

Ecological Impact Assessment of Groins in Varna Bay (Black Sea, Bulgaria) – a Prerequisite for Application of Environmentally Friendly Shore Protection Structures

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Abstract: Intensive building of shore protection structures to control erosion of the shores took place along the Bulgarian Black Sea coast during the 1980s. The main goal of the accomplished investigations was to assess the role of fouling assemblages on a T-shaped shore protection structure for the biodiversity increase in comparison with the natural rocky reef (Aladzha Bank) fouling complex under recent environmental conditions along the Bulgarian coastal zone. The most significant changes in relation to environmental factors were caused by the introduction and mass development of the alien predator *Rapana venosa* during the past 30-40 years. By destroying the population of the main habitat forming species *M. galloprovincialis*, it contributed to the negative changes in the epifauna, expressed in reduction of pollution-sensitive species and biodiversity in the area of the shore protection structures and stagnant zones formed at the T-shaped groin. In order to achieve the maximum positive environmental effect, manifested by elimination of stagnant zones and *R. venosa* presence, we recommend submerged breakwaters similar to the natural bank, exposed to the prevailing NE winds and waves from East for implementation in the future.

Key words: groin, epifauna, habitat forming species

Introduction

The impact of the shore protection hydro-technical structures on the coast can be both positive and negative. A comparative study on the macrozoobenthos at a T-shaped groin and at flat rocky bottom in Varna Bay was conducted in 1993, in order to assess the changes in the rocky bottom macrozoobenthic communities in response to the groins (KONSULOVA, TODOROVA 1996). The results obtained showed that the diversity and ecological status of the macrozoobenthic community at the groin influenced zone were “undisturbed” according to the method of WARWICK *et al.* (1987). Only the macrozoobenthic community at the inner corner of the groin was found as “moderately disturbed”, probably as a result of restricted water circulation and oxygen depletion in this zone, because of the non-permeable type of the shore protection structure. These structures are capable of inflicting larger damages to the ecosystems by

displacing zoocenoses, favoring the development of invasive alien species at the expense of native species, or even can lead to the reduction or extinction of natural habitats, as well as dominant and rare species (KONSULOVA 1987, CHIKINA *et al.* 2005, MICU *et al.* 2007).

A major negative impact on the coastal ecosystem, including the Varna Bay area, was due to the species *Rapana venosa* (VALENCIENNES 1846), a voracious predator, introduced into the Black Sea in the early 1940s (KANEVA-ABADZHEVA 1958, IVANOV 1961). Its population caused significant changes and damages to benthic communities, in particular, a reduction in the stock of the mussel *Mytilus galloprovincialis* LAMARCK, 1819 – the most powerful biofilter of the Black Sea (DRAPKIN 1963). The big black mussel *M. galloprovincialis* is a characteristic species of the Black Sea, it reaches a shell

length of up to 140 mm and an individual weight of 25-30 g. Another common habitat forming species is the small black mussel *Mytilaster lineatus* (GMELIN 1791), which is found at shallow depths, most often in bays, tolerant to strong refreshment of the sea water (up to 5 ‰). It forms large colonies attaching to solid substrates by byssal threads; it is tolerant to oxygen deficiency and reaches up to 25 mm of shell length (MARINOV 1990).

The main goal of the present study is to assess the role of fouling assemblages on shore protection structures for the biodiversity increase in comparison with the natural rocky reef fouling complex under the changed environmental conditions along the Bulgarian coastal zone. The results obtained should help to estimate the environmental compatibility of the type of the used structures and to outline appropriate recommendations for future sustainable coastal zone protection activities.

Materials and Methods

Study sites

Comparative surveys were carried out at the T-shaped groin 102 B located in Varna Bay and the natural rocky Aladzha Bank, in August 2011 (Fig. 1).

The T-shaped groin (102 B) consists of 142 m long main structure and similarly shaped right and left arms with lengths of 81 m and 53 m, respectively. The centre of the main structure consists of blasted quarry rock material, armoured with large rock blocks. The arms are constructed using reinforced concrete frames forming vertical boxes filled with blasted rock material. The frames are laid on a levelled rock bed. The open-sea side is protected by a beam of large rock blocks and standard 4t tetrapods.

