vector is extremely limited. *C. garbinii* was recently described by Ruffo, Tarocco & Latella (2014) as a new species, previously identified as *C. cavimana*. In the Baltic Sea, *C. garbinii* was first recorded (as *O. litorea*) at the end of the 19th century (Selgio 1899) in the southern part only (former West Prussia). *P. platensis* is a cosmopolitan species distributed both in the temperate and tropical regions (Behbehani & Croker 1982). It was originally described from Montevideo in Uruguay in 1845 by Krøyer (1845). However, its place of origin is unclear due to the fact that this site was close to the international port of Montevideo (La Fontaine 1902). According to the latest studies, *P. platensis* is a non-indigenous species in Europe, genetically related to the populations across the Atlantic (Hupało & Grabowski 2018). In the Baltic Sea, *P. platensis* was first found in Denmark in the northern part of Øresund in 1860 (Dahl 1946), then in the 1930s and 1940s it appeared to be common on both sides of Øresund and the Swedish coast of Kattegat. It expanded its distribution along the German and Swedish coast of the Baltic Sea (Backlund 1945; Dahl 1946; Urbański 1948; Karlbrink 1969; Zettler 1999; Persson 2001). *P. platensis* was first reported in Poland from the Hel Peninsula in Puck Bay in 2005 (Spicer & Janas 2006). Elsewhere, *P. platensis* can coexist with indigenous species, sometimes successfully outcompeting them (e.g. Dahl 1946; Karlbrink 1969; Persson 2001). So far, no coexistence of *P. platensis* with other Talitridae in the southern part of the Baltic Sea has been observed.

Although talitrids play an important role in the food web and they serve as a link between marine and terrestrial ecosystems, they have received little attention from marine or terrestrial biologists. *T. saltator* is likely to be the most important of the macrofaunal consumers of the stranded macrophyte detritus (Jędrzejczak 2002; Adin & Riera 2003). The importance of talitrids, especially *T. saltator*, in the food web was emphasized by the study of their biochemical composition (El Gtari et al. 2013).

The objective of this research was to answer the following questions: (1) what is the Talitridae species composition, distribution and abundance in the southern Baltic Sea, (2) has non-indigenous *P. platensis* extended its range of occurrence since the introduction, (3) do non-indigenous species co-occur with indigenous species and (4) in what types of habitats do individual Talitridae species occur?

1 Regulation of the Minister of the Environment of 16 of December 2016 on the protection of animal species (Dz. U. 2016, item 2183)

Materials and methods

Forty three sampling sites were established in the supralittoral zone, roughly every 10 km along 500 km of the entire Polish Baltic Sea coast (Węsławski et al. 2000a) (Fig. 1, Appendix). The field work was conducted from 12 August to 16 September 2017. Five replicates were collected at each sampling site within a distance of 1 m from each other, parallel to the coastline, at the boundary between wet and dry sand. Each sampling location was categorized by the habitat type according to our observations and the presence or absence of stranded flora. Three habitat-type categories were established: bare sand – 16 study sites, sand with plants – 21 sites, boulders with plants – 6 sites. At each sampling site, talitrids were collected through the core sampling, using a hand corer (diameter 10 cm, depth 20 cm) as described in the HELCOM guidelines (HELCOM Combine 2014). Each sample was sieved through a 1 mm mesh. The material left on the sieve was transferred to plastic containers and preserved. All amphipods were preserved in 96% ethanol, except *T. saltator*, which was identified in situ, counted, photographed and released. The identification of *T. saltator* was based on its morphological features: the shape (broader toward the head) and the pattern on the dorsal side, i.e. a longitudinal dark line along the pereion and pleosome with two or several perpendicular short symmetric stripes or shades as in Photo 1. in Spicer & Janas (2006). The identification of other Talitridae was completed in the laboratory following the identification keys for Talitridae (Lincoln 1979; Spicer & Janas 2006; Zettler & Zettler 2017). The collected wrack was preserved in 96% ethanol, then washed with tap water in the laboratory, dried to wet mass using a salad spinner and then further dried on blotting paper and weighed on a scale (accuracy of 0.0001 g). Talitridae density was expressed as a number of individuals per m^2 (ind. m^{-2}). The relationship between the biomass of wrack and amphipod density was determined by Spearman's rank correlation coefficient test. The difference between the densities in different habitat types was tested using the Mann-Whitney *U*-test for *T. saltator* and *P. platensis*. Differences between densities of four Talitridae species on sandy habitat was tested by the Kruskal-Wallis rank sum test and pairwise comparison was tested using Dunn's-test for multiple comparisons of independent samples with Bonferroni's *p*-adjustment method. Prior to the statistical analysis, the normality of the data was tested (Shapiro-Wilk test $p < 0.05$). All statistical analyses were conducted using R 3.4.4. and Dell Statistica 13.1. The cartographic visualizations were carried out using Esri ArcGIS Pro 2.0.1.

