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DISTRIBUTION OF COMMON BIVALVES IN THE POLISH COASTAL ZONE OF THE BALTIC SEA

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Abstract

The populations of common Baltic bivalves *Macoma balthica*, *Mytilus edulis* and *Cerastoderma glaucum* were studied in the Polish coast (up to 4 Nm), both in estuary and open coastal zones of the Middle Pomerania as well as in the Puck Bay and the Gulf of Gdańsk (up to 2 Nm). The following parameters were investigated: density of the bivalves and environmental conditions (distance from the shore, substrate type, coast type, depth). Relationships between environmental conditions and abundance of the consecutive bivalve species were analysed with the help of ordination method (redundancy analysis RDA) and multivariate regression trees (MRT). RDA analysis indicated that *C. glaucum* density depended mainly on the localisation along the coast while *M. edulis* occurrence was governed by the distance from the shore and depth. Only density of *M. balthica* depended evenly on all the environmental parameters. MRT analysis revealed that the main factors influencing the distribution of bivalves were sediment granularity and depth.

Key words: Polish Baltic coastal zone, bivalves, density, MRT, RDA

INTRODUCTION

Bivalves are common species widely distributed in seas and oceans on the northern hemisphere (North America, Europe, Asia), (e.g. Wenne and Klusek 1985). The Baltic coastal zone is mainly inhabited by three bivalve species – *Macoma balthica*, *Cerastoderma glaucum* and *Mytilus edulis*, even down to 100 m of depth (e.g. Warzocha 1994). Due to their common occurrence in various bottom zones, those species have been used by Warzocha (1995) for biological characteristics of the Baltic Sea bed (for example *Macoma balthica – Mya arenaria* community). Bivalves play an important ecological role in the Baltic since they are part of hemiplankton (larval forms) and benthos (Gunther et al. 1998). Due to feeding habits (deposit-feeders) they eliminate seston (bacteria, phyto- and zooplankton) from bottom water layer and contribute to biosedimentation of agglutinates and fecal matter. Bivalves are also food source for fish and water fowls, including economically useful fish (Krzykawski and Załachowski 1983).

The discussed bivalve species have been repeatedly investigated during research of benthos in the Baltic Sea (Demel and Mulicki 1954, Mulicki and Żmudziński 1969, Warzocha 1994), Pomeranian Bight and the Gulf of Gdańsk (Herra and Wiktor 1985, Osowiecki 2000, Kube et al. 1997, Żmudziński and Ostrowski 1990). In the Polish territorial waters, mainly in the most shallow zones subjected to wavy motion, the bivalves *Macoma*, *Cerastoderma* and *Mytilus* were studied as the element of macrozoobenthos by Kotwicki (1997), Haque et al. (1997), Żmudziński and Andrulewicz (1997), Piesik et al. (2003) and Obolewski et al. (2007).

Bivalves are important bioindicative organisms, useful in the assessment of ecological changes in the shallow-watered zones (including estuaries) of the Baltic Sea (Obolewski 2005). The coastal zone is in direct contact with mainland and receives waters with high load of pollutants. Therefore, apart from deep waters, it is the most endangered area of the Baltic Sea. That situation has been reflected in the European Union Water Directive, which indicates that monitoring of estuary sections is necessary (Kudelska and Soszka 1996).

The aim of that study was to determine the distribution of three bivalve species *Macoma baltica*, *Cerastoderma glaucum* and *Mytilus edulis* in the Polish coastal zone of the Baltic Sea between Kołobrzeg and Gdańsk and to assess their occurrence in the dependence on environmental conditions. The obtained data were analysed using ordinations (redundancy analysis RDA) and multivariate regression trees (MRT). Additionally the distribution and abundance of bivalves as regards potential food source for animals, including economically useful fish, were investigated.

MATERIAL AND METHODS

Study sites

The Polish coastal zone of the Baltic Sea is 528 km long and extends along the Szczecin, Koszalin and Gdańsk shorelands. Within that area a few large rivers flow into the sea, i.e. Odra, Parsęta, Wieprza, Słupia, Łupawa, Łeba and Wisła. Contact zones between saline and riverine freshwaters form 1st order estuaries which constitute distinct habitats for aquatic animals. The load of contaminants contributes to changes in habitat conditions which affect bivalves, particularly sensitive to the deterioration of water quality.

The Puck Bay and the Gulf of Gdańsk have different hydrological conditions. Their area is 364 km^2 and 838 km^2, respectively. They are separated from the proper Baltic Sea by the Hel Peninsula which enables the occurrence both marine and freshwater species. The proximity of densely populated shore contributes to the degradation of those reservoirs.