The natural rocky Aladzha Bank is situated at a distance of about 400 m from the beach, in front of the Zlatni Pyasatsi resort and at 6 miles distance from the investigated groin. The upper part of the submerged bank is found at 1.8 m below the sea surface. Winds from North-East and waves from East prevail in the region (VALCHEV *et al.* 2010).

Field survey

The distribution (percentage cover of the main habitat forming species), biodiversity, qualitative and quantitative species composition of the epibiota complex on the hard substrates of a man-made shore protection structure and natural coastal rock were studied. A total of sixteen stations, were investigated: nine of them were located at the groin walls and the tetrapods (Fig. 2), and seven at the Aladzha Bank site (Fig.

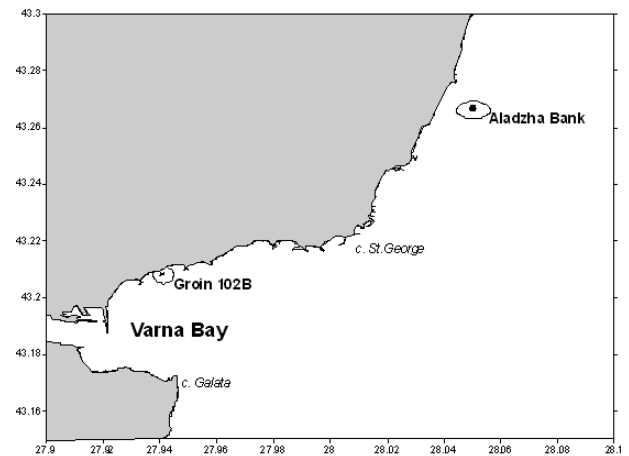


Fig. 1. Location of studied sites

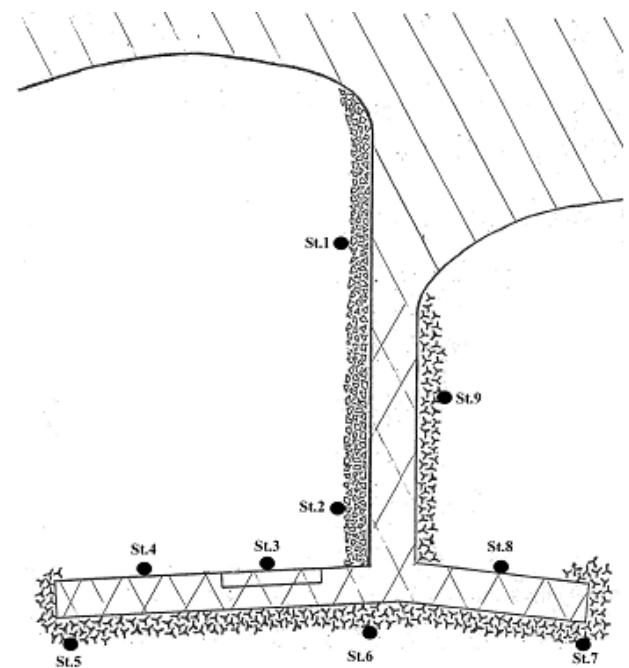


Fig. 2. Sampling stations for the macrozoobenthos investigations at the T-shaped groin (102 B) in Varna Bay

3). Two positions of the sampling stations were identified around the sites: landward and seaward. Field sampling was accomplished by using Scuba-diving techniques by means of a scraper 20x20 cm (covered area 0.04 m²) (KONSULOVA, TODOROVA 1996). Samples from the groin were collected at 2 m depth below the water surface, while from Aladzha Bank at 2 m distance from the top of the rock massif.

Laboratory processing

Laboratory analyses of the samples were carried out following the methodology of GRAY *et al.* (1992). The percentage cover of the main habitat forming species *M. galloprovincialis*, *M. lineatus* and the

group of Algae (*Calithamnion*, *Ceramium*, *Ulva*) was estimated using a plastic frame divided into 25 sub-quadrates of 6 x 6 cm, and by assigning a score from 0 to 4% to each species and Algae in each sub-quadrante. The total cover was obtained by summing up the values over the 25 sub-quadrates (MAGGI *et al.* 2009). The estimation was done using underwater photos: three replicated photographs at each station, taken at the same depth as the sampling.