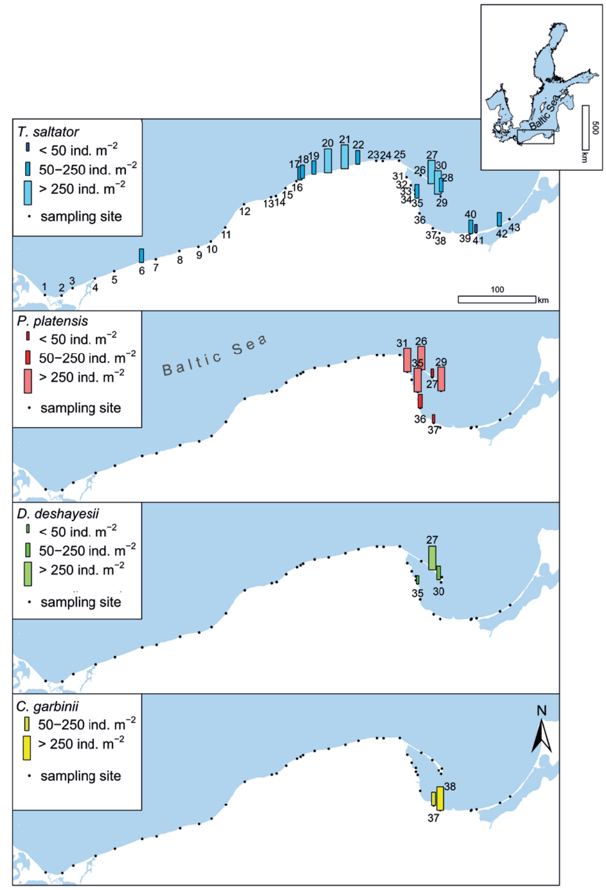

Figure 1

Talitridae distribution and density in the southern Baltic Sea

Results

Four Talitridae species were found at the sampling sites: *T. saltator, D. deshayesii, C. garbinii* and *P. platensis*. *O. gammarellus* was not recorded. The Talitridae occurred at 20 out of 43 sampling sites, which accounts for 47% of the surveyed area. *T. saltator* was recorded at 14 sampling sites (33% of the surveyed area), *D. deshayesii* – at three sampling sites (7%), *P. platensis* – at seven sampling sites (16%) and *C. garbinii* – at two sampling sites (5%). *T. saltator* occurred both at the coast of the open sea and in the Gulf of Gdańsk. The three other species, *D. deshayesii, P. platensis* and *C. garbinii,* were found only around the Gulf of Gdańsk (Fig. 1).

The highest mean densities of *T. saltator* (over 600 ind. m^{-2}) were recorded at three sampling sites (21, 27 and 30; Appendix). At nine sampling sites, the density of *T. saltator* ranged from 50 to 250 ind. m^{-2}

and at only one sampling site (41) it was less than 50 ind. m^{-2} (25 ind. m^{-2}) (Fig. 1). The average density of *T. saltator* at places of its occurrence reached over 200 ind. m^{-2}.

The highest average densities of *P. platensis* (over 5000 ind. m^{-2}) were determined at sites 26 and 35 (Appendix). At only two sampling sites the density was less than 50 ind. m^{-2} (sites 27, 37) (Fig. 1). The average density of *P. platensis* was about 2000 ind. m^{-2}.

The highest average density of *D. deshayesii* was recorded at site 27 (280 ind. m^{-2}). At one sampling site (30), the average density was 152 ind. m^{-2} and at one site (35) it was 25 ind. m^{-2} (Fig. 1, Appendix).

C. garbinii was recorded at two sites. At one site (37), the average density was 102 ind. m^{-2}. By the Dead Vistula River (site 38), the average density reached 1299 ind. m^{-2} (Fig. 1, Appendix).

At two sampling sites, non-indigenous *P. platensis* was found together with indigenous species: *T. saltator* and *D. deshayesii* (Fig. 2). At one sampling site (30), two indigenous species co-occurred (*T. saltator* and *D. deshayesii*) and at one site (37) – non-indigenous species co-occurred (*P. platensis* and *C. garbinii*) (Fig. 2).

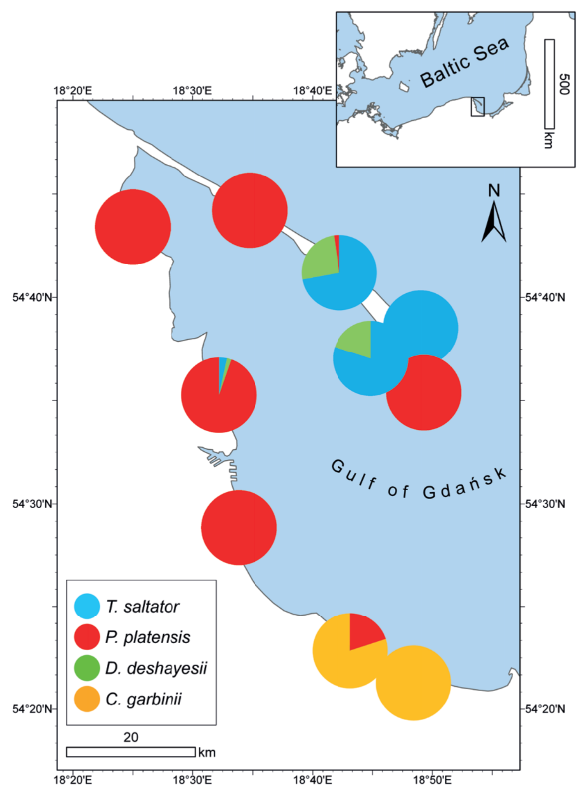

Figure 2

Talitridae species composition in the Gulf of Gdańsk, southern Baltic Sea

Most of the southern Baltic Sea coast is homogeneous, represented mainly by open sandy beaches. More diverse habitats occur within the Gulf of Gdańsk, where, in addition to sandy beaches, boulder areas occur more often (Appendix). At the open sea coast, the common component of wrack was *Fucus vesiculosus* L. and *Zostera marina* L., whereas *Z. marina* dominated in the Gulf of Gdańsk, both on sandy beaches and boulders.

D. deshayesii occupied only sandy habitats with stranded wrack (Fig. 3). *T. saltator* was found exclusively on sandy beaches, both with and without stranded wrack. The density of *T. saltator* was significantly higher in sandy habitats with stranded wrack than on bare sand (Mann-Whitney *U*-test, $p < 0.05$). The frequency of *T. saltator* was higher in the habitat with stranded wrack (Fig. 4).