Table 1

Comparison of researched bivalves density: range, mean abundance ($\bar{x}$), excluding places omitted by this species ($\bar{x}_z$), standard deviation (SD), coefficient of variability (CV) in coastal zone and open coastal zone in region different level pollution and urbanization, (SU) – open coastal zone in strong urbanization region (town, harbour)

Area type	*Cerastoderma glaucum*				*Macoma balthica*				*Mytilus edulis*			
	Middle Pomerania	Wlady-slawowo (SU)	Puck Lagoon (SU)	Gulf of Gdansk (SU)	Middle Pomerania	Wlady-slawowo (SU)	Puck Lagoon (SU)	Gulf of Gdansk (SU)	Middle Pomerania	Wlady-slawowo (SU)	Puck Lagoon (SU)	Gulf of Gdansk (SU)
Coast type	estuary	open coastal	bay	bay	estuary	open coastal	bay	bay	estuary	open coastal	bay	bay
Range abundance (ind. m^{-2})	0-485 n = 22	0-15 n = 6	0-191 n = 13	0-190 n = 23	2-22 n = 22	20-90 n = 6	0-59 n = 13	0-494 n = 23	0-1705 n = 22	0 n = 6	0-45 n = 13	0-10 n = 23
Abundance min – max (ind. m^{-2})	5-485	5-15	22-191	38-190	2-22	20-90	11-59	19-494	50-1705	0	4-45	5-10
$\bar{x}$ – mean abundance (ind. m^{-2})	5.83 n = 22	5.0 n = 6	84.7 n = 13	25.1 n = 6	11.1 n = 22	44.3 n = 6	22.8 n = 13	102.2 n = 23	420.4 n = 22	0 n = 6	5.89 n = 13	0.65 n = 23
$\bar{x}_z$ – excluding places omitted by this species (ind. m^{-2})	81.6 n = 8	10.0 n = 3	95.2 n = 8	57.7 n = 3	37.1 n = 15	44.3 n = 6	39.4 n = 5	213.6 n = 11	1401.1 n = 14	0	17.7 n = 3	7.5 n = 2
SD_z	121.2	6.32	67.9	54.2	30.4	27.1	25.2	145.6	2589.0	0	14.8	2.29
CV	4.63	1.26	0.80	2.16	2.74	0.61	1.15	1.42	6.16	0	2.51	3.51
$\bar{x}$ wet mass (g m^{-2})	5.62	5.67	83.30	0.09	6.20	28.76	8.27	3.88	32.41	0	0.42	0.31
Domination range size	9.5-13.2	5.1-14.3	7.0-10.0	9.0-13.0						0		
Domination age class	2+	2+	1+	2+	3+					-		
Median (Me)	27.0	5.0	69.0	38.0	27.0	37.5	11.0	152.0	286.0	0	4.0	7.5
F (%)	36	50	61	50	39.8	24.5	38.5	48	63.3	0	50	8.7

