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Occurrence of the nonindigenous clams *Rangia cuneata* in the macrozoobenthos community in the coastal waters of the Pomeranian Bay (southern Baltic Sea)

by

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Abstract

This study provides important monitoring of the further expansion of the Atlantic rangia *Rangia cuneata*, especially migration patterns in the western Baltic Sea. The collected macrozoobenthos samples delivered information on the structure of macrozoobenthos and on the locations of occurrence of living clams in the coastal waters of the Pomeranian Bay. Identification of key environmental factors affecting abundance and biomass structure of macrofaunal assemblages also was carried out. Additionally, granulometric analyses of surface sediments were performed. Dominated species of macrozoobenthos community were typical for the coastal zone of the Pomeranian Bay. *Rangia cuneata* was identified in three locations, in the depth range of 6.3–12.1 m, in the open Baltic waters on extension of the Świna Strait up to 4 km from it and approximately 21 km east of the Odra estuary. The high abundance of living individuals of *Rangia cuneata* in the macrozoobenthos community, reaching 5280 ind. m^{-2}, has never been recorded before in studies on this species in the Baltic coastal waters outside rivers, lagoons and sheltered bays.

Key words: *Rangia cuneata*, non-indigenous species, bivalve, clams, macrozoobenthos, Pomeranian Bay, Baltic Sea

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1. Introduction

The spread of nonindigenous species often has a negative impact on the marine environment; however, some of these become permanent and nonthreatening species for the local ecosystem (Leppäkoski & Olenin, 2001; Ojaveer et al., 2017). An example of a bivalve species in the Baltic Sea is *Mya arenaria*. Therefore, recording the presence of the alien clam *Rangia cuneata* (G.B. Sowerby I, 1832) in the Baltic Sea and exploring the possibility of its further spread is important, as this species is becoming a dominant component of the macrozoobenthos in new locations year by year, which may pose a serious ecological issue. Does it have negative effects or, on the other hand, is it a positive phenomenon as a new food resource for fish and seabirds? The answer to this question is not possible without studying the role of the population of *R. cuneata* in the functioning of local ecosystems based on quantitative data in the macrozoobenthos community in the Baltic Sea.

The nonindigenous bivalve *R. cuneata*, a species native to the Gulf of Mexico and the Atlantic coast of North America (Foltz et al., 1995), has been reported in the Baltic Sea since 2010, when it was observed first time in the eastern areas in the Russian part of the Vistula Lagoon (Rudinskaya & Gusev, 2012). The invasion history of *R. cuneata* shows that this species has spread widely in the Baltic Sea, especially in rivers, lagoons, and bays (Table 1). Research on bivalve species *R. cuneata* in the Pomeranian Bay in 2018 included observation of empty shells or living clams only on the beach in Świnoujście or within a 15-km range from LNG terminal in Świnoujście on the beach in 2019 (Warszów, Międzyzdroje) collected by hand and using adjustable sampling rakes (Panicz et al., 2022). Czerniejewski et al. (2023) indicated that the species migration patterns extend across the estuarine waters of the Odra River and adjacent Szczecin Lagoon, so there is a real threat of expansion of *R. cuneata* toward the inland waters, but Solovjova et al. (2019) and Panicz et al. (2022) also signaled second possible direction of expansion, i.e., laterally along the southern coast of the Baltic Sea.

R. cuneata is a medium-sized clam of up to 40–50 mm with a lifespan estimated between 4 years and 5 years (Kendzierska et al., 2024; Wolfe & Petteway, 1968). It is a typical r-strategist, characterized by high reproduction, short developmental cycle, high tolerance to variable environmental factors such as a wide range of temperatures from 2 to 30°C (Cain, 1975), salinity ranging from 0 to 33 (Hopkins & Andrews, 1970; LaSalle & de la Cruz, 1985; Wakida-Kusunoki & MacKenzie, 2004), low sensitivity to stress including extremely resistant to oxygen depletion, and occurrence of toxic metals (Harrel & McConnell, 1995; LaSalle & de la Cruz, 1985; Olson & Harrel, 1973). These traits facilitate settlement in unstable ecosystems and potentially support the colonization of new areas (Kornijów et al., 2018). In the Szczecin and Vistula lagoons, this clam is a food of the roach (*Rutilus rutilus*), the round goby (*Neogobius melanostomus*), the common carp (*Carassius gibelio*), the silver bream (*Blicca bjoerkna storni*), the European flounder

Table 1

Invasion history of the clam *Rangia cuneata* in the Baltic Sea.

Year	Site in the Baltic Sea Root	Country	Reference
2010	The eastern part of Vistula Lagoon; Port of Kaliningrad	Russia	Rudinskaya and Gusev (2012), Ezhova (2012)
2011	The western part of the Vistula Lagoon	Poland	Warzocha and Drgas (2013), Janas et al. (2014), Kornijów et al. (2018)
2013	Curonian Lagoon	Lithuania	Solovjova (2014)
	Gulf of Riga	Estonia	Solovjova (2014), Solovjova et al. (2019)
	Schellbruch Lagoon	Germany	Wiese et al. (2016)
2014	Vistula estuary	Poland	Janas et al. (2014)
	Pärnu Bay (first dead shells)	Estonia	Möller and Kotta (2017)
2015	The channel connecting the North Sea and the Baltic Sea with an entry in Brunsbüttel and around Lübeck	Germany	Wiese et al. (2016)
2016	Swedish Baltic fjord–Svensksundsviken Bay	Sweden	von Proschwitz (2018)
	Pärnu Bay (first living individuals)	Estonia	Möller and Kotta (2017)
2018	Pomeranian Bay–beach of Świnoujście	Poland	Panicz et al. (2022)
2019	Szczecin Lagoon (Odra estuary)	Poland	Czerniejewski et al. (2023)
2021	Ustka Bay	Poland	Kurek and Wiatrowska (2023)

(*Platichthys flesus*), and the European eel (*Anguilla anguilla*) (Charlebois et al., 1997; Kottelat & Freyhof, 2007; Radziejewska & Schernewski, 2008). In the Vistula Lagoon, clams serve as food for ducks (Kornijów et al., 2018). Additionally, empty shells accumulated on the surface of sediments have habitat-forming importance for those benthic organisms that require a hard bottom (Gutierrez et al., 2003).

The goal of the current study is documentation of the direction of the species spread and evidence for the presence of living individuals of *R. cuneata* in the coastal waters of the Pomeranian Bay as well as the assessment of whether this bivalve is a permanent component of the malacofauna in the exposed coastal waters of the southwestern part of the Baltic Sea. Another objective was to evaluate the habitat preference of the nonindigenous bivalves in the coastal waters of the Pomeranian Bay in contrast to the estuary waters of the western Baltic, i.e., brackish water niches of rivers and lagoons. The qualitative and quantitative structure of the benthic macrozoobenthos community was determined in relation to native bivalves with the identification of potential key factors, which determine macrofaunal and *R. cuneata* assemblages, their abundance, and biomass.

2. Material and methods

This study was conducted at 12 sampling stations in September 2022 from aboard Hydrocat 2 in the coastal waters of the Pomeranian Bay (Fig. 1). The Pomeranian Bay is a basin in the southwestern part of the Baltic Sea. It is a shallow bay located north of the Odra River estuary between Germany and Poland with an area of approximately 6000 km^2. The northern boundary is the 20-m isobath to the Arkona and Bornholm basins (Powilleit & Forster, 2018). The average depth of the bay is 13 m (Beszczyńska-Möller, 1999), and salinity ranges from 7.8 to 8.5 PSU (Kube et al., 1996). In the coastal area, outside river mouths dominate fine sand sediments, poor in nutrients, which indicates a low content of organic matter, although coarse sands and gravel can be found locally in the southern parts of the bay (Bobertz & Harff, 2004; Powilleit & Forster, 2018; Rokicka-Praxmajer et al., 1998). Three main rivers flow