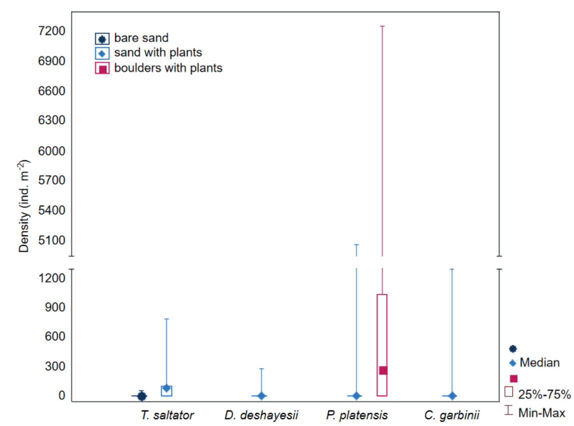

Figure 3

Density of Talitridae in different habitats (with a break in the ordinate axis)

P. platensis was the only species that occurred on a habitat with boulders. In addition to areas with boulders, it also occurred in the same habitats as indigenous species, i.e. sandy beaches. The density of *P. platensis* differed significantly between habitats, with the higher density in the boulder area (Mann-Whitney *U*-test, $p < 0.05$) (Fig. 3). The frequency of *P. platensis* at sites with boulders reached 67% (Fig. 4).

The density of four studied Talitridae species on sandy beaches with stranded wrack was significantly different (Kruskal-Wallis test, $p < 0.001$). The density of *T. saltator* was significantly higher than all other species (post hoc Dunn's-test, $p < 0.05$) (Fig. 3).

The density of *P. platensis* was positively correlated with wrack biomass (Spearman's test, $r_s = 0.619$, $p < 0.000000001$). The positive correlation between the density of *T. saltator* and wrack biomass was also significant (Spearman's test, $r_s = 0.468$, $p < 0.02$).

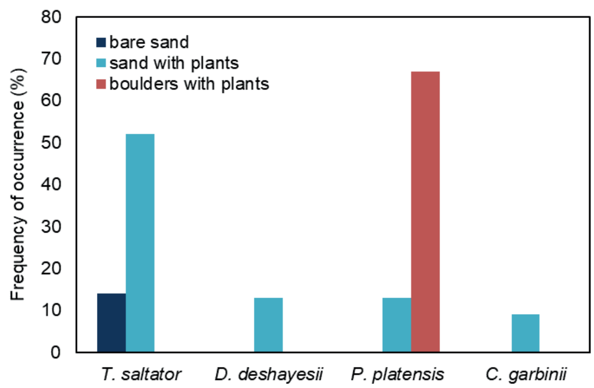

Figure 4

Frequency of Talitridae in different habitats

Discussion

Declining sandhopper populations

T. saltator is still a common inhabitant of the exposed sandy beaches along the southern Baltic Sea coast, but it has disappeared from a number of previously occupied localities (Fig. 5). In the study from the 1960s, *T. saltator* occurred along the entire southern Baltic Sea coast, with the highest densities on the open sea coast (Drzycimski & Nawodzińska 1965). Densities exceeding 250 ind. m^{-2} were recorded at 45% of the sampling sites. *D. deshayesii* was found only on the Hel Peninsula, where at one site the species co-occurred with *T. saltator*. In the 1990s, a significant decline in the density of *T. saltator*, as well as a decrease in its distribution area were observed (Węsławski et al. 2000a). In the 1990s, *T. saltator* was found in 40% of the surveyed area and its density did not exceed 250 ind. m^{-2} and was lower than 50 ind. m^{-2} in 76% of the sampling sites (Fig. 5). However, it should be noted that the methods of sampling were not identical during the conducted studies. Węsławski and others (2000a) sampled one square meter within the most populated areas, but Drzycimski and Nawodzińska (1965) collected the talitrids from an undefined area, at a depth of up to 25–30 cm. Neither samples were sieved.

Twenty years after the last research in 1997, an increase in the density of *T. saltator* was recorded, the average density of *T. saltator* in areas of its occurrence reached over 200 ind. m^{-2}. The density of *T. saltator* was below 50 ind. m^{-2} at only 7% of the sampling sites, yet the abundance from the 1960s has not been reached. However, *T. saltator* was found in areas where it was previously not recorded, mainly in the Słowiński National Park. Nonetheless, *T. saltator* distribution has decreased in the study area. It was found in 33% of the surveyed area, while in 1997 the species inhabited 40% of the area. This may be related to tourism and mechanical beach cleaning, known to denude the