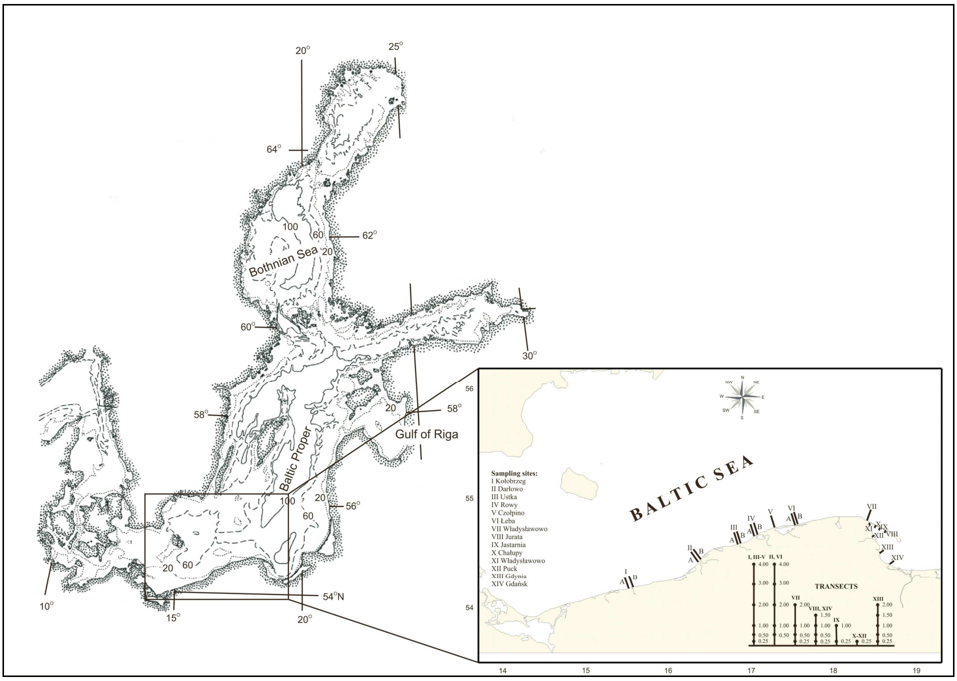

Fig. 1. Location of sampling sites

The common bivalve species were investigated over the years 1996-2005 in the 4 Nm wide Polish coastal zone of the Baltic Sea between Kołobrzeg and Władysławowo as well as in the Puck Bay and the Gulf of Gdańsk within the distance of 2 Nm from the shore (Fig. 1). The samples were collected at 73 sampling sites using the Van Veen bottom grab with a surface of 0.1 m^2. At each site 2-3 grabs were taken (180 samples altogether). Location of the sampling profiles and sites were determined with the help of global positioning system GPS and radiolocation.
The collected material was sieved through a benthos sieve of 1 mm mesh size and then preserved with 4% solution of formaldehyde. In a laboratory the bivalves were counted and their amount was related to the area of 1 m^2. Additionally depth and distance from the shore were measured at the consecutive sampling sites. Grain size analysis of the samples, performed according to norms ISO 4365 and ISO 9195, was applied in order to determine the substrate characteristics. The following substrate types were distinguished: gravel, fine-grained sand, medium-grained sand, coarse-grained sand, silty sand, gravelly sand, stones, sand with mud, sand with loam and sand with stones. Detailed characteristics of the study area is presented in Table 1.

Data analysis

Redundancy Analysis – RDA

Statistical analyses were preceded by the transformation of experimental data in order to obtain normal distribution and eliminate the influence of rare species on the analyses. The applied transformation was log(x+1) because it is applicable to data with null values and allows to avoid negative values in the transformed data set due to further ordination analyses. The additional variable "Zone" was introduced into the data set which determined the type of cost: 1. open coast, 2. estuary, 3. bay. Substrate type was not included in the ordination analyses due to difficulties with changing it into ordinal variable.

Relationships and redundancy (co-linearity) between the predictors (environmental factors) were determined with the help of variance inflation factor VIF in the canonical correspondence analysis CCA, which included both environmental parameters and the densities of bivalve species. Next, the detrended correspondence analysis DCA was applied in order to determine the gradient of the first DCA axis. Values <2 standard deviations indicated monotonic responses of bivalves to environmental gradients (ter Braak 1995). Therefore, relationships between the environment and bivalve abundance were finally analysed with the redundancy analysis RDA (ter Braak 1995).

Ordination analyses were performed with the help of R 2.1.1 software (The R Foundation for Statistical Computing). The following packages were used: cca (ter Braak 1986, Legendre and Legendre 1998), decorana (Hill and Gauch 1980, Oksanen and Minchin 1997) and rda (ter Braak 1986, Legendre and Legendre 1998).

Multivariate regression trees MRT

The next applied statistical technique was multivariate regression tree method (MRT) (Breiman et al. 1984, De'ath and Fabricus 2000, De'ath 2002). The whole set of original variables was included in the analysis. The overall fit of the tree was specified as relative error (RE; SSD – sum of squared Euclidian distances in clusters divided by SSD of the undivided data) and the predictive accuracy was assessed by cross-validated relative error CVRE (Breiman et al. 1984, De'ath and Fabricus 2000). In this study, the finally selected tree was the most complex model within one standard error (1 SE) of the best predictive tree (Breiman et al. 1984), using 2000 multiple cross validations to stabilize CVRE. MRT analysis was carried out in R 2.1.1 (R Development core team, 2004) using the mvpart (Multivariate Partitioning) package.

RESULTS

Macrozoobenthos along the Polish coastal zone (Kołobrzeg-Gdańsk) was predominated by bivalve species *Macoma balthica* (L.), *Mytilus edulis* L. and *Cerastoderma glaucum* Poiret. Cockle density and frequency of occurrence were the highest in the Puck Bay (Tab. 1). The average density of *C. glaucum* in that ecosystem was 17-fold higher than in the vicinity of Władysławowo or in the Middle Pomerania and over 3-fold higher than in the Gulf of Gdańsk (Tab. 1). Cockles occurred in large agglomerations, the most numerous in the Puck Bay and in the estuary zone of the Middle Pomerania but the least numerous in the open coastal zone near Władysławowo (Tab. 1). Cockle abundance depended on the distance from the shore. The highest