Analytical methods

Univariate indices, such as the Shannon-Weaver diversity index (H') (SHANNON, WEAVER 1949) and Pielou's evenness index (J') (PIELOU 1976), were used to measure attributes of species diversity.

Principal Component Analysis (PCA) was performed on non-transformed zoobenthos species density to identify species distribution pattern in the studied areas. ANOVA and MANOVA tests were conducted to investigate the effects of the independent variables across dependent variables (FREEDMAN 2005; FRENCH *et al.* 2010). The coverage pattern of Algae, *M. lineatus* and *M. galloprovincialis*, as dependant variables was analyzed with the factors:

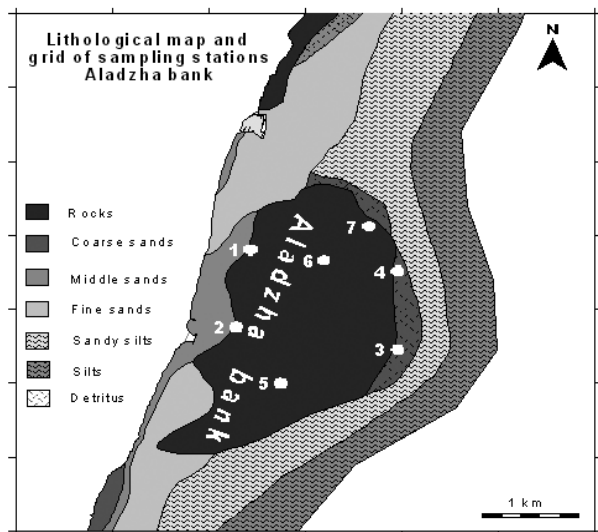


Fig. 3. Sampling stations for the macrozoobenthos investigations at Aladzha Bank

site – Aladzha Bank (AB) and Groin 102B (Gr); and position – landward (LW) and seaward (SW).

PRIMER 5 (CLARKE *et al.* 2001), STATISTICA 6, SPSS 20 and Microsoft Excel software packages were employed for the statistical analyses.

The following abbreviations for designation of sites and the position of stations are used in the text: sites: Gr – Groin; AB – Aladzha Bank; positions: LW – Landward; SW – Seaward.

Results and Discussion

Percentage cover by site

At both sites (Gr and AB) the epibiota assemblages were dominated by the habitat forming mussels *M. galloprovincialis* and *M. lineatus*, together with the complex of Algae (*Calithamnion*, *Ceramium*, *Ulva*).

With respect to *M. galloprovincialis*, the percentage cover values differed considerably for the two studied sites: at the groin the values were much lower than at Aladzha Bank – at the stations located on the top horizontal part of the natural rock the percentage cover reached over 80% (Station 5) and increased to a maximum of 100% at Station 6 (Fig. 4). The mean values of the percentage cover of *M. galloprovincialis* at the bank exceeded those of the groin almost 4 times (Table 1).

M. lineatus dominated at the groin with 3 times higher average percentage cover compared to the bank (Table 1). This was a result of the powerful press of the predatory snail *R. venosa*, found mainly in the groin area. *R. venosa* destroyed the *M. galloprovincialis* population, which is its staple food, while *M. lineatus* due to its small sizes was not of interest to the snail as a food resource.

R. venosa has irregular distribution and as a mobile animal its population cannot be assessed quantitatively by the currently used research method. This snail with a heavy shell cannot attach itself to the substrate and feeds in areas exposed to high wind wave impact. According to SAVINI *et al.* (2004), the *Rapana* snails collected at breakwaters were

Table 1. Descriptive statistic percentage cover of Algae, *M. lineatus* and *M. galloprovincialis* by sites: Groin (Gr) and Aladzha Bank (AB): Mean – average percentage cover; N – number of cases; Std. Dev. – Standard Deviation