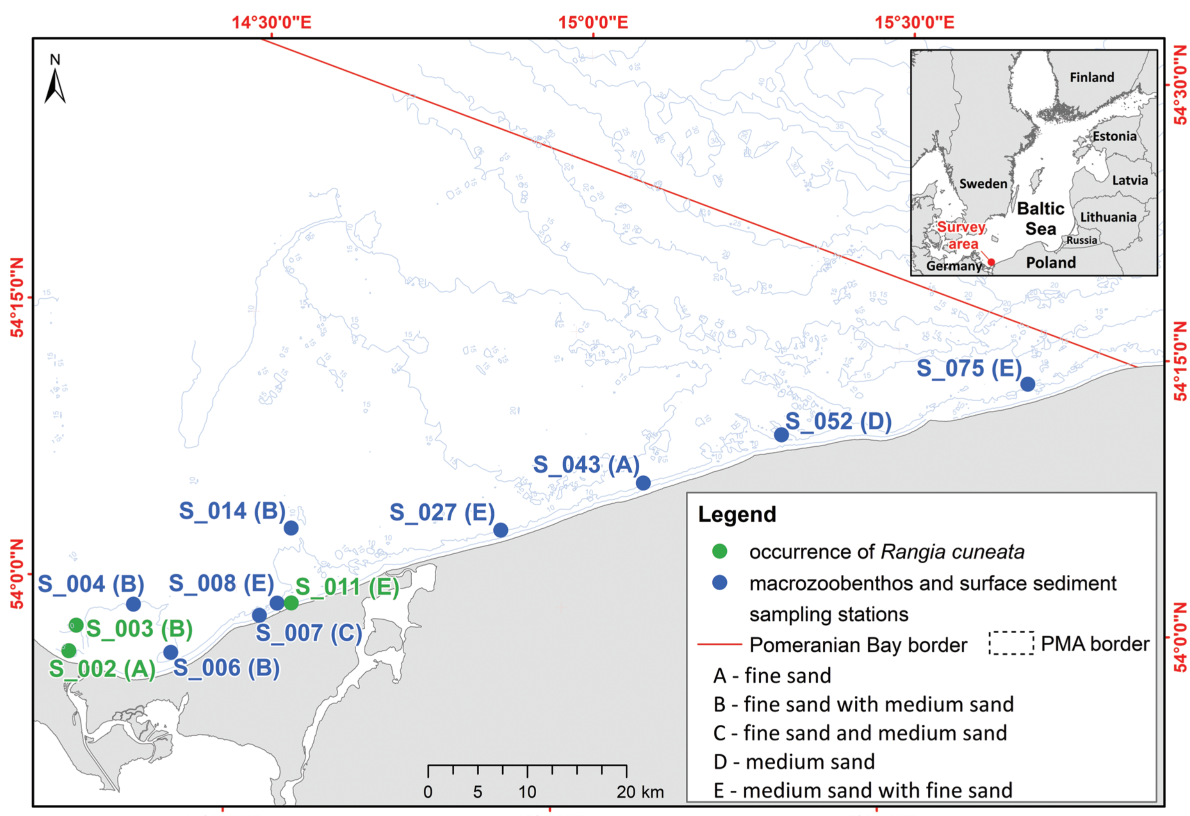

Figure 1

Map of the study area in the coastal waters of the Pomeranian Bay with indication of places of occurrence of *Rangia cuneata* in the macrozoobenthos community.

into the Pomeranian Bay: Peene, Świna, and Dziwna, carrying a large load of fresh water and nutrients. Depending on wind direction, waters from the river mouths move either northwest or northeast along the coast (Schernewski et al., 2001; Siegel et al., 2005).

The quantitative macrozoobenthos samples from the soft bottom have been collected with a standard van Veen grab sampler with a gripping surface of 0.1 m^2 and a mass of approximately 60 kg. On board a vessel, the samples were rinsed through a 1-mm mesh size sieve. The sieving residue was placed in containers and preserved with a 4% formalin solution. The measurements of salinity, temperature, dissolved oxygen concentration, and pH above the bottom were conducted at each station using a multiparameter CTD probe. Additionally, at each of 12 stations, one sample of surface sediment was collected using a van Veen grab for granulometric analyses.

Laboratory analyses of macrozoobenthos samples were performed in accordance with the methods presented in the HELCOM (2021)—*Manual for Marine Monitoring in the COMBINE Programme of HELCOM. Part C. Programme for monitoring of eutrophication and its effects. Annex C-8. Soft bottom macrozoobenthos* and in the *Guidelines to the monitoring of biological elements and the classification of ecological status of surface waters.* Updating methods. *Macrozoobenthos in transitional and coastal waters* (Osowiecki & Błeńska, 2020). The scope of laboratory analyses included the qualitative structure of macrozoobenthos based on taxonomic composition to the lowest possible taxonomic group, where the names were given following the World Register of Marine Species (WoRMS; www.marinespecies.org), and the quantitative analyses included abundance except representatives of Gymnolaemata and Hydrozoa as well as biomass of individual taxa expressed as wet weight in grams, an accuracy of 0.001 g. The abundance and biomass of each taxon was calculated per 1 m^2.

In the laboratory, the samples of surface sediments were examined for the granulometric composition of coarse-grained soils based on sieve analysis after macroscopic examination. The dry sieving method was used in accordance with the standard method of testing soil granulation (PN-EN ISO 17892-4:2017-01). A mechanical shaker was used to perform the tests. The samples were dried for 24 hr at 105°C before granulometric analysis.

Statistical analyses were conducted using PRIMER v.7 & PERMANOVA+ (Primer-E Ltd., Plymouth, UK) (Clarke & Gorley, 2015). The macrozoobenthos data were used to calculate the Bray–Curtis similarity after a square root transformation. A two-dimensional representation of the comparison between the sampling stations was obtained by means of nonparametric multidimensional scaling (nMDS). Environmental data were normalized. Distance-based linear modeling (DistLM) routine and BEST routine in case of environmental parameters were used to identify the abiotic factors that significantly covaried with the macrozoobenthos community structure.

3. Results

Among 12 stations located in the coastal waters of the Pomeranian Bay, in the depth range of 6.3–12.1 m, living individuals of *R. cuneata* were identified at three stations. Two of these three stations are situated approximately 2.5 km and 4 km from the Świna Strait connecting the Odra River estuary with the Pomeranian Bay. The third station with the presence of *R. cuneata* is located approximately 21 km east of the Świna mouth and 10 km east of the Dziwna mouth (Fig. 1 and Table 2).

The stations with the existence of *R. cuneata* in the macrozoobenthos communities differed in-depth, type of bottom sediments, and quantitative structure in the abundance and biomass. The most numerous clams *R. cuneata* occurred at station S_002 closest to the Świna mouth, with numbers reaching 5280 ind. m^2, at a depth of 6.9 m on the fine sand sediment, where juveniles of this species with a length not exceeding 11 mm were identified in the sample. Detailed information on *R. cuneata* in the coastal waters of the Pomeranian Bay together with environmental data is presented in Table 2.

The provided research results allowed for determining the qualitative and quantitative structure of macrozoobenthos communities in the coastal waters of the Pomeranian Bay. A maximum of 23 macrozoobenthos taxa were found, representing 8 classes: Thecostraca, Gymnolaemata, Polychaeta, Clitellata, Malacostraca, Hexapoda, Gastropoda, and Bivalvia. On average, about 11 macrozoobenthos taxa occurred at the examined soft bottom stations. The average number of macrozoobenthos was 4895 ± 5532 ind. · m^{-2}, and the average biomass was 531 ± 177 g · m^{-2}. Species that were classified as absolutely constant (according to Trojan, 1980) were *Peringia ulvae*, *Pygospio elegans*, *Cerastoderma glaucum*, *Marenzelleria* spp., *Mya arenaria*, and *Hediste diversicolor*. The dominance of macrozoobenthos in abundance and biomass is shown in Figs. 2 and 3.