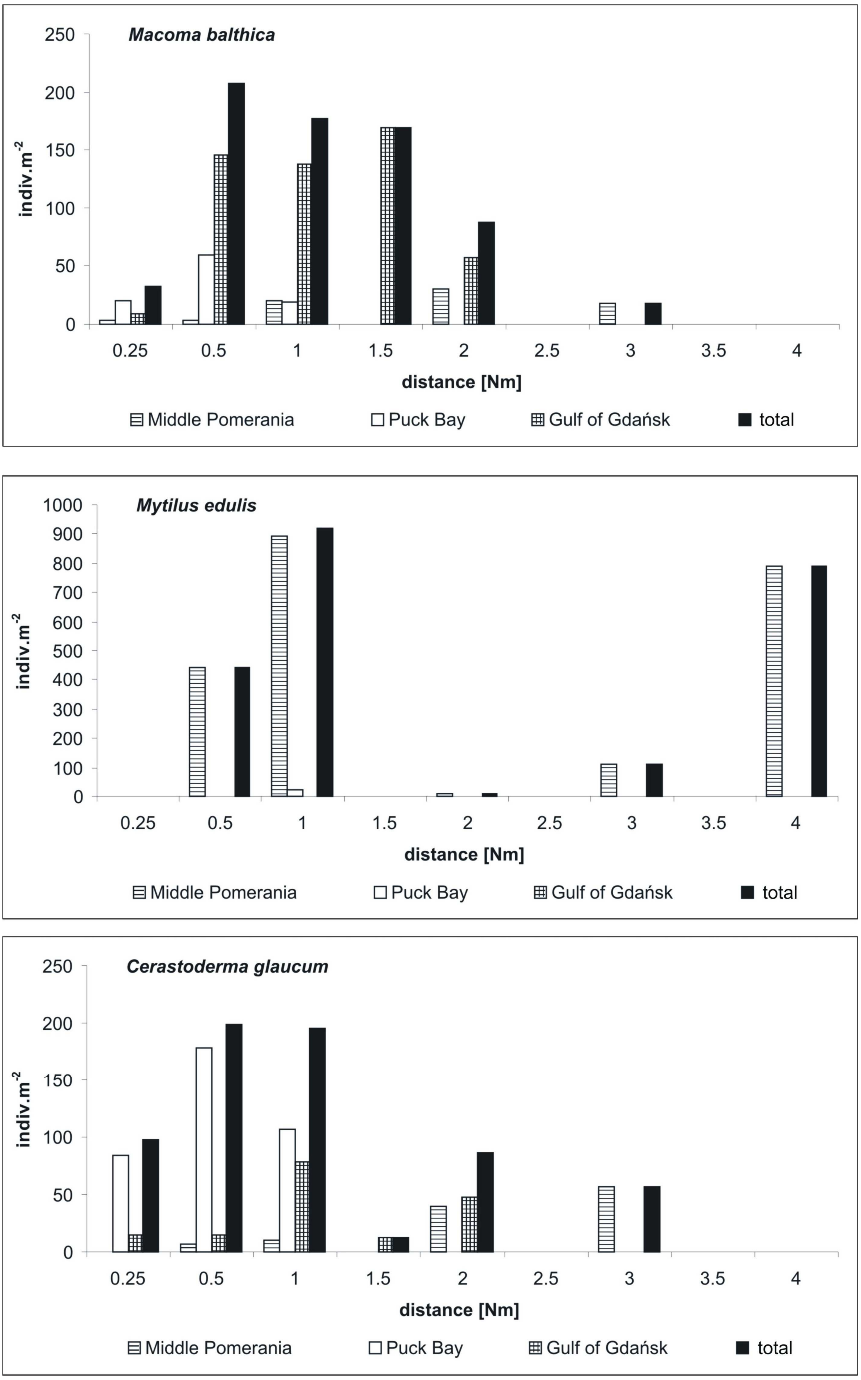

Fig. 2. Density of bivalve species in dependence on distance from the shore at the studied areas of the Polish Baltic coastal zone