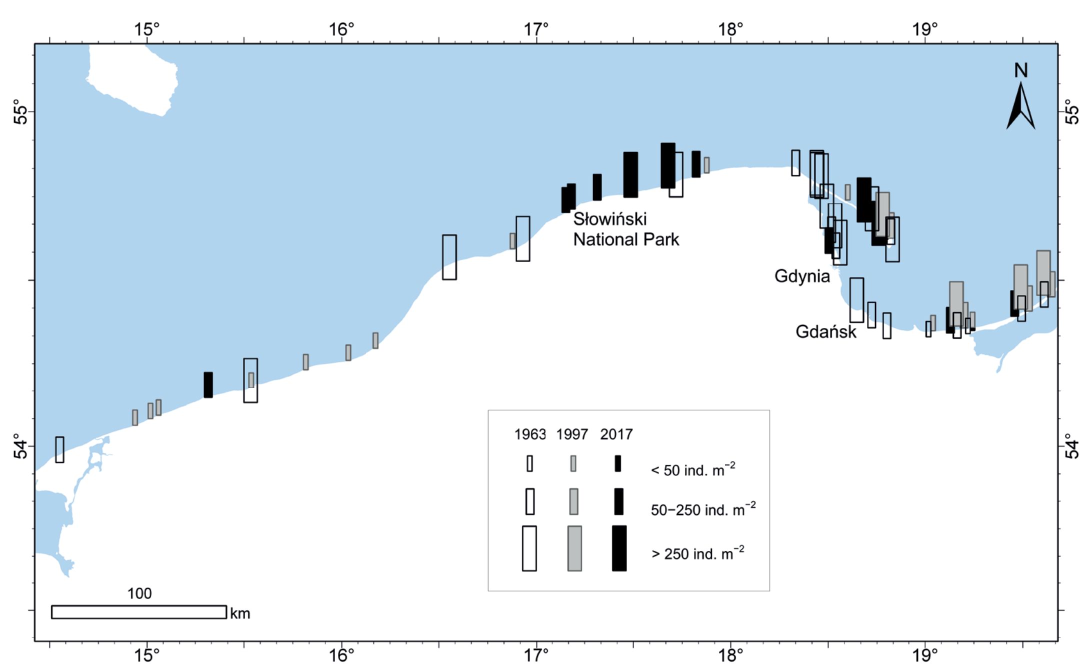

Figure 5

Distribution and density of *T. saltator* in 1963 (Drzycimski & Nawodzińska 1965), in 1997 (Węsławski et al. 2000a) and in 2017 (this study) coastal macrofauna (Dugan et al. 2003; Fanini et al. 2005). Considering the positive relationship between the density of *T. saltator* and wrack biomass, the wrack removal could affect the distribution of *T. saltator*. In addition to beach cleaning and other tourism-related activities, pollution and changes in trophic conditions, climatic changes such as storm frequency, severity of winters and sea level rise could also contribute to the reduction of the *T. saltator* distribution area (Węsławski et al. 2000a). *T. saltator*, once abundant in the southwestern part of the Gulf of Gdańsk (Drzycimski & Nawodzińska 1965), is no longer recorded in this area (Węsławski et al. 2000a). On the other hand, we observe that *P. platensis* is now present in the area.

The significant decrease in the abundance of *T. saltator* in 1997 could be related to the disappearance of seaweed meadows and decline of macroalgae species in the coastal waters of the southern Baltic during the pollution crisis in the 1970s and 1980s (Węsławski 2000a). Recently, a natural recovery of *Z. marina* meadows has been observed after a dramatic decline in the last century (Dąbrowska et al. 2016; Jankowska et al. 2018) and this may positively affect an increase in the *T. saltator* abundance. However, *T. saltator* has faced new challenges, like the potential invasion of the new talitrid, *P. platensis*.

Expansion by *P. platensis*

The first report on the colonization of the Baltic Sea by *P. platensis* came from the Scandinavian region (Dahl 1946) and we can currently presumably observe an ongoing secondary dispersal in the Baltic Sea (Persson 2001). *P. platensis* was first observed in Poland by Spicer & Janas (2006) in May 2005. At that time, it was recorded in only one area on the Hel Peninsula – in Kuźnica (sampling site 26). Since then, *P. platensis* has apparently been gradually spreading around Puck Bay. In 2006, a survey by students (Kotwicki et al. 2009) recorded *P. platensis* at two sites, Kuźnica and nearby Jurata (corresponding to our sampling sites 26, 27). In 2012, *P. platensis* was found at the end of the Hel Peninsula (site 29) (U. Janas, unpublished observations). By 2013, *P. platensis* spread to the other side of Puck Bay where it was recorded at sampling site 35, while the following year it reached sites 31 and 33. Our current data show a significant spread of *P. platensis* on the southern Baltic coast. *P. platensis* was recorded at seven sampling sites. It has reached Gdynia and Gdańsk (36, 37) and expanded its territory beyond the area of Puck Bay.

P. platensis occurred only around the Gulf of Gdańsk, where it was most likely introduced by synanthropic transport, taking under consideration the distance from the nearest German population and its absence along the open sea coast. The secondary dispersal in the Gulf of Gdańsk could involve passive transport by currents. *P. platensis*, as a beach flea living in beach-cast wrack, is more exposed to a swash risk and is likely to be passively transported by currents (Fanini & Lowry 2014). Fanini & Lowry (2014) tested the survival behavior of talitrids when swashed away and subjected to passive transportation. Talitrids were able to survive in seawater, to swim precisely and quickly head toward an object and then cling on it.

Our research confirms that *P. platensis* can be observed in a variety of habitats, like wrack beds, sandy shores, boulders and driftwood (Rasmussen 1973; Persson 2001; Lacey 2009), which is different from most beach fleas and sandhoppers. This could enhance the possible invasive character of *P. platensis* in the southern Baltic Sea. Since *P. platensis* occurs on rocky shores with stranded wrack, it is more likely to be dispersed via drifting wrack than *T. saltator*, which exclusively inhabits sandy beaches above the high-tide level, buried under the sand surface, which is reflected in the genetic structure of the populations of these species in the Mediterranean area (De Matthaeis et al. 2000).

P. platensis occurred mainly in areas with anthropogenic changes (six out of seven studied sites). It was initially discovered on boulders used for coastal reinforcement (sampling site 26). It has then spread to other nearby artificial substrates and has reached areas unchanged by human activity, where indigenous species occur. It can therefore be suggested that the anthropogenic environment favors non-indigenous *P. platensis* and supports its further spreading.