Taking into account all the macrozoobenthos samples, in the abundance snails, *P. ulvae* and bivalves *C. glaucum* were dominated (Fig. 2), while in the

Table 2

Characteristics of the stations with *Rangia cuneata* identification in the macrozoobenthos community

Station	S_002	S_003	S_011
Geographical coordinates	14° 14′57 648″ E 53° 55′59 064″ N	14° 15′29 124″ E 53° 57′23 820″ N	14° 35′08 136″ E 53° 59′21 534″ N
Depth [m]	6.9	10.1	6.3
Temperature [°C]	14.589	14.847	14.589
Salinity [PSU]	7.345	7.331	7.345
Dissolved oxygen content [$mg \cdot L^{-1}$]	10.54	10.53	10.54
pH	8.36	8.24	8.36
Bottom substrate	Fine sand	Fine sand with medium sand	Medium sand with fine sand
Abundance [$ind. \cdot m^{-2}$]/biomass [$g \cdot m^{-2}$] of *R. cuneata*	5280/51.771	10/115.667	80/0.838
Average length [mm]/biomass [$g \cdot m^{-2}$] of individual of *R. cuneata*	≤11/0.1	333/11.57	≤11/0.1
Dominant in abundance/biomass at the station	*Peringia ulvae, Rangia cuneata/ Mya arenaria, Rangia cuneata*	*Pygospio elegans, Marenzelleria spp./Mya arenaria*	*Peringia ulvae/Mytilus trossulus, Cerastoderma glaucum*

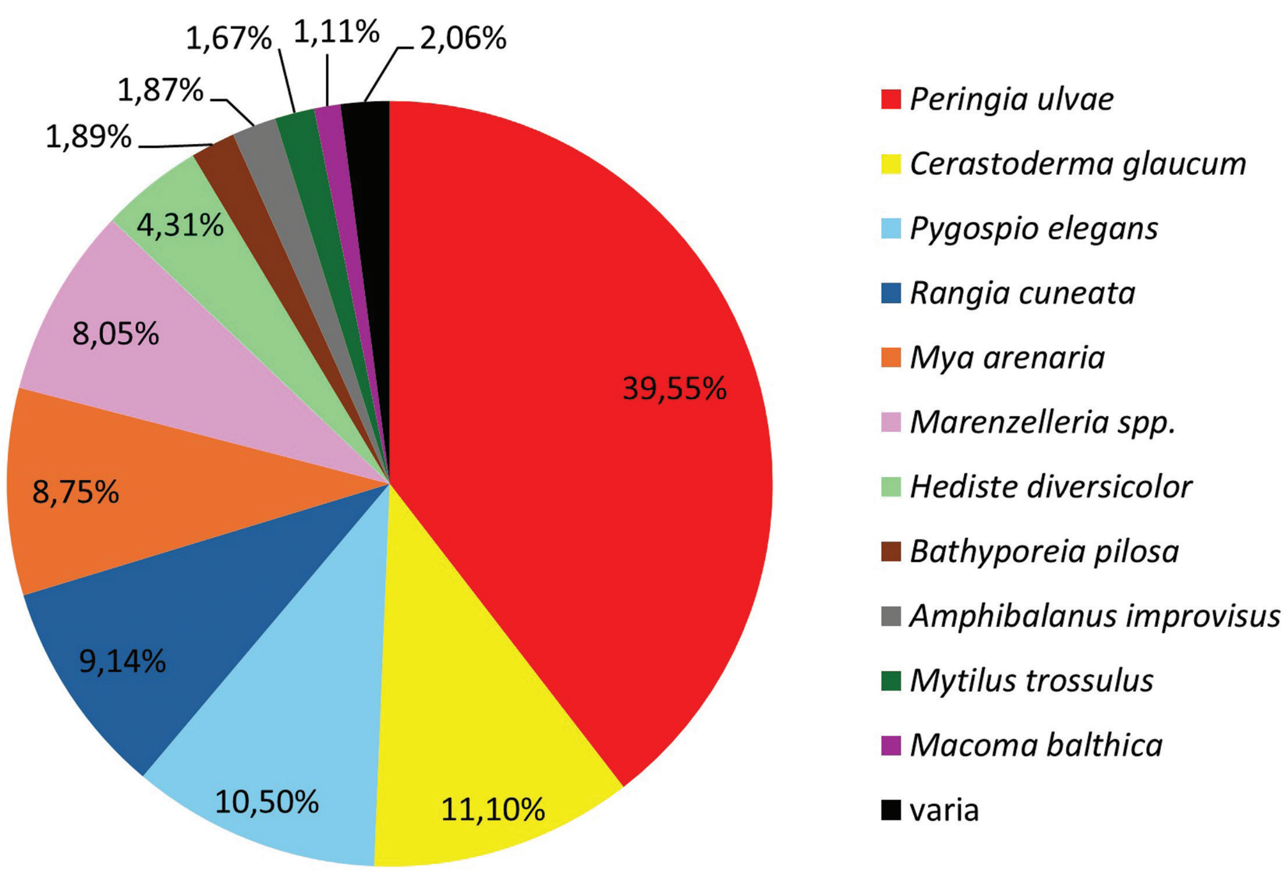

Figure 2

Dominance structure in the total abundance of macrozoobenthos in the coastal zone of the Pomeranian Bay.

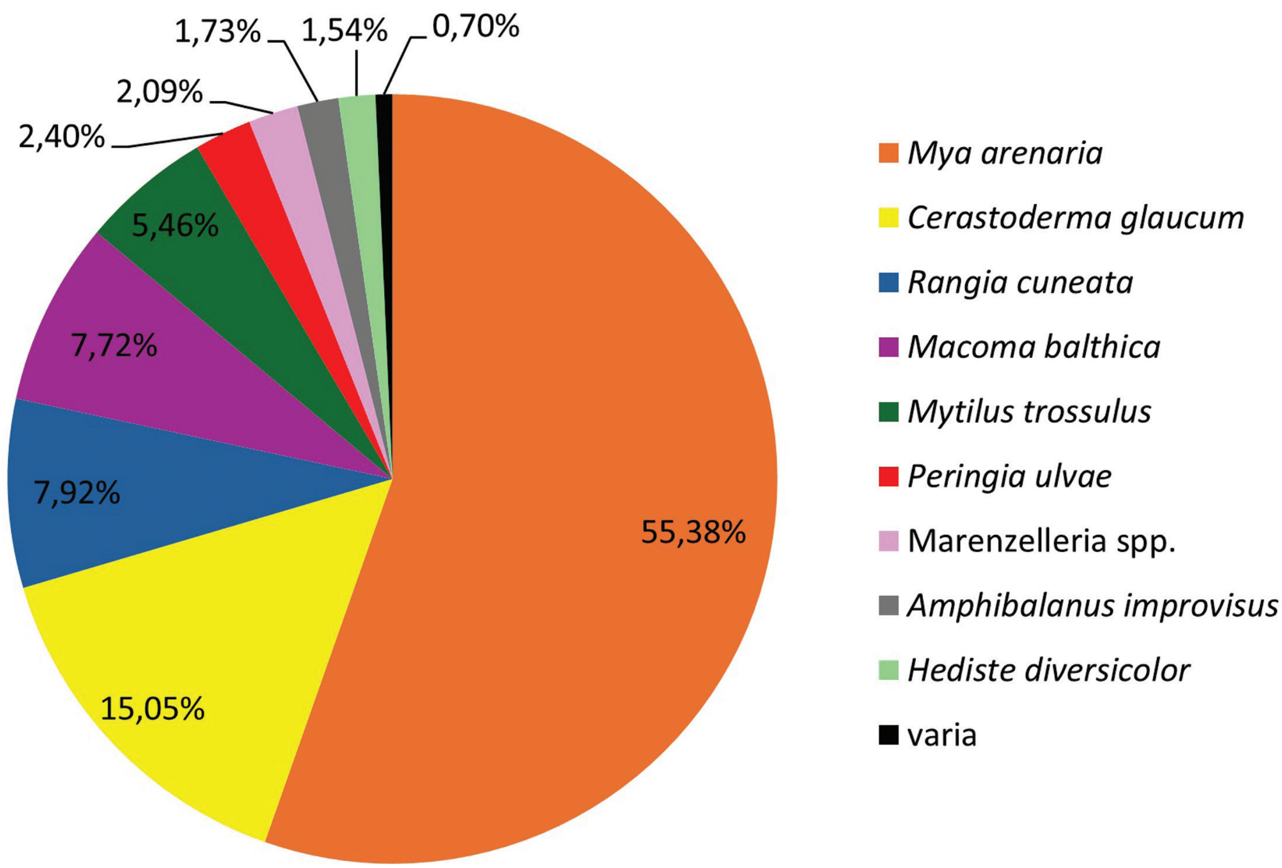

Figure 3

Dominance structure in the total biomass of macrozoobenthos in the coastal zone of the Pomeranian Bay.

biomass definitely bivalves *M. arenaria* prevailed (Fig. 3). Fine sands and fine sands with medium sands predominated at the examined stations, and areas with medium sands or medium sands with fine sands were also identified (Fig. 1).

The distribution of the abundance and biomass of all bivalve species was identified at these stations where *R. cuneata* occurred. The species composition of bivalves at stations S_002 and S_003 was similar, where, in addition to *R. cuneata*, three species of bivalves co-occurred, i.e., *M. arenaria*, *C. glaucum*, and *Macoma balthica*. Station S_011 was distinguished from the previous ones by the presence of bivalves, in addition to *R. cuneata*, such as *M. arenaria*, *Mytilus trossulus*, and *C. glaucum*. In terms of numbers, bivalves at station S_002 reached almost 8000 ind. · m^{-2}, while the highest biomass of mussels of approximately 500 g · m^{-2} was found at station S_003 (Fig. 4).