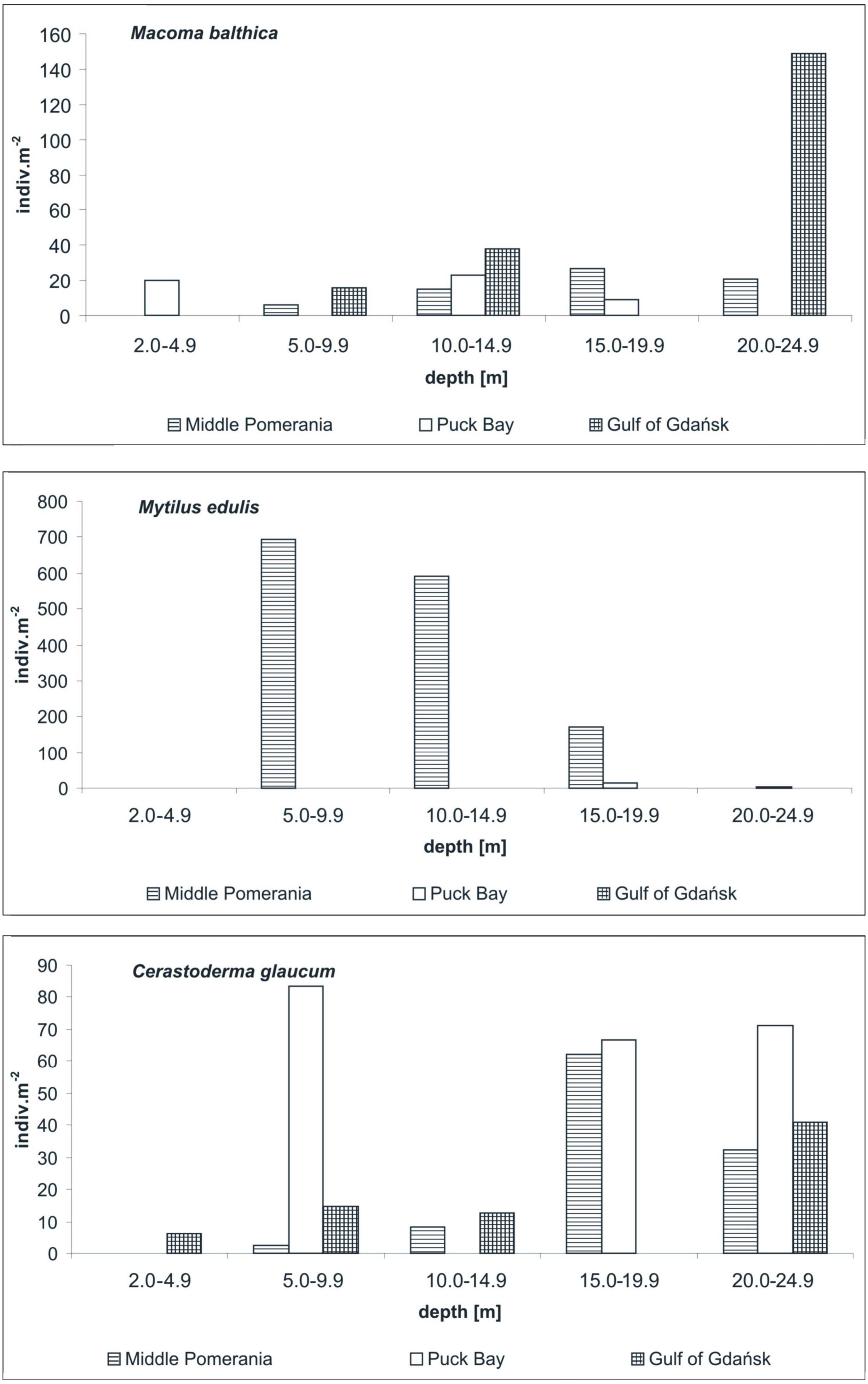

Fig. 3. Density of bivalves in dependence on depth

density was observed 0.5 Nm from the coast (Fig. 2). In the Gulf of Gdańsk it increased up to 1 Nm, in the Puck Bay up to 0.5 Nm while in the Middle Pomerania cockle density was the highest at the deepest sampling sites (3 Nm from the shore). The youngest population of *C. glaucum* was found in the Puck Bay (domination of two-year-old individuals), (Tab. 1).

M. balthica density was lower than the density of *Mytilus edulis* only near Darłówko and Rowy in the Middle Pomerania and it varied considerably. The highest values were observed in the Gulf of Gdańsk while the lowest in the estuary zones (Tab. 1). The total abundance of that bivalve increased up to 0.5 Nm from the shore and than gradually decreased. In the Puck Bay its abundance rose up to 0.5 Nm from the shore while along the Middle Pomerania up to 2 Nm (Fig. 2). The number of *M. balthica* representatives was the highest near Gdańsk which was almost 6-fold higher than in the estuary zones and 5-fold higher than in the open coast or the Puck Bay. In turn, the biomass of that bivalve species reached the highest values near Władysławowo while the lowest in the Gulf of Gdańsk (Tab. 1). *M. balthica* occurred the most frequently near Gdańsk (F=48%) while the least in the vicinity of Władysławowo (F=24.5%).

Blue mussels (*M. edulis*) occurred commonly in the studied estuary zone of the Polish coast and reached the position of constant species (F=63.3%). It was also abundant in the Puck Bay but in the Gulf of Gdańsk it occurred rarely and avoided open sea (Władysławowo). (Tab. 1). Numerous agglomerations of blue mussels were noticed in the estuary zones of the Middle Pomerania (x=1401 indiv. m^{-2}) which was accompanied by considerable biomass of that bivalve species (32.41 g m^{-2}). *M. edulis* reached high density at 1 Nm from the shore but 0.5 Nm from the coast its abundance was almost 2-fold lower (Fig. 2).

The analysis of relationships between the studied bivalve species and the depth of sampling sites indicated that *M. balthica* reached the highest density at considerable depths in the Gulf of Gdańsk (Fig. 3). In other regions that species preferred lower depth: in the Middle Pomerania it was the most abundant at the depth of 20 m while in the Puck Bay at 15 m.