Site	Algae Mean	Algae N	Algae Std. Dev.	<i>M. lineatus</i> Mean	<i>M. lineatus</i> N	<i>M. lineatus</i> Std. Dev.	<i>M. galloprovincialis</i> Mean	<i>M. galloprovincialis</i> N	<i>M. galloprovincialis</i> Std. Dev.
Gr	16.15	675	22.55	45.07	675	31.89	19.04	675	26.45
AB	2.86	525	10.31	15.24	525	18.76	69.14	525	30.93
All Groups	10.33	1200	19.39	32.02	1200	30.74	40.96	1200	37.81

significantly larger and heavier than those at sand substrate. The larger sizes and thicker shells of the *Rapana* specimens at the breakwaters can be a consequence of the large availability of food resources accessible in that habitat. This snail avoids vertical surfaces and according to our visual observations it was most widely found in the wind and wave protected LW positioned stations and near the bottom of the hard substrates, both at the parts constituting the groin and at the bank site. That is why, its main prey *M. galloprovincialis* was mostly found at the stations exposed to the prevailing northeast winds and east winds and waves (SW) in Varna Bay, as well as

in the adjacent coastal zone, where it was fouling the upper parts of the groin (Stations 5, 6 and 7) and Aladzha Bank (Stations 5 and 6) most intensively (Fig. 4, Table 2).

The Algae were much better represented at the walls and tetrapods of the groins than at Aladzha Bank (Tables 1 and 2).

Percentage cover according to the position

Regarding the position of the LW and SW stations, *M. galloprovincialis* clearly preferred SW direction at both sites (Table 3). Similar trend of lower abundance of *M. galloprovincialis* on the landward sides

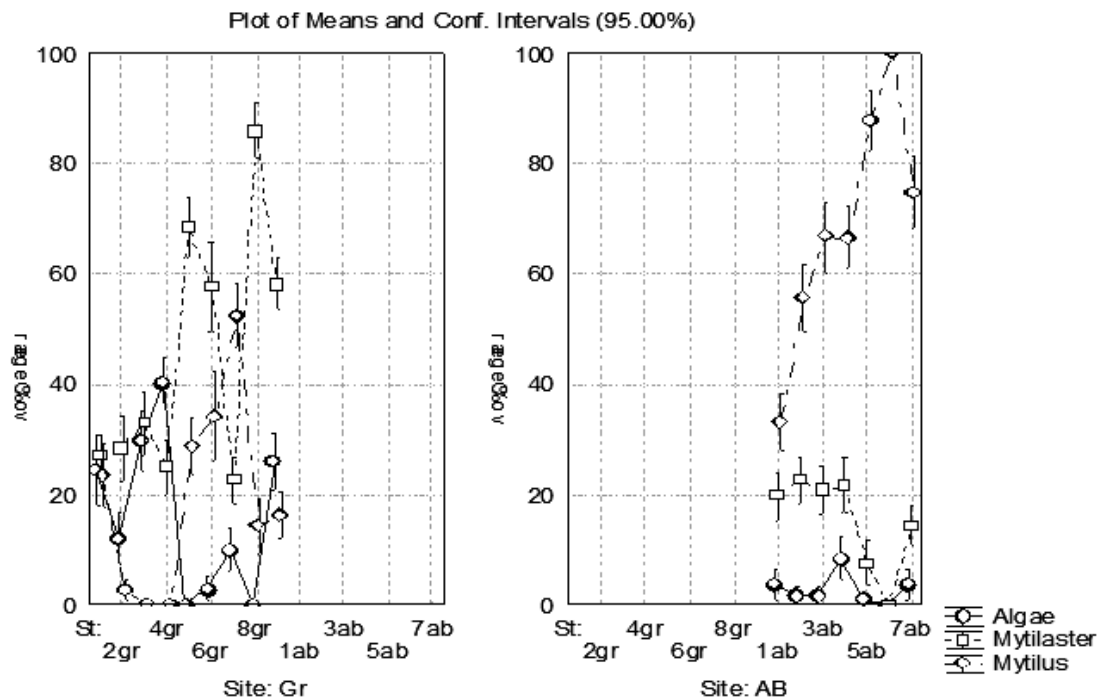


Fig. 4. Plot of mean and confidence intervals of percentage cover of Algae, *M. lineatus* and *M. galloprovincialis* by stations and sites: Gr (gr) – Groin (left), AB (ab) – Aladzha Bank (right)