Considering the physical data from all stations, the temperature fluctuated from 13.6 to 15.0°C, salinity ranged from 7.3 to 7.7, oxygen content varied between 8.85 mg · L^{-1} and 11.06 mg · L^{-1}, and pH range was 7.77–8.37.

Nonmetric MDS plot of the macrozoobenthos samples showing two groups (one with six stations and the second with three stations) and three stations at the similarity level of 60%, but *R. cuneata* was distinguished into three different groups. The most distinct station S_002 was characterized by a very high abundance of *R. cuneata*. In turn, stations S_052 and S_075 were distinguished by a lower abundance and biomass of macrozoobenthos compared to the other stations as well as by their sediment type, medium sand, and medium sand with fine sand, respectively (Fig. 5).

Additionally, a distance-based redundancy analysis (dbRDA) plot of DistLM results was generated in a two-dimensional space to illustrate the relationships between environmental variables and macrozoobenthos taxonomic composition. The length and direction of the vectors represent the strength and direction of the relationship. Among all variables (depth, salinity, temperature, dissolved oxygen concentration, and pH), only depth was statistically significant ($p < 0.01$). Environmental variables accounted for $r^2 = 0.43$ (DistLM adjusted r^2) of the variation in species composition.

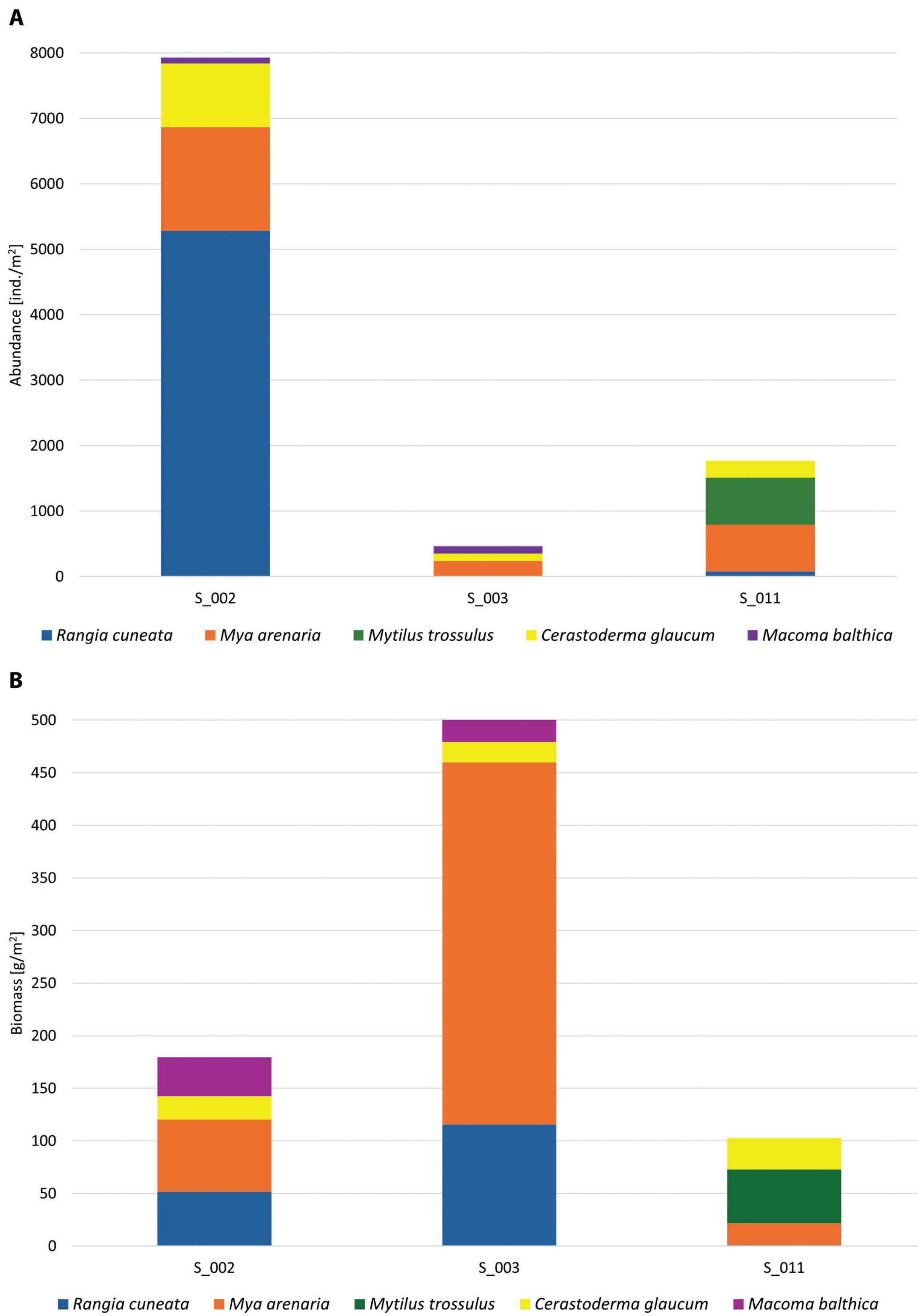

Figure 4

The contribution in the abundance (A) and biomass (B) of each bivalve species.

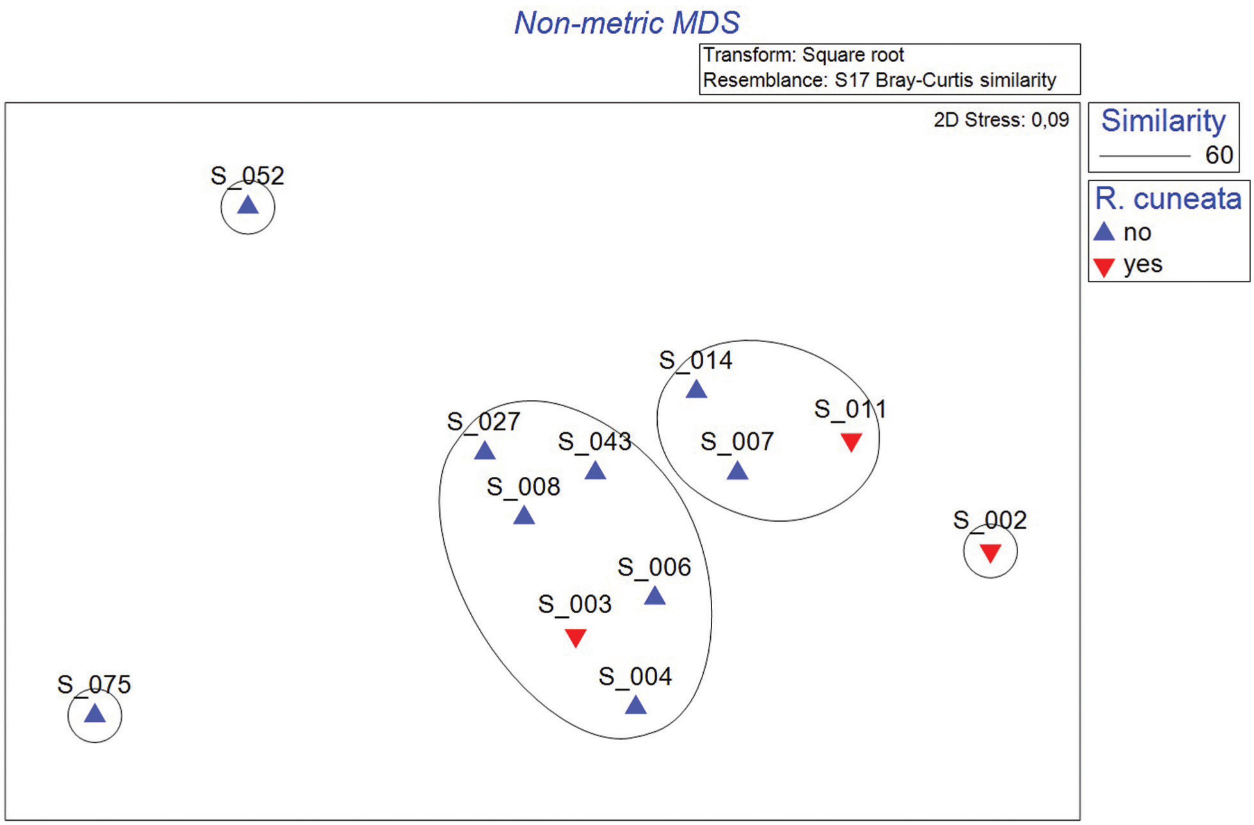

Figure 5

Nonmetric MDS plot of the macrozoobenthos samples in the coastal waters of the Pomeranian Bay. Black ovals show 60% similarity, and different colors of symbols indicate the presence of *Rangia cuneata*.