Mytilus edulis reached its maximum density at the depth of 10 m and preferred the estuary region of the Middle Pomerania. Both in the Gulf of Gdańsk and the Puck Bay that bivalve species occurred rarely (Fig. 3).

Deeper sampling sites were preferred by *Cerastoderma glaucum* which had the highest density in the Gulf of Gdańsk at maximum of the studied depths (20-25 m). Cockles in estuaries of the Middle Pomerania occurred abundantly at the depth of 15-19.9 m while in the Puck Bay down to 5-10 m and then at larger depths (Fig. 3).

The observed tendencies in bivalve distribution needed to be confirmed by statistical analyses. Due to multidimensionality of the data set the following methods were chosen: ordination techniques (redundancy analysis RDA) and multivariate regression trees (MRT).

First, the relationships and redundancy (co-linearity) between predictors (environmental parameters) were assessed with the variance inflation factor (VIF) in canonical correspondence analysis (CCA). Both environmental parameters (zone: estuary, open coast, bay; distance from the shore; depth) and density of bivalve species

(*Macoma balthica*, *Mytilus edulis*, *Cerastoderma glaucum*) were taken into account. Since the VIF coefficients were below 10, which indicated low redundancy, all the predictors were included into further analyses.
Next, the detrended correspondence analysis (DCA) was performed, in order to assess the length of first DCA axis. The value below 2 indicated monotonic responses of the consecutive bivalve species to environmental gradients. Therefore, the redundancy analysis (RDA) was further applied (Tab. 2).

Table 2
Biplot scores for constraining variables in RDA analysis

Variables	RDA axis	
	RDA1	RDA2
Zone	0.7478	0.5157
Distance from the shore	-0.8504	0.4406
Depth	-0.8951	0.2581

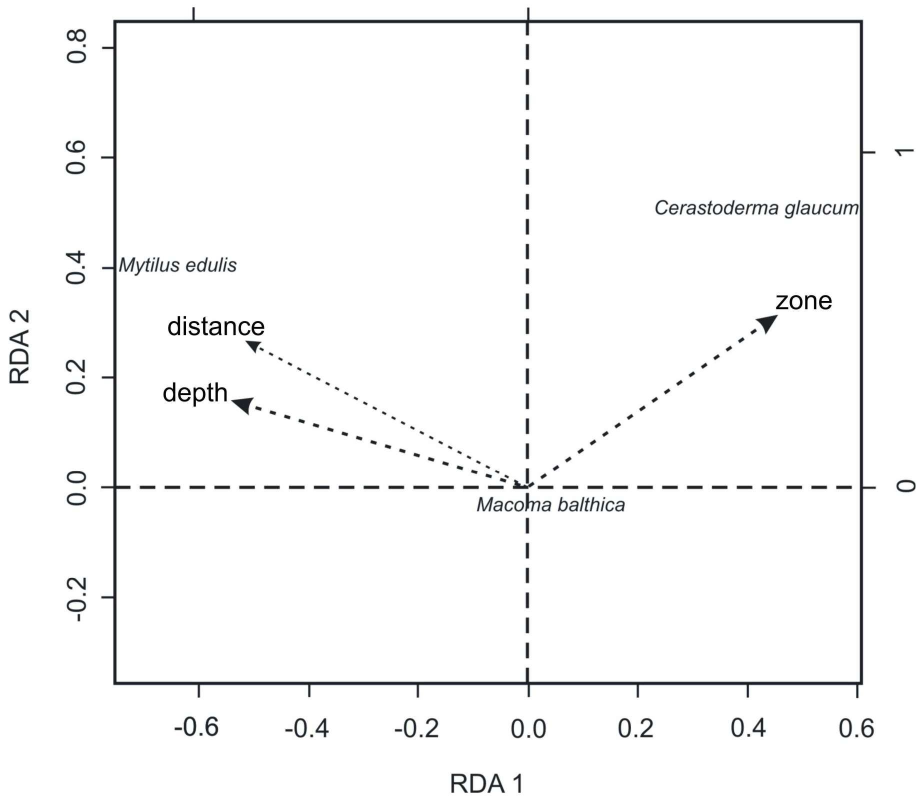

Fig. 4. RDA analysis of relationships between environmental parameters and density of bivalve species

The axis RDA1 explained 36.21% of the total variance while RDA2 18.85%. Distance from the shore and depth negatively contributed to RDA1 while zone positively. All the predictors had positive input into RDA2. *Mytilus edulis* turned out to prefer deeper sites, considerably distant from the shore in bays, opposite to *Cerastoderma glaucum* which preferred shallower sites in the open coast (Fig. 4). The population of *Macoma balthica* did not show any dependence on the analysed environmental parameters.