The density of *P. platensis* was positively correlated with wrack biomass. Such a strong correlation is presumably related to higher accumulation of wrack on artificial boulders. Thus, the removal of wrack from sandy beaches due to tourism-related mechanical beach cleaning affects mainly the distribution of *T. saltator* and not necessarily *P. platensis*, due to its habitat (i.e. boulders). The relationship with wrack biomass has been studied for another non-indigenous talitrid in the Baltic Sea – *C. garbinii* (Herkül et al. 2006). As with *P. platensis*, the occurrence of *C. garbinii* was positively correlated with wrack biomass.

Interactions between different talitrid species

Considering the coexistence of *P. platensis* with all other Talitridae species, it seems necessary to undertake further research on the ecology of Talitridae and the potential interactions between species on the southern Baltic Sea coast. The competition between *P. platensis* and other species, such as *O. gammarellus*, has been demonstrated for Swedish populations (Dahl 1946; Karlbrink 1969; Persson 2001). *P. platensis* outcompetes other species at lower salinities (Persson 2001) and up to 30% water loss (Morritt & Spicer 1998). Furthermore, *P. platensis* is a more active jumper than *O. gammarellus*, so it may be better at evading predators (Karlbrink 1969). *P. platensis* has presumably a longer reproductive period than *T. saltator*, which may account for the competitive superiority of this non-indigenous species (Dahl 1946; Węsławski et al. 2000b).

D. deshayesii

According to Drzycimski and Nawodzińska (1965), *D. deshayesii* occurred only on the Hel Peninsula from the side of Puck Bay, but its density remained unknown. In our research, *D. deshayesii* was found on both sides of Puck Bay, both at the Hel Peninsula and near Gdynia (sampling site 35), thus its area of distribution has increased. This study confirms that it is one of the rarest talitrids species in the Baltic Sea (Zettler & Zettler 2017).

C. garbinii

There are no previous studies on the abundance of *C. garbinii* or its distribution along the southern Baltic Sea coast, but it is likely that the area of its distribution has expanded. We observed that apart from previous sites (Żmudziński 1990; Konopacka et al. 2009), the species also occurred in Sobieszewo (sampling site 38), in a closed protected artificial dune established after creating the international Deepwater Container Terminal in Gdańsk. The dune was created using sand from a nearby beach. The presence of *C. garbinii* in this new area could be an effect of secondary dispersal from the Dead Vistula River or, given the proximity of the international harbor, this could be a new anthropogenic introduction. The population genetics research, like the one performed by Hupało and Grabowski (2018) on *P. platensis*, seems to be necessary to tackle the history of the introduction, because otherwise it will not be certain whether *C. garbinii* is non-indigenous species or not. *C. garbinii* is commonly found in damp habitats, beneath stones and decaying vegetation, close to fresh or brackish water (Spicer & Janas 2006; Konopacka et al. 2009). In the Gulf of Gdańsk, *C. garbinii* coexisted only with *P. platensis*.

Conclusions

Over the last five decades, changes in both indigenous and non-indigenous Talitridae species have occurred. The density of *T. saltator* has increased, but the area of its occurrence has decreased during the last two decades. The area of *D. deshayesii* occurrence has increased since the 1960s. *T. saltator* occurred along the cost of the open sea as well as in the Gulf of Gdańsk, while *D. deshayesii*, *C. garbinii* and *P. platensis* occurred only in the Gulf of Gdańsk. The non-indigenous species *P. platensis* has extended its range of occurrence and can coexist with both indigenous and non-indigenous species. *P. platensis* has successfully colonized the Gulf of Gdańsk and it has been observed in a variety of habitats, unlike other species of Talitridae. Nevertheless, little is known about the ecological role of talitrids and it seems necessary to undertake further research on their ecology and the potential interspecific interactions in the southern Baltic Sea.

Acknowledgements

This study was funded by the BONUS COCOA project, which was supported by BONUS (Art 185) funded jointly by the EU and the National Centre for Research and Development in Poland under grant No. BONUS-UE-2012-01/2014. We thank all those who volunteered to join the field work for their dedication and invaluable contribution to our research. We thank the reviewers for their constructive comments.

References

Adin, R. & Riera, P. (2003). Preferential food source utilization among stranded macroalgae by *Talitrus saltator* (Amphipod, Talitridae): A stable isotopes study in the northern coast of Brittany (France). *Estuarine, Coastal and Shelf Science* 56(1): 91–98. DOI: 10.1016/S0272-7714(02)00124-5.

Ahyong, S.T., Lowry, J.K., Alonso, M., Bamber, R.N., Boxshall, G.A. et al. (2011). Subphylum Crustacea Brünnich, 1772. In Z.-Q. Zhang (Ed.) Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. *Zootaxa* 3148: 165–191.

Andrulewicz, E. & Witek, Z. (2002). Anthropogenic Pressure and Environmental Effects on the Gulf of Gdansk: Recent Management Efforts. In G. Schernewski (Ed.) *Baltic Coastal Ecosystems: Structure, Function and Coastal Zone Management* (pp. 119–139). DOI: 10.1007/978-3-662-

04769-9_9.

Ayari-Akkari, A., Jelassi, R., Khemaissia, H. & Nasri-Ammar, K. (2014). Life history of the sandy beach amphipod *Deshayesorchestia deshayesii* (Crustacea: Talitridae) from Bizerta beach (North of Tunisia). *Invertebrate Reproduction and Development* 58(4): 269–277. DOI: 10.1080/07924259.2014.920422.

Backlund, H.O. (1945). Wrack fauna of Sweden and Finland, Ecology and chorology. *Opusc. Entomol.* 5(Suppl.): 1–236.

Behbehani, M.J. & Croker, R.A. (1982). Ecology of beach wrack in northern New England with special reference to *Orchestia platensis*. *Estuar. Coast. Shelf Sci.* 15: 611–620.