Among these, temperature (2.44% of variation) and oxygen concentration (6.45% of variation) explained the most variation. The first axis of dbRDA plot explains 34.2% of the total variation, while the second axis shows 17.1% of the total variation (Fig. 6).

Besides, BEST (BIO-ENV) routine was used to investigate the relationship between macrozoobenthos taxonomic composition and physical variables including depth, salinity, water temperature, oxygen concentration, and pH. The results were statistically significant ($p < 0.01$). The analysis indicated that among the six examined variables, the combination of temperature and oxygen concentration best explained the observed patterns in macrozoobenthos taxonomic composition (Table 3).

4. Discussion

Species dominated in the coastal zone of the Pomeranian Bay in this study, i.e., *P. ulvae*, *M. arenaria*, *M. balthica*, *P. elegans*, *H. diversicolor*, and *Marenzelleria* spp., are typical estuarine species that have not changed for 30 years (Powilleit et al., 1995) with the exception of the appearance of the new bivalve species *R. cuneata* in several locations. In the study by Glockzin and Zettler (2008), which was the first research on biotic and environmental interactions of macrozoobenthos in the shallow areas (4–16 m) of the German part of Pomeranian Bay, the dominant species in terms of abundance were *P. ulvae*, *P. elegans*, and the bivalves, i.e., *M. arenaria* and *C. glaucum*. Factors such as water depth, sediment characteristics (including organic content, sorting, and permeability), and the food supply in the bottom water were considered the most important factors controlling the distribution of macrofauna in the coastal waters of the Pomeranian Bay (Kube et al., 1996; Powilleit & Forster, 2018). However, statistical analysis in 2022 has shown that the abundance of macrozoobenthos community was positively correlated with temperature and oxygen concentrations.

In previous studies, the abovementioned macrozoobenthos species accounted for nearly 90% of the dominance, but in the present study, they constituted 82% of the community with *R. cuneata* contribution

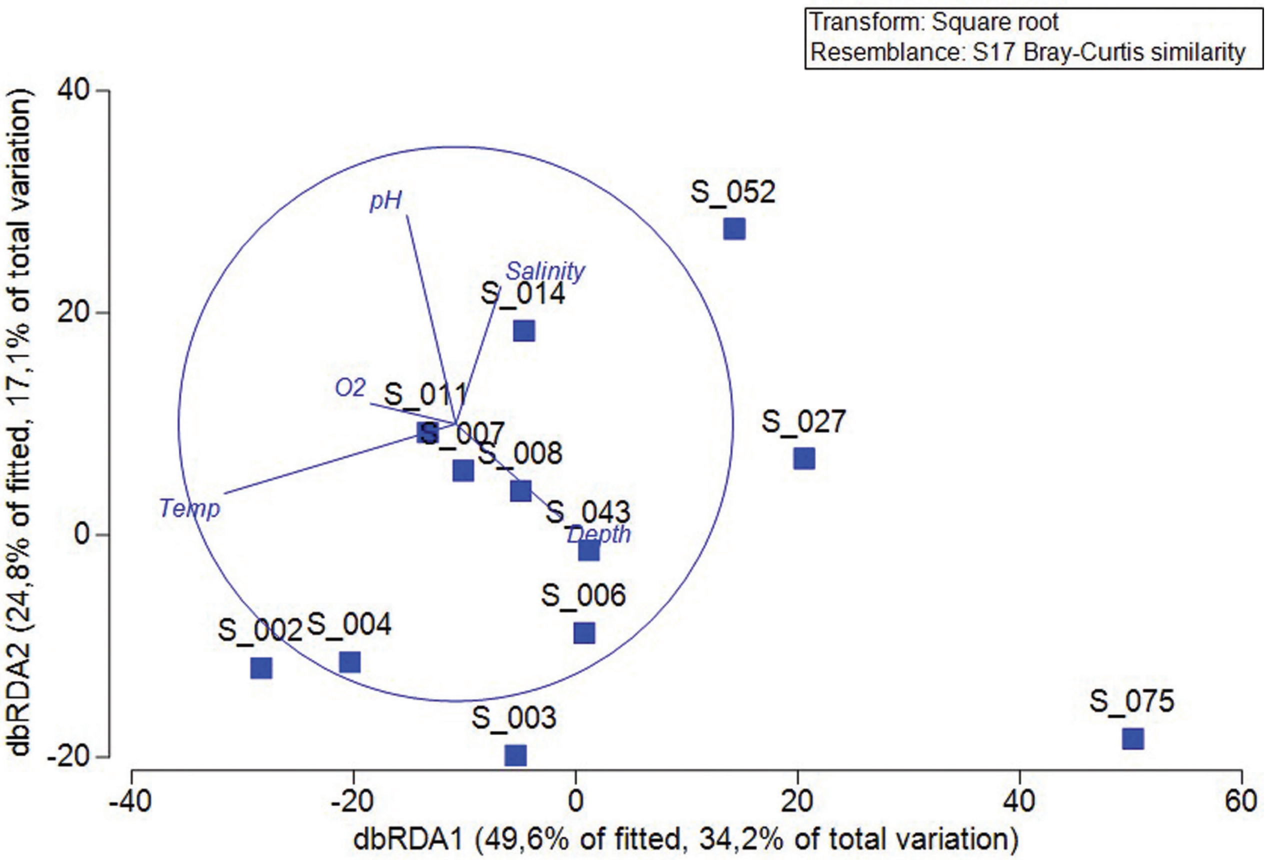

Figure 6

Distance-based redundancy analysis (dbRDA) plot based on macrozoobenthos taxonomic composition and environmental variables.

Table 3

Best result for each number of variables.

No. of variable	Correlation	Selections
1	0.603	Temperature
2	0.725	Temperature, O_2
3	0.722	Temperature, O_2, pH
4	0.698	Depth, temperature, O_2, pH
5	0.651	Depth, temperature, salinity, O_2, pH

on average 9% of the macrozoobenthos community abundance in the areas where it occurred. The occurrence of *R. cuneata* in the coastal waters of the Pomeranian Bay confirms the possibility of its colonization not only in lagoons, river estuaries, and sheltered bays but also in the coastal waters of the open sea. The maximum distance of 4 km from the Świna mouth as well as a depth of up to 10 m were found to be limiting factors. In contrast, in the bays, the species is most common in shallow areas up to 6 m deep, with a preference for waters up to 2.5 m deep (Wakida-Kusunoki & MacKenzie, 2004). In comparison to the preference related to the type of bottom sediments, such as mainly silt and less often sandy substrates, e.g., in the Szczecin Lagoon (Czerniejewski et al., 2023), it was not confirmed that an even sediment type determined the distribution of *R. cuneata*. The individuals of *R. cuneata* found in the Baltic open waters occurred on sandy substrates of fine to medium granularity, which is consistent with the species' preference for inhabiting this type of sediment rich in organic matter and phosphate (Failletaz et al., 2020; Möller & Kotta, 2017). The occurrence of *R. cuneata* in the coastal waters of the Pomeranian Bay was observed in the vicinity of the Świna mouth and to the east of it. This suggests an expansion of the species from areas where the population is stabilized, i.e., from the Szczecin Lagoon with good environmental conditions toward open waters in line with the Świna River plume distribution as a component of the Odra River estuarine system and in line with the current direction along the coast of the Pomeranian Bay.

Current conditions in the Świna Strait depend mainly on the nature and magnitude of changes in water levels and their mutual relations in the Pomeranian Bay and the Szczecin Lagoon. The distribution pattern of the Świna River plume is controlled by the prevailing wind system. Dominant westerly winds in summer, autumn, and winter produce an eastward transport along the Polish coast, while easterly winds prevailing in spring result in the plume being directed westward and northwestward. Consequently, the highest accumulation rates, detectable in the form of increased organic enrichment of the sediment, are typical of the areas in the Świna mouth (Łazuga et al., 2016; Siegel et al., 2005).