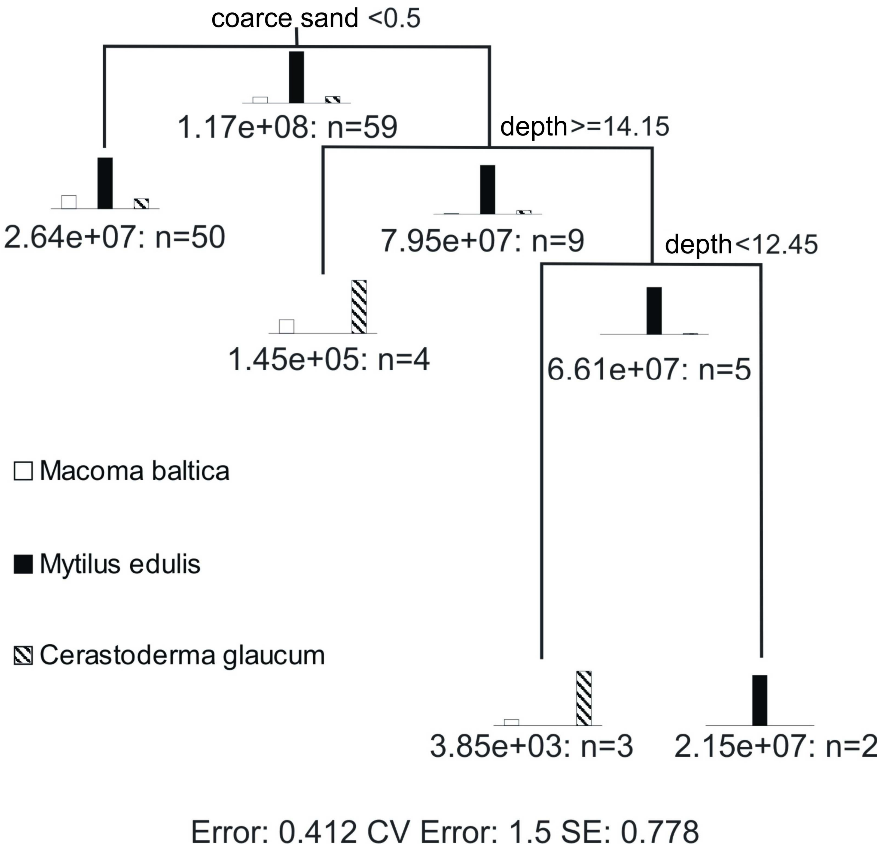

Fig. 5. MRT analysis of relationships between environmental parameters and bivalve species composition

MRT analysis allowed for indicating the most important parameters influencing density of bivalves. It turned out that the composition of bivalve species depended the most on substrate type, namely the lack or presence of coarse sand. Density of *Mytilus edulis* at sites with coarse sand was much more higher than for fine sand (Fig. 5). The next important variable was depth which particularly influenced species composition at sites with coarse sand on the bottom.

DISCUSSION

The studied coastal zone of the Baltic Sea is strongly exposed to unfavourable influence from mainland and it particularly concerns estuary zones as well as large urban areas. The degree of river effect depends on river flow velocity, contamination and eutrophication levels while the influence of urban areas increases with their size and the scale of urban development. Different conditions prevail in the open sea than in marine bays where water exchange is limited. In estuary zones it is crucial if a given river flows through a larger reservoir which then plays the function of sediment trap. Considerable amounts of abiseston, heavy metals, PCB compounds and other substances detrimental to hydrobionts can be accumulated there. On the other hand, in such reservoirs (Szczecin Lagoon, Kamieński Lagoon, Gardno Lake, Łebsko Lake) an increase in primary production (development of bacterioplankton, phytoplankton) as well as in secondary production (for instance zooplankton development) are observed. Typical freshwater plankters usually atrophy after contact with more saline (7-8 PSU) Baltic water and then enrich bottom sediment with organic matter. Rivers carry into the Baltic coastal zone mineral compounds, including nutrients, which contribute to the increase in primary production through the growth of autochthonous planktonic algae (Friedrich and Wilamski 1985, Niemkiewicz 1999, Poleszczuk and Sitek 1995). Considerable amounts of organic seston (high level of BOD_5) and nutrients by increasing the primary production in marine parts of estuaries also favour the development of bivalves and other macrozoobenthos representatives. That influence depends on hydrological conditions (dislocation of bottom sediments by currents), type of bottom substrate and biotic factors (for example predatory). The other important environmental factors are depth and distance from the shore. The Baltic Sea is a shelf sea with not big average depth which in the coastal zone is only partly correlated with the distance from the shore.