Bulnheim, H.P. & Scholl, A. (1986). Genetic differentiation between populations of *Talitrus saltator* and *Talorchestia deshayesii* (Crustacea: Amphipoda) from coastal areas of the north-western European continent. *Marine Biology.* 92: 525–536.

Dahl, E. (1946). The Amphipoda of the Sound. Part 1. Terrestrial Amphipoda. *Acta University Lund, N.F. Adv. 2* 42: 1–53.

Davolos, D., Vonk, R., Latella, L. & De Matthaeis, E. (2018). The name of a model species: the case of *Orchestia cavimana* (Crustacea: Amphipoda: Talitridae). *The European Zoological Journal* 85(1): 229–231.

Dąbrowska, A.H., Janas, U. & Kendzierska, H. (2016). Assessment of biodiversity and environmental quality using macrozoobenthos communities in the seagrass meadow (Gulf of Gdańsk, southern Baltic). *Oceanological and Hydrobiological Studies* 45(2): 286–294. DOI: 10.1515/ohs-2016-0024.

De Matthaeis, E., Davolos, D., Cobolli, M. & Ketmaier, V. (2000). Isolation by distance in equilibrium and nonequilibrium populations of four talitrid species in the Mediterranean Sea. *Evolution* 54(5): 1606–1613.

Drzycimski, I. & Nawodzińska, G. (1965). Amphipoda from beaches of Polish Baltic Sea. *Przeg. Zool.* 3: 267–273.

Dungan, E.J., Hubbard, D.M., McCrary, M.D. & Pierson, M.O. (2003). The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. *Estuarine, Coastal and Shelf Science.* 58S: 28–40.

El Gtari, M., Bouriga, N., Medini-Bouaaziz L. & Charfi-Cheikhrouha, F. (2013). Biochemichal composition of six Talitridae species of the Bizerte area (northern Tunisia). In 15th International Colloqium on Amphipoda. 2–7 September 2013 (pp. 34). Łódź: Piktor S.C.

Fallaci, M., Aloia, A., Audoglio, M., Colombini, L., Scapini, F. et al. (1999). Differences in behavioural strategies between two sympatric talitrids (Amphipoda) inhabiting an exposed sandy beach of the French Atlantic coast. *Estuarine, Coastal and Shelf Science* 48: 469–482.

Fanini, L. & Lowry, J. (2014). Coastal talitrids and connectivity between beaches: A behavioural test. *Journal of Experimental Marine Biology and Ecology* 457: 120–127.

HELCOM (2013a). Red List Species Information Sheet, *Talitrus saltator*. Retrieved June 20, 2018, from http://helcom.fi/Red%20List%20Species%20Information%20Sheet/HELCOM%20Red%20List%20Talitrus%20saltator.pdf.

HELCOM (2013b). Red List Species Information Sheet, Deshayesorchestia deshayesii. Retrieved June 20, 2018, from http://helcom.fi/Red%20List%20Species%20Information%20Sheet/HELCOM%20Red%20List%20Deshayesorchestia%20deshayesii.pdf.

HELCOM (2014). Soft bottom macrozoobenthos. COMBINE program Annex C-8.

Herkül, K., Kotta, J. & Kotta, I. (2006). Distribution and population characteristics of the alien talitrid amphipod *Orchestia cavimana* in relation to environmental conditions in the Northeastern Baltic Sea. *Helgoland Marine Research* 60(2): 121–126. DOI: 10.1007/s10152-006-0030-y.

Herold, W. (1925). Der Amphipode Orchestia cavimana Heller in Pommern. *Abhandlungen und Berichte der Pommerschen Naturforschenden Gesellschaft* 6: 109–110.

Horton, T., Lowry, J., De Broyer, C., Bellan-Santini, D., Coleman, C.O. et al. (2018). World Amphipoda Database. Talitridae Rafinesque, 1815. Accessed through: World Register of Marine Species at: http://www.marinespecies.org/aphia.php?p=taxdetails&id=101411 on 2018-08-30.

Hupało, K. & Grabowski, M. (2018). A first insight into the transatlantic population genetic structure of the beach flea, *Platorchestia platensis* (Krøyer,1845). *BioInvasions Records* 7(2):165–170. DOI: 10.3391/bir.2018.7.2.08.

Jankowska, E., De Troch, M., Michel, L.N., Lepoint, G. & Włodarska-Kowalczuk, M. (2018). Modification of benthic food web structure by recovering seagrass meadows, as revealed by trophic markers and mixing models. *Ecological Indicators* 90: 28–37. DOI: 10.1016/j.ecolind.2018.02.054.

Jędrzejczak, M.F. (2002) Stranded *Zostera marina* L. vs wrack fauna community interactions on a Baltic sandy beach (Hel, Poland): A short-term pilot study. Part II. Driftline effects of succession changes and colonisation of beach fauna. *Oceanologia* 44(3): 367–387.

Karlbrink, F. (1969) Distribution and dispersal of *Talitridae* (Amphipoda) in southern Sweden. *Oikos* 20: 327–334.

Kinzelbach, R. (1965). Ein Flochkrebs, *Orchestia cavimana* Heller, am Oberrhein. *Beiträge zu naturkundlichen Forschung in Südwestdeutschland* 24: 153–157.

Kinzelbach, R. (1972). Zur Verbreitung und Ökologie des Süßwasser-Strandflohs *Orchestia cavimana* Heller 1865 (Crustacea, Amphipoda: Talitridae). *Bonner Zoologische Beiträge* 23: 267–282.