The presence of living individuals of *R. cuneata* indicates that this species may reproduce in the identified locations of the coastal waters of the Pomeranian Bay, especially north of the Świna mouth, where juvenile individuals (yearlings) and few adults predominated. On the other hand, at station S_011, located east of the Świna mouth in the coastal waters of the Pomeranian Bay, despite the occurrence of juvenile individuals of *R. cuneata*, no adult individuals were recorded. Therefore, it is not certain whether in this location the clam population is established and produces new cohorts or planktonic larvae were brought by currents from the region of the Świna mouth, where the population is stable. The only distinguishing factor for station S_011 compared to other stations is its shallowest depth of 6.3 m, but the remaining physical parameters were comparable across the observed stations. The reproductive activity of *R. cuneata* is influenced by temperature and salinity. Gametogenesis is triggered by temperature fluctuations, typically occurring when the temperature reaches at least 15°C (Cain, 1975; Jovanovich & Marion, 1989). Gonads usually reach maturity twice a year—once in the spring and again from late summer through late fall (Jovanovich & Marion, 1989). Additionally, embryo and larval survival are closely linked to salinity fluctuations. Spawning does not occur at salinity below 1 and appears to be induced by changes in salinity, such as an increase from 0 to 5 (Cain, 1973, 1975; Chanley, 1965; Hopkins & Andrews, 1970; Sundberg & Kennedy, 1993). If salinity remains stable, energy is redirected toward somatic growth, resulting in increased clam size (Cain, 1975; Hoese, 1973; Hopkins & Andrews, 1970). Adults reach sexual maturity at approximately 14–25 mm in length, typically in their second or third year (Cain, 1972; Ebersole & Kennedy, 1994; Fairbanks et al., 1963). The maximum lifespan of *R. cuneata*, confirmed outside the Baltic Sea, is estimated to range from 4–6 years to 15 years (Fairbanks et al., 1963; LaSalle & de la Cruz, 1985; Wolfe & Petteway, 1968).

What other reasons may be limiting the occurrence of *R. cuneata* in coastal waters of the Pomeranian Bay outside the Odra estuary? Presumably, these may include higher hydrodynamic action at the exposed coast, sediment with less organic material, and reduced food resources in comparison to lagoons and estuaries. Additionally, mortality could potentially play a significant role in controlling the growth of *R. cuneata* population. It has also been noted that low winter temperatures negatively affect the survival of clams in the Vistula Lagoon (Gallagher & Wells, 1969; Kornijów et al., 2018; Rudinskaya & Gusev, 2012). At low temperatures and salinities, *R. cuneata* may move to the sediment surface and close its shell, relying on anaerobic metabolism. This behavior can deplete its metabolic reserves and limit its chances of surviving in the winter (Tuszer-Kunc et al., 2020). However, some individuals are able to survive temperatures as low as 1°C (Cain, 1972; Gallagher & Wells, 1969). Mortality induced by abiotic factors tends to be higher among larger clams, especially in spring, while predation seems to be the second control mechanism as observed in the Vistula Lagoon. Post-settlement individuals of *R. cuneata* due to the shallowness of the waters in this lagoon serve as a feeding ground for diving ducks, which contributes to their mortality (Kornijów et al., 2018).

The high abundance of living individuals of *R. cuneata* in the macrozoobenthos community, reaching 5280 ind. · m^{-2} in this research, has never been recorded before in studies on this species of bivalves in the Baltic coastal waters. In 2014, the abundance of *R. cuneata* in the Wisła Śmiała River flowing into the Gulf of Gdańsk varied from 40 ind. · m^{-2} to 540 ind. · m^{-2} (Janas et al., 2014). In the same year, in the Vistula Lagoon, clams reached an abundance of up to 200 ind. · m^{-2}, dominating the macrozoobenthic biomass (Warzocha et al., 2016), while the maximum abundance of *R. cuneata* (4040 ind. · m^{-2}) was observed in the areas adjacent to the Kaliningrad Sea channel (Rudinskaya & Gusev, 2012). In 2021, in the Szczecin Lagoon, the average density of *R. cuneata* was 13.2 ± 7.11 ind. · m^{-2} of the bottom surface, with a maximum of 21.1 ind. · m^{-2} (Czerniejewski et al., 2023). However, in the coastal waters of Lithuania, the number of living clams remained low, with a maximum of only four individuals collected in a van Veen sample in 2016 (Solovjova et al., 2019). Outside the Baltic Sea, i.e., in the waters of northwestern France, densities of *R. cuneata* ranged from 8.55 ind. · m^{-2} to 132.48 ind. · m^{-2} (Faillettaz et al., 2020).

In the sheltered bays, lagoons and rivers *R. cuneata* may have negative effects due to its numerous, thick shells that create a barrier between the water and bottom sediment, limiting the exchange of oxygen (Kendzierska et al., 2024). On the other hand, positive effects can occur as their shells provide a hard, habitat-forming substrate for the settlement of fouling species, algae and invertebrates, similar to *Dreissena polymorpha*. They can also serve as a shelter for small fish and crustaceans (Czerniejewski et al., 2023; Kornijów et al., 2018; Möller & Kotta, 2017).

The bottom macrofauna of the Pomeranian Bay is highly tolerant of variable environmental conditions. Most of these species were listed by Pearson and Rosenberg (1978) as indicators of organic pollution and are expected to respond strongly to changes in additional food sources. The export of nutrients from the eutrophic Szczecin Lagoon into the Pomeranian Bay creates relatively high primary production and excellent trophic conditions for the local benthic fauna, particularly in the vicinity of the Świna mouth, where the benthic macroinvertebrates are abundant (Masłowski, 2003; Ochocki et al., 1999; Rokicka-Praxmajer et al., 1998). The presence of organic matter enables macrozoobenthos to achieve high biomass, but population fluctuations are controlled by numerous factors. The biomass of bottom macrofauna near the Świna mouth was among the highest in the Pomeranian Bay (Powilleit et al., 1995). In the areas near stations S_002 and S_003, literature surveys showed that the macrofaunal biomass was dominated by *M. arenaria* (Masłowski, 2003). The second most important species in terms of biomass was *M. balthica*, which dominated areas where *M. arenaria* was absent. Together, these two bivalves made up over 80% of the total macrozoobenthos biomass. In the present study, the results are comparable, with the additional occurrence of the bivalve *C. glaucum* at station S_002. All species of bivalves, excluding *R. cuneata*, constituted about 55% of the total macrozoobenthos biomass. *R. cuneata* contributed an additional 22% of biomass, bringing the total biomass of these bivalves to nearly 80%. Similar biomass values of bivalves were found at station S_003. This suggests that the biomass of bivalves in the present study is comparable to the data in earlier studies, indicating that *R. cuneata* may be a competitor to other species of bivalves. *R. cuneata* is a burrowing, obligatory suspension-feeding clam and nonselective filter feeder, which consumes large quantities of seasonally available phytoplankton and detritus suspended just above the sediment surface (Gaston et al., 1997; Janas et al., 2014; Möller & Kotta, 2017; Wakida-Kusunoki & MacKenzie, 2004). Other suspension feeders found in the same place as *R. cuneata* are *C. glaucum* and *M. arenaria*. *M. balthica* is known for both surface deposit feeding and suspension feeding, but it switches to suspension feeding only in food-limited sediment (Hummel, 1985; Olafsson, 1986). Selective filter-feeding mussels *Mytilus* spp. are important bivalves in estuarine and coastal rocky shore ecosystems, where they are a major group of seston-feeding bivalves. These mussels thrive in environments with relatively high and variable abundance of suspended particulate matter (Arfin & Bendell-Young, 2001; Kotta et al., 2009).

5. Conclusions

In accordance with the recommendation of previous researchers, the possibility of the expansion of *Rangia cuneata* has been traced. Surveys conducted along the coastal part of the Pomeranian Bay have shown for the first time the presence, abundance, and biomass structure per square meter of the invasive living *Rangia cuneata* as a component of macrozoobenthos community in the open Baltic waters, not only in the vicinity of the river mouth but also outside it. This indicates that *Rangia cuneata* is not only a permanent component of the malacofauna in Polish lagoons, rivers flowing into the bays, and the sheltered bays, but also expands its range of occurrence to the exposed coastal waters of the southwestern part of the Baltic Sea. While in the Świna mouth the population seems to be established, the situation is not entirely clear outside it. This indicates that the limited distribution of *Rangia cuneata* is related to specific environmental factors such as temperature and oxygen concentrations. Although the composition of macrozoobenthos in the coastal waters of the Pomeranian Bay is typical, in the places where *Rangia cuneata* occurs, this clam competes with other species of bivalves, mainly *Mya arenaria* and *Cerastoderma glaucum*, in terms of numbers and biomass. The monitoring of benthic communities in light of this invasion is essential to understanding the long-term ecological impact of *Rangia cuneata* in the Baltic Sea.