Table 2. Descriptive statistic percentage cover of Algae, *M. lineatus* and *M. galloprovincialis* by sites and position: seaward (SW) and landward (LW). Mean – average percentage cover; N – number of cases; Std. Dev. – Standard Deviation; St. – Station

Site	Position	Algae Mean	Algae N	Algae Std. Dev.	<i>M. ineatus</i> Mean	<i>M. lineatus</i> N	<i>M. lineatus</i> Std. Dev.	<i>M. galloprovincialis</i> Mean	<i>M. galloprovincialis</i> N	<i>M. galloprovincialis</i> Std. Dev.
Gr	LW (St. 1,2,3,4,8,9)	22.06	450	24.14	42.83	450	31.13	9.39	450	18.03
Gr	SW (St.5,6,7)	4.33	225	12.30	49.56	225	32.98	38.33	225	29.88
AB	LW (St. 1,2)	2.67	150	9.23	21.17	150	18.49	44.33	150	26.88
AB	SW (St.3,4,5,6,7)	2.93	375	10.73	12.87	375	18.36	79.07	375	26.59
All Groups		10.33	1200	19.39	32.02	1200	30.74	40.96	1200	37.81

of breakwaters was established in the Mediterranean (BACCHIOCCHI *et al.* 2003). The Algae grew on the more wind and wave protected sections of the groin (LW stations), while at the bank they were under-represented. There were no significant differences in the spatial distribution of *M. lineatus* regarding the location of stations (SW or LW). The average coverage of *M. lineatus* was 26.63% at LW stations and 37.42% at SW ones (Tables 2 and 3).

The results about the differences between sites and positions were confirmed by the MANOVA analysis: the factor Position (SW-LW) significantly affected the difference in the distribution of Algae and *M. galloprovincialis*, but the percentage cover of *M. lineatus* was not significantly affected: $F=0.217$; $p>0.05$. (Table 4).

Comparative analysis of qualitative and quantitative composition of the epibiota assemblages in both sites

Taxonomic composition and structure

The list of recorded macrobenthic epifauna in both sites Gr and AB during the studied period comprised 72 taxa belonging to three major taxonomic groups: Polychaeta represented by 31 species, Crustacea represented by 23 species and Mollusca with 13 species, as well as to the following groups: Turbellaria, Nemertini, Oligochaeta, Anthozoa and Diptera: Chironomidae (5 taxa), indicated as category Varia (Fig. 5).

Regarding the number and percentage share in the total number of epifauna taxa, both sites were not significantly different, which is understandable because of their location in an area of relatively uniform environmental conditions (Varna Bay and adjacent coastal area). In the area of the groin, the epifauna had a slightly higher number of benthic species than in the Aladzha Bank (62 and 51, respectively), mostly due to the higher number of polychaetes which occupied the largest percentage share in the total species number (46% and 41%, respectively). The reason is that this group of zoobenthos species has high tolerance to adverse environmental conditions, such as provided mostly by the stagnant zones of the T-shaped shore protection structures.

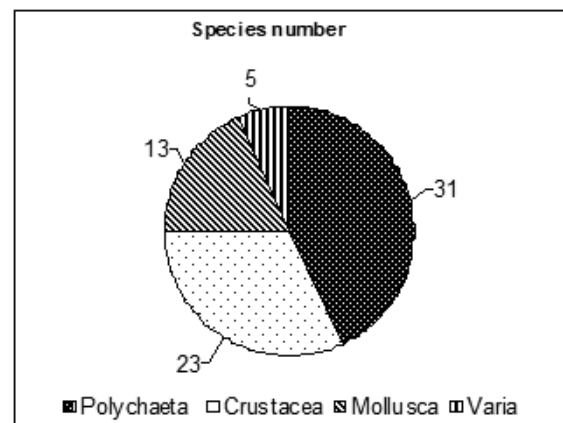


Fig. 5. Taxonomic structure of macrobenthic epifauna registered at both sites

Table 3. Descriptive statistic percentage cover of Algae, *M. lineatus* and *M. galloprovincialis* by position: seaward (SW) and landward (LW). (Mean, N and Std. Dev. – the same as in Table 1)