Konopacka, A., Grabowski, M., Bacela-Spychalska, K. & Rewicz, T. (2009). *Orchestia cavimana* Heller, 1865 (Amphipoda: Talitridae) enters freshwater inland habitats in the Vistula River, Poland. *Aquatic Invasions* 4(4): 689–691. DOI: 10.3391/ai.2009.4.4.16.

Kotwicki, L., Baczewska, A., Janas, U., Krajczyk, J., Sztybor, K. et al. (2009). Increased human impact on talitrids on the Polish coast. In 5th International Symposium on Sandy

Beaches. 19–23 October. Rabat. Morocco.

Kozieł, M. (2004). Changes in location of population of sandhoppers *Talorchestia deshayesii* (Audouin, 1826), according to age. *Baltic Coastal Zone* 8: 95–203.

La Fontaine, H. (1902). Pasicrisie international 1794–1900 – Historie documentaire des arbitrages internationaux. Berne: Stampfli.

Lacey, N. (2008). Description of a Polish population of *Platorchestia platensis* (Krøyer), with a comparison of *P. monodi* and *P. japonica*. Unpublished bachelor dissertation. Plymouth University.

Lincoln, R.J. (1979). *British Marine Amphipoda: Gammaridea*. London: British Mus. (Natural History).

Morritt, D. & Spicer, J.I. (1998). The physiological ecology of talitrid amphipods: an update. *Canadian Journal of Zoology* 76: 1965–1982.

Ojaveer, H., Olenin, S., Narščius, A., Florin, A.-B., Ezhova, E. et al. (2017). Dynamics of biological invasions and pathways over time: a case study of a temperate coastal sea. *Biological Invasions* 19: 799–813. DOI: 10.1007/s10530-016-1316-x.

Pavesi, L., Wildish, D.J., Gasson, P., Lowe, M. & Ketmaier, V. (2015). Further morphological and molecular studies of driftwood hoppers (Crustacea: Amphipoda: Talitridae) from Mediterranean/north-east Atlantic coastlines. *Journal of Natural History* 49: 1047–1071. DOI: 10.1080/00222933.2014.974708.

Persson, L.E. (2001). Dispersal of *Platorchestia platensis* (Kröyer) (Amphipoda: Talitridae) along Swedish coasts: A Slow but Successful Process. *Estuarine Coastal and Shelf Science* 52(2): 201–210.

Rasmussen, E. (1973). Systematics and ecology of the Isefjord marine Fauna (Denmark). *Ophelia* 11(1):1–507.

Ruffo, S., Tarocco, M. & Latella, L. (2014). *Cryptorchestia garbinii* n. sp. (Amphipoda: Talitridae) from Lake Garda (Northern Italy), previously referred to as *Orchestia cavimana* Heller, 1865, and notes on the distribution of the two species. *Italian Journal of Zoology.* 81(1): 92–99.

Spicer, J.I & Taylor, A.C. (1987). Respiration in air and water of some semi- and fully terrestrial talitrids (Crustacea: Amphipoda: Talitridae). *Journal of Experimental Marine Biology and Ecology.* 106: 265–277.

Spicer, J.I. & Janas, U. (2006). The beachflea *Platorchestia platensis* (Krøyer, 1845): A new addition to the Polish fauna (with a key to Baltic talitrid amphipods). *Oceanologia* 48(2): 321–329.

Urbański J., (1948). *Orchestia cavimana* Heller 1865 (Crustacea, Amphipoda) na wyspie Wolin, oraz rozmieszczenie tego gatunku na ziemiach polskich. *Bad. Fizjogr. Pol. Zach.* 1: 170–189.

Węsławski, J.M., Stanek, A., Siewert, A. & Beer, N. (2000a). The sandhopper (*Talitrus saltator,* Montagu 1808) on the Polish Baltic Coast. Is a victim of increased tourism? *Oceanological Studies* 29(1): 77–87.

Węsławski, J.M., Kupidura, T. & Żabicki, M. (2000b). The sandhoppers, *Talitrus saltator* (Montagu, 1808) (Amphipoda, Gammaridea), at the Polish Baltic coast: seasonal and spatial distribution patterns. *Crustaceana* 73(8): 961–969.

Wildish, D.J. (1988). Ecology and natural history of aquatic Talitroidea. *Canadian Journal of Zoology* 66: 2340–2359. DOI: 10.1139/z88-349.

Wildish, D.J. (2012). Long distance dispersal and evolution of talitrids (Crustacea: Amphipoda: Talitridae) in the northeast Atlantic islands. *Journal of Natural History* 46: 2329–2348. DOI: 10.1080/00222933.2012.708458.

Wildish, D.J. (2017). Evolutionary ecology of driftwood talitrids: a review. *Zoosystematics and Evolution* 93(2): 353–361. DOI: 10.3897/zse.93.12582.

Wildish, D.J., Pavesi, L. & Ketmaier, V. (2012). Talitrid amphipods (Crustacea: Amphipoda: Talitridae) and the driftwood ecological niche: A morphological and molecular study. *Journal of Natural History* 46: 2677–2700. DOI: 10.1080/00222933.2012.717971.

Williams, J.A. (1983). Environmental Regulation of the Burrow Depth Distribution of the Sand-beach Amphipod *Talitrus saltator. Estuarine, Coastal and Shelf Science.* 16: 291–298.

Zettler M.L. (1999). Untersuchungen zum Makrozoobenthos des Breitlings (sûdliche Ostsee) unter besonderer Berücksichtigung der Crustacea. *Rostock. Meeresbiolog. Beitr.* 7: 79–90.

Zettler, M.L. & Zettler, A. (2017). *Marine and freshwater Amphipoda from the Baltic Sea and adjacent territories*. Harxheim: ConchBooks.

Żmudziński, L. (1990). Świat zwierzęcy Bałtyku – atlas makrofauny. Warszawa: WSiP.