Statements and declarations

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References

Arfin, Z., & Bendell-Young, L. (2001). Coast of selective feeding by the blue mussel (*Mytilus trossulus*) as measured by respiration and ammonia excretion rates. *Journal of Experimental Marine Biology and Ecology, 260*(2), 259–269. https://doi.org/10.1016/S0022-0981(01)00255-6

Beszczyńska-Möller, A. (1999). Transport of the Odra river waters and circulation patterns in the Pomeranian Bay. *Oceanologia, 41*(3), 279–309.

Bobertz, B., & Harff, J. (2004). Sediment facies and hydrodynamic setting: A study in the south western Baltic Sea. *Ocean Dynamics, 54*(1), 39–48. https://doi.org/10.1007/s10236-003-0061-8

Cain, T. D. (1972). *The reproductive cycle and larval tolerances of Rangia cuneata in the James River, Virginia* (Paper 1627407610) [Dissertations, Theses, and Masters Projects. William & Mary]. https://doi.org/10.25773/R1V6-RX65

Cain, T. D. (1973). The combined effects of temperature and salinity on embryos and larvae of the clam *Rangia cuneata*. *Marine Biology, 21*(1), 1–6. https://doi.org/10.1007/BF00351185

Cain, T. D. (1975). Reproduction and recruitment of the brackish water clam, *Rangia cuneata* in the James River, Virginia. *Fishery Bulletin, 73*(2), 412.

Chanley, P. (1965). Larval development of the brackish water mactrid clam, *Rangia cuneata*. *Chesapeake Science, 6*(4), 209–213. https://doi.org/10.2307/1350815

Charlebois, P. M., Marsden, J. E., Goettel, R. G., Wolfe, R. K., Jude, D. J., & Rudnika, S. (1997). *The round goby, Neogobius melanostomus (Pallas): A review of European and North American literature* (p. 20). Illinois Natural History Survey Special Publication.

Clarke, K. R., & Gorley, R. N. (2015). *PRIMER v7: User manual/tutorial*. PRIMER-E.

Czerniejewski, P., Dąbrowski, J., Brysiewicz, A., & Formicki, K. (2023). Population structure and density of a new invasive species *Rangia cuneata* in the Szczecin Lagoon (Odra/Oder estuary, Poland). *Aquatic Invasions, 18*(3), 371–384. https://doi.org/10.3391/ai.2023.18.3.109673

Ebersole, E. L., & Kennedy, V. S. (1994). Size selection of Atlantic rangia clams, *Rangia cuneata*, by blue crabs, *Callinectes sapidus*. *Estuaries, 17*(3), 668–673. https://doi.org/10.2307/1352414

Ezhova, E. E. (2012). Novyj vselenets v Baltiyskye Morye–mollusc *Rangia cuneata* (Bivalvia: Mactridae). *Marine Ecology, 11*, 29–32.

Faillettaz, R., Roger, C., Mathieu, M., Robin, J. P., & Costil, K. (2020). Establishment and population features of the non-native Atlantic rangia, *Rangia cuneata* (Mollusca: Bivalvia) in northwestern France. *Aquatic Invasions, 15*(3), 367–381. https://doi.org/10.3391/ai.2020.15.3.02

Fairbanks, L. D., Fingerman, M., Nagabhushanam, R., & Fitzpatrick, J. F. (1963). Biodemographic studies of the clam *Rangia cuneata* gray. *Tulane Studies in Zoology, 10*, 3–47.

Foltz, D. W., Sarver, S. K., & Hrincevich, A. W. (1995). Genetic structure of brackish water clams (*Rangia* spp.). *Biochemical Systematics and Ecology, 23*(3), 223–233. https://doi.org/10.1016/0305-1978(95)00012-J

Gallagher, J. L., & Wells, H. W. (1969). Northern range extension and winter mortality of *Rangia cuneata*. *The Nautilus, 83*(1), 22–25.

Gaston, K. J., Blackburn, T. M., & Lawton, J. H. (1997). Interspecific abundance-range size relationships: An appraisal of mechanisms. *Journal of Animal Ecology, 66*(4),579–601. https://doi.org/10.2307/5951

Glockzin, M., & Zettler, M. L. (2008). Spatial macrozoobenthic distribution patterns in relation to major environmental factors – A case study from the Pomeranian Bay (southern Baltic Sea). *Journal of Sea Research, 59*(3), 144–161. https://doi.org/10.1016/j.seares.2008.01.002

Gutierrez, J. L., Jones, C. G., Strayer, D. L., & Iribarne, O. O. (2003). Mollusks as ecosystem engineers: The role of shell production in aquatic habitats. *Oikos, 101*(1), 79–90. https://doi.org/10.1034/j.1600-0706.2003.12322.x

Harrel, R. C., & McConnell, M. A. (1995). The estuarine clam *Rangia cuneata* as a biomonitor of dioxins and furans in the Neches River, Taylor Bayou, and Fence Lake, Texas. *Estuaries, 18*(1), 264–270. https://doi.org/10.2307/1352637

HELCOM. (2021). Manual for marine monitoring in the COMBINE programme of HELCOM. Part C. Programme for monitoring of eutrophication and its effects. Annex C-8. Soft bottom macrozoobenthos. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.helcom.fi/wp-content/uploads/2019/08/Manual-for-Marine-Monitoring-in-the-COMBINE-Programme-of-HELCOM_PartC_AnnexC8.pdf&ved=2ahUKEwiGh62u_I6OAxUs_7sIHad2NGgQFnoECBYQAQ&usg=AOvVaw35FMagsZ2ky8dJ-2KRb5Ui

Hoese, H. D. (1973). Abundance of the low salinity clam, *Rangia cuneata*, in southwestern Louisiana. *Proceedings of the National Shellfisheries Association*, *63*, 99-106

Hopkins, S. H., & Andrews, J. D. (1970). *Rangia cuneata* on the East Coast: Thousand mile range extension, or resurgence? *Science, 167*(3919), 868–869. https://doi.org/10.1126/science.167.3919.868

Hummel, H. (1985). An energy budget for a *Macoma balthica* (Mollusca) population living on a tidal flat in the Dutch Wadden Sea. *Netherlands Journal of Sea Research, 19*(1), 84–92. https://doi.org/10.1016/0077-7579(85)90045-6

Janas, U., Kendzierska, H., Dąbrowska, A. H., & Dziubińska, A. (2014). Non-indigenous bivalve—the Atlantic rangia *Rangia cuneata*—in the Wisła Śmiała River (coastal waters of the Gulf of Gdańsk, the southern Baltic Sea). *Oceanological and Hydrobiological Studies, 43*(4), 427–430. https://doi.org/10.2478/s13545-014-0158-3

Jovanovich, M. C., & Marion, K. R. (1989). Gametogenic cycle of *Rangia cuneata* (Mactridae, Mollusca) in Mobile Bay, Alabama, with comments on geographic variation. *Bulletin of Marine Science, 45*(1), 130–138.

Kendzierska, H., Czenczek, Z., & Janas, U. (2024). *Czy małż Rangia cuneata* może stać się dominującym składnikiem makrozoobentosu Morza Bałtyckiego? IV Konferencja Naukowa Polskich Badaczy Morza "Stan i trendy zmian środowiska morskiego", 16-09-2024–18-09-2024. (in Polish).

Kornijów, R., Pawlikowski, K., Drgas, A., Rolbiecki, L., & Rychter, A. (2018). Mortality of post-settlement clams *Rangia cuneata* (Mactridae, Bivalvia) at an early stage of invasion in the Vistula Lagoon (South Baltic) due to biotic and abiotic factors. *Hydrobiologia, 811*(1), 207–219. https://doi.org/10.1007/s10750-017-3489-4

Kotta, J., Herkül, K., Kotta, I., Orav-Kotta, H., & Lauringson, V. (2009). Effects of the suspension feeding mussel *Mytilus trossulus* on a brackish water macroalgal and associated invertebrate community. *Marine Ecology, 30*(Suppl. 1), 56–64. https://doi.org/10.1111/j.1439-0485.2009.00303.x

Kottelat, M., & Freyhof, J. (2007). *Handbook of European freshwater fishes* (p. 13). Publications Kottelat.

Kube, J., Peters, C., & Powilleit, M. (1996). Spatial variation in growth of *Macoma balthica* and *Mya arenaria* (Mollusca, Bivalvia) in relation to environmental gradients in the Pomeranian Bay (southern Baltic Sea). *Archive of Fishery and Marine Research, 44*, 81–93.