Macoma balthica for many reasons constitutes an important component of macrozoobenthos inhabiting the Baltic Sea down to 90 m of depth (Warzocha 1994). Due to its common occurrence the following assemblies with Baltic clam have been distinguished so far: *Mya arenaria – Macoma balthica*, *Macoma balthica – Mesidothea* (Saduria) *entomon* and *Scoloplos armiger – Macoma balthica*. The assembly *Macoma* has been also noticed in other seas like the Norwegian Sea (Oug 2001). In the coastal zone *M. balthica* is often a dominant species among the bottom fauna (Osowiecki 2000, Warzocha 1994). In the Pomeranian Bight, depending on the distance from Odra estuary and detritus abundance, *Macoma* is substituted by the assembly *Mya arenaria – Mytilus edulis* (Powilleit et al. 1995).

According to Obolewski et al. (2007) the Baltic clam predominated among macrozoobenthos species in the Middle Pomeranian coastal zone of the Baltic Sea of 3 Nm width except for the vicinity of Ustka (transect X) where *Cerastoderma glaucum* reached 1.5-fold higher biomass and 5-fold higher density comparing to *Macoma*.

The performed research indicated that the Polish coastal zone of the southern Baltic Sea was commonly inhabited by *M. balthica* (F = 25-100%). The consecutive regions had various habitat conditions which was reflected by differences in the Baltic clam density (Tab. 2). The study indicated that *M. balthica* found more favourable conditions for growth in the Gulf of Gdańsk than in the coastal zone of the Middle Pomerania, the Puck Bay and the Pomeranian Bight. Comparing to the results obtained by Warzocha (1995), i.e. averaged density of *Macoma* in the Polish coastal zone (428 indiv. m^{-2}), our investigation indicated 5-fold lower density in the Pomeranian Bight (78.3 indiv. m^{-2}) and 24-fold lower density in the Middle Pomerania region (17.6 indiv.m^{-2}).

Cerastoderma glaucum is a species typical of coastal, shallow-watered zones of the Baltic Sea and inhabits bottom down to 104 m of depth (Jagnow and Gosselck 1987). It is the most abundant in sheltered bays at the depth of 30-40 m (Żmudziński 1987). The lagoon cockle in our study also preferred considerable depths although the RDA analysis indicated that its occurrence also depended on the location along the coastline.

Blue mussels occur in large clusters even up to 30 thousands of individuals per 1 m^2. Blue mussels live in intertidal areas attached to rocks and other hard substrates by strong (and somewhat elastic) thread-like structures called byssal threads. These are secreted by byssal glands located in the foot of the mussel.

SUMMARY AND CONCLUSIONS

1. The obtained data about the studied three bivalve species *Cerastoderma glaucum*, *Mytilus edulis* and *Macoma balthica* indicated that they were common in the Polish coastal zone of the Baltic.
2. *C. glaucum* reached the highest density in the Puck Bay, *M. balthica* in the Gulf of Gdańsk and *M. edulis* in the estuary zone of the Middle Pomerania region.
3. The abundance of consecutive bivalve species was determined by bottom type, depth and distance from the shore. *M. baltica* preferred the distance of 0.5-1.5 Nm and depth 20-25 m, *M. edulis* 0.5 to 1 Nm and depth 5-10m while *C. glaucum* 0.25 to 1 Nm and depth 20-25 m.
4. RDA analysis revealed that the density of *C. glaucum* depended mainly on the coast type while *M. edulis* on the distance from the shore and depth. Only the density of *M. balthica* evenly depended on all of the studied parameters. MRT analysis indicated the main factors influencing bivalve species composition: sediment granularity and depth.

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ROZMIESZCZENIE POSPOLITYCH MAŁŻY W POLSKIEJ STREFIE PRZYBRZEŻNEJ BAŁTYKU

Streszczenie

Badano populację pospolitych bałtyckich małży *Macoma balthica*, *Mytilus edulis* i *Cerastoderma glaucum* w polskiej strefie przybrzeżnej (do 4 Nm) w strefach estuariowych i otwartego wybrzeża Pomorza Środkowego oraz strefie Zatoki Puckiej i Gdańskiej (do 2 Nm). Określono zagęszczenie badanych gatunków w wodach przybrzeżnych, w tym w rejonach ujść rzek Wieprzy, Słupi, Łupawy i Łeby oraz na obszarze Zatoki Puckiej i Gdańskiej, a także warunki środowiskowe (odległość od brzegu, typ podłoża, typ wybrzeża, głębokość). Z wykorzystaniem metod ordynacyjnych (RDA) oraz drzew regresyjnych (MRT) ustalono znaczenie poszczególnych parametrów środowiskowych dla każdego z gatunków małży. Według

RDA zagęszczenie *C. glaucum* związane jest głównie z miejscem wybrzeża, natomiast *M. edulis* z odległością od brzegu i głębokością. Jedynie zagęszczenie *M. balthica* było równocześnie uzależnione od wszystkich parametrów. Drzewo regresyjne (MRT) wytypowało główny czynnik, jakim była w pierwszej kolejności ziarnistość osadów, a następnie głębokość.