DE GRUYTER

Appendix

Sampling locations, ID of the Marine Protected Area (if established), description of the habitat and Talitridae density (ind. m^{-2})

N	Sampling location	Marine Protected Area ID (sub-basin)	Latitude N	Longitude E	Habitat [a)]	Talitridae species [b)]			
						TS mean ± SD (min.–max)	DD mean ± SD (min.–max)	PP mean ± SD (min.–max)	CG mean ± SD (min.–max)
1	Świnoujście	86 (Bornholm Basin)	53°55′39″	14°13′51″	S	0	0	0	0
2	Międzyzdroje	86, 170 (Bornholm Basin)	53°55′25″	14°25′20″	S	0	0	0	0
3	Wisełka		53°58′26″	14°32′54″	S + P	0	0	0	0
4	Dziwnów	170 (Bornholm Basin)	54°02′22″	14°48′49″	S + P	0	0	0	0
5	Niechorze		54°05′20″	15°02′08″	B + P	0	0	0	0
6	Mrzeżyno		54°09′17″	15°20′54″	S + P	76 ± 70 (0–127)	0	0	0
7	Kołobrzeg		54°10′19″	15°30′48″	S + P	0	0	0	0
8	Ustronie morskie		54°13′38″	15°47′33″	S + P	0	0	0	0
9	Mielno		54°15′20″	16°00′37″	S + P	0	0	0	0
10	Łazy		54°17′30″	16°09′11″	S + P	0	0	0	0
11	Dąbki	179 (Bornholm Basin, Eastern Gotland Basin, Gdansk Basin)	54°23′11″	16°19′05″	S + P	0	0	0	0
12	Jarosławiec		54°32′30″	16°32′02″	S + P	0	0	0	0
13	Ustka		54°35′21″	16°51′13″	S	0	0	0	0
14	Orzechowo		54°35′48″	16°54′35″	S	0	0	0	0
15	Rowy		54°38′57″	17°01′10″	S	0	0	0	0
16	Smołdzino	85, 179 (Bornholm Basin, Eastern Gotland Basin, Gdansk Basin)	54°41′47″	17°08′38″	S	0	0	0	0
17	Smołdziński Las		54°42′32″	17°11′05″	S + P	102 ± 139 (0–254)	0	0	0
18	Czołpino		54°43′10″	17°12′47″	S + P	76 ± 170 (0–381)	0	0	0
19	Boleniec		54°44′52″	17°20′43″	S + P	102 ± 227 (0–508)	0	0	0
20	Rąbka		54°45′43″	17°30′24″	S + P	279 ± 375 (0–889)	0	0	0
21	Biebrowo	179 (Bornholm Basin, Eastern Gotland Basin, Gdansk Basin)	54°47′20″	17°41′54″	S + P	787 ± 854 (0–2032)	0	0	0
22	Lubiatowo		54°48′56″	17°51′10″	S + P	76 ± 114 (0–254)	0	0	0
23	Dębki		54°50′01″	18°03′59″	S	0	0	0	0
24	Karwia		54°49′56″	18°08′30″	S	0	0	0	0
25	Jastrzębia Góra		54°50′03″	18°19′46″	S	0	0	0	0
26	Kuźnica	84 (Gdansk Basin)	54°44′08″	18°34′36″	B + P	0	0	7391 ± 4171 (2921–13335)	0
27	Jurata		54°41′11″	18°42′15″	S + P	787 ± 704 (0–1524)	279 ± 425 (0–1016)	25 ± 57 (0–127)	0
28	Hel – Góra Szwedów	–	54°37′46″	18°49′03″	S + P	76 ± 70 (0–127)	0	0	0
29	Hel – Cypel	84 (Gdansk Basin)	54°35′41″	18°48′33″	B + P	0	0	1041 ± 981 (127–2540)	0
30	Hel – Dzika Plaża		54°37′02″	18°46′44″	S + P	610 ± 618 (0–1397)	152 ± 275 (0–635)	0	0
31	Puck		54°43′21″	18°24′57″	B + P	0	0	457 ± 480 (0–1016)	0
32	Osłonino		54°40′06″	18°27′57″	B + P	0	0	0	0
33	Rewa		54°38′06″	18°30′49″	S + P	0	0	0	0
34	Mechelinki		54°36′32″	18°30′54″	S	0	0	0	0
35	Babie Doły		54°35′15″	18°32′07″	S + P	76 ± 114 (0–254)	25 ± 57 (0–127)	5055 ± 9972 (0–22860)	0
36	Orłowo		54°28′50″	18°33′52″	B + P	0	0	76 ± 170 (0–381)	0
37	Stogi		54°22′49″	18°43′08″	S + P	0	0	25 ± 57 (0–127)	102 ± 166 (0–381)
38	Sobieszewo	302 (Gdansk Basin)	54°20′54″	18°47′50″	S + P	0	0	0	1295 ± 863 (0–2286)
39	Jantar	–	54°20′40″	19°01′11″	S	0	0	0	0
40	Sztutowo	–	54°20′58″	19°09′37″	S	51 ± 70 (0–127)	0	0	0
41	Kąty Rybackie	83 (Gdansk Basin)	54°21′14″	19°13′08″	S	25 ± 57 (0–127)	0	0	0
42	Krynica Morska		54°23′59″	19°29′22″	S + P	127 ± 220 (0–508)	0	0	0
43	Piaski		54°26′31″	19°36′21″	S	0	0	0	0

[a] S – bare sand, S + P – sand with plants, B + P – boulders with plants; [b] TS – *T. saltator*, DD – *D. deshayesii*, PP – *P. platensis*, CG – *C. garbini*