Kurek, P., & Wiatrowska, B. (2023). New record of *Rangia cuneata* (Mollusca: Bivalvia: Mactridae) on southern coast of Baltic Sea (N Poland). *European Journal of Ecology, 9*(2), 6–8. https://doi.org/10.17161/eurojecol.v9i2.19751

LaSalle, M. W., & de la Cruz, A. (1985). Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico): Common rangia (p. 82). Fish and Wildlife Service.

Łazuga, K., Gucma, L., & Gucma, M. (2016). Analysis of hydro-meteorological conditions in the area of the Port of Świnoujście between 2011-2015. *Scientific Journals of the Maritime University of Szczecin, 46*(118), 203–208.

Leppäkoski, E., & Olenin, S. (2001). The meltdown of biogeographical peculiarities of the Baltic Sea: The interaction of natural and man-made processes. *AMBIO: A Journal of the Human Environment, 30*(4), 202–209. https://doi.org/10.1579/0044-7447-30.4.202

Masłowski, J. (2003). Effects of trophic conditions on benthic macrofauna in the vicinity of the River Świna mouth (Pomeranian Bay; southern Baltic Sea). *Oceanologia, 45*(1), 41–52.

Möller, T., & Kotta, J. (2017). *Rangia cuneata* (G.B. Sowerby I, 1831) continues its invasion in the Baltic Sea: The first record in Pärnu Bay, Estonia. *BioInvasions Records, 6*(2), 167–172. https://doi.org/10.3391/bir.2017.6.2.13

Ochocki, S., Chmielowski, H., Nakonieczny, J., & Zalewski, M. (1999). The impact of Odra river waters on the seasonal and spatial distribution of primary production and chlorophyll a concentrations in the Pomeranian Bay in 1996-1997. *Oceanologia, 41*(3), 373–388.

Ojaveer, H., Olenin, S., Narščius, A., Florin, A. B., Ezhova, E., Gollasch, S., Jensen, K. R., Lehtiniemi, M., Minchin, D., Normant-Saremba, M., & Strāke, S. (2017). Dynamics of biological invasions and pathways over time: a case study of a temperate coastal sea. *Biological Invasions, 19*(3), 799–813. https://doi.org/10.1007/s10530-016-1316-x

Olafsson, E. B. (1986). Density dependence in suspension-feeding and deposit-feeding populations of the bivalve *Macoma balthica*: A field experiment. *Journal of Animal Ecology, 55*(2), 517–526. https://doi.org/10.2307/4735

Olson, K. R., & Harrel, R. C. (1973). Effect of salinity on acute toxicity of mercury, copper, and chromium for *Rangia cuneata* (Pelecypoda, Mactridae). *Contributions in Marine Science, 17*, 9–13.

Osowiecki, A., & Błeńska, M. (2020). Makrobezkręgowce bentosowe. In Przewodniki metodyczne do badań terenowych i analiz laboratoryjnych fitoplanktonu, innej flory wodnej i makrobezkręgowców bentosowych w wodach przejściowych i przybrzeżnych (pp. 65–84). Biblioteka Monitoringu Środowiska.

Panicz, R., Eljasik, P., Wrzecionkowski, K., Śmietana, N., & Biernaczyk, M. (2022). First report and molecular analysis of population stability of the invasive Gulf wedge clam, *Rangia cuneata* (GB Sowerby I, 1832) in the Pomerian Bay (Southern Baltic Sea). *The European Zoological Journal, 89*(1), 568–578. https://doi.org/10.1080/24750263.2022.2061612

Pearson, T. H., & Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology-An Annual Review, 16*, 229–311.

Powilleit, M., & Forster, S. (2018). Continuous and high transport of particles and solutes by benthos in coastal eutrophic sediments of the Pomeranian Bay. *Frontiers in Marine Science, 5*(472). https://doi.org/10.3389/fmars.2018.00472

Powilleit, M., Kube, J., Maslowski, J., & Warzocha, J. (1995). Distribution of macrobenthic invertebrates in the Pomeranian Bay (southern Baltic) in 1993/1994. *Bulletin of the Sea Fisheries Institute, 3*, 75–87.

Radziejewska, T., & Schernewski, G. (2008). The Szczecin (Oder-) Lagoon. In *Ecology of Baltic coastal waters* (pp. 115–129). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-73524-3_5

Rokicka-Praxmajer, J., Radziejewska, T., & Dworczak, H. (1998). Meiobenthic communities of the Pomeranian Bay (southern Baltic): Effects of proximity to river discharge. *Oceanologia, 40*(3), 243–260.

Rudinskaya, L. V., & Gusev, A. A. (2012). Invasion of the North American wedge clam *Rangia cuneata* (G. B. Sowerby I, 1831) (Bivalvia: Mactridae) in the Vistula Lagoon of the Baltic Sea. *Russian Journal of Biological Invasions, 3*(3), 220–229. https://doi.org/10.1134/S2075111712030071

Schernewski, G., Neumann, T., Podsetchine, V., & Siegel, H. (2001). Spatial impact of the Oder river plume on water quality along the south-western Baltic coast. *International Journal of Hygiene and Environmental Health, 204*(2–3), 143–155. https://doi.org/10.1078/1438-4639-00086

Siegel, H., Seifert, T., Schernewski, G., Gerth, M., Ohde, T., Reißmann, J., & Podsetchine, V. (2005). Discharge and transport processes along the German Baltic Sea Coast. *Ocean Dynamics, 55*, 47–66. https://doi.org/10.1007/s10236-005-0110-6

Solovjova, S. (2014). Finding of new mollusk species *Rangia cuneata* (G.B.Sowerby I, 1831) (Bivalvia: Mactridae) in the Lithuanian coastal waters. Environmental Protection Agency, Lithuania. https://aquanisresearch.com/aquanis/introductions/view/id/3840.

Solovjova, S., Samuilovienė, A., Srėbalienė, G., Minchin, D., & Olenin, S. (2019). Limited success of the non-indigenous bivalve clam *Rangia cuneata* in the Lithuanian coastal waters of the Baltic Sea and the Curonian Lagoon. *Oceanologia, 61*(3), 341–349. https://doi.org/10.1016/j.oceano.2019.01.005

Sundberg, K., & Kennedy, V. S. (1993). Larval settlement of the Atlantic rangia, *Rangia cuneata* (Bivalvia: Mactridae). *Estuaries, 16*, 223–228. https://doi.org/10.2307/1352493

Tuszer-Kunc, J., Normant-Saremba, M., & Rychter, A. (2020). The combination of low salinity and low temperature can limit the colonisation success of the non-native bivalve *Rangia cuneata* in brackish Baltic waters. *Journal of Experimental Marine Biology and Ecology, 524*, 151228. https://doi.org/10.1016/j.jembe.2019.151228

von Proschwitz, T., (2018). Two invasive brackish water mussel species in Sweden: *Rangia cuneata* (G. B. Sowerby I) and *Mytilopsis leucophaeata* (Conrad). *Journal of Conchology*, *43* (1): 111–113.

Wakida-Kusunoki, A. T., & MacKenzie, C. L. Jr. (2004). Rangia and marsh clams, *Rangia cuneata*, *R. flexuosa*, and *Polymesoda caroliniana*, in Eastern México: Distribution, biology and ecology, and historical fisheries. *Marine Fisheries Review, 66*(3), 13–20.

Warzocha, J., & Drgas, A. (2013). The alien gulf wedge clam (*Rangia cuneata* G. B. Sowerby I, 1831) (Mollusca: Bivalvia: Mactridae) in the Polish part of the Vistula Lagoon (SE. Baltic). *Folia Malacologica, 21*(4), 291–292. https://doi.org/10.12657/folmal.021.030

Warzocha, J., Szymanek, L., Witalis, B., & Wodzinowski, T. (2016). The first report on the establishment and spread of the alien clam *Rangia cuneata* (Mactridae) in the Polish part of the Vistula Lagoon (southern Baltic). *Oceanologia, 58*(1), 54–58. https://doi.org/10.1016/j.oceano.2015.10.001

Wiese, L., Niehus, O., Faass, B., & Wiese, V. (2016). Ein weiteres Vorkommen von *Rangia cuneata* in Deutschland (Bivalvia: Mactridae). *Schriften zur Malakozoologie, 29*, 53–60.

Wolfe, D. A., & Petteway, E. N. (1968). Growth of *Rangia cuneata* gray. *Chesapeake Science, 9*(2), 99–102. https://doi.org/10.2307/1351251

World Register of Marine Species. Retrieved January 15, 2025, from http://www.marinespecies.org