Position	Algae Mean	Algae N	Algae Std. Dev.	<i>M. lineatus</i> Mean	<i>M. lineatus</i> N	<i>M. lineatus</i> Std.Dev.	<i>M. galloprovincialis</i> Mean	<i>M. galloprovincialis</i> N	<i>M. galloprovincialis</i> Std. Dev.
LW	17.21	600.00	22.99	37.42	600.00	29.99	18.13	600.00	25.55
SW	3.46	600.00	11.35	26.63	600.00	30.55	63.79	600.00	34.13
All Groups	10.33	1200.00	19.39	32.02	1200.00	30.74	40.96	1200.00	37.81

Table 4. MANOVA results regarding comparison between average percentage cover of Algae, *M. lineatus* and *M. galloprovincialis* at both sites in respect to the factors: position (seaward, SW, and landward, LW) and sites (Groin, Gr, and Aladzha Bank, AB)

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	P
Position SW-LW	Algae	19043.5	1	19043.5	64.828	<0.001
	<i>M. lineatus</i>	155.6	1	155.6	0.217	0.641
	<i>M. galloprovincialis</i>	253428.7	1	253428.7	422.108	<0.001
Site AB-Gr	Algae	27011.1	1	27011.1	91.951	<0.001
	<i>M. lineatus</i>	212835.7	1	212835.7	297.484	<0.001
	<i>M. galloprovincialis</i>	357945.4	1	357945.4	596.190	<0.001

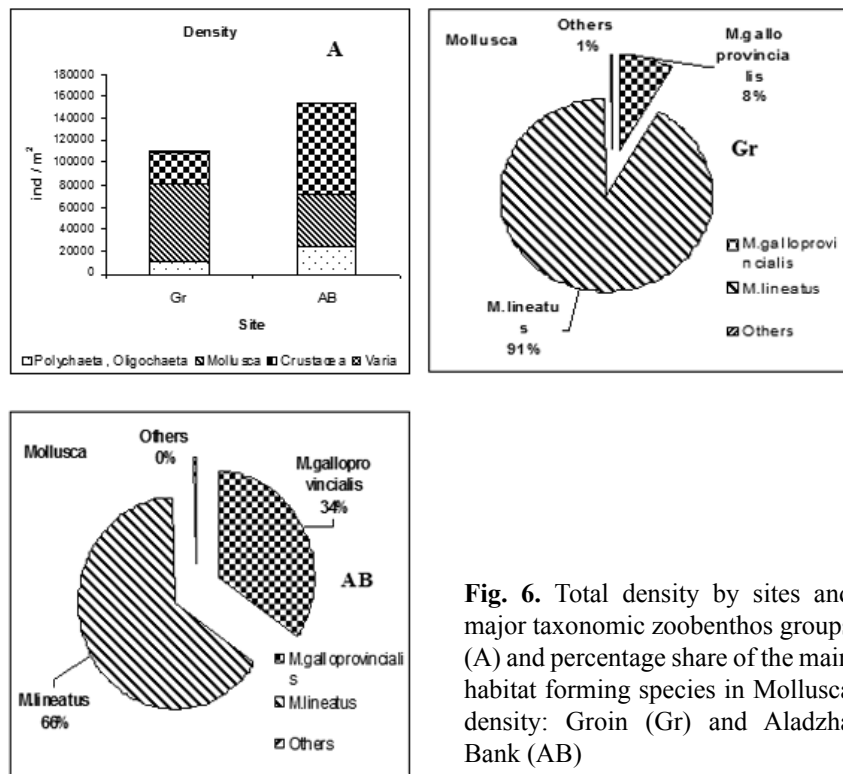


Fig. 6. Total density by sites and major taxonomic zoobenthos groups (A) and percentage share of the main habitat forming species in Mollusca density: Groin (Gr) and Aladzha Bank (AB)

The total density of the fouling macroinvertebrate fauna at Aladzha Bank was higher in comparison with the epifauna at the groin (154 897 ind.m⁻² vs. 110 961 ind.m⁻²). That was due to the higher percentage cover with *M. galloprovincialis* at the bank site, which determined better development of the accompanying complex of invertebrate fauna species in this type of zoocenosis (*Mytilus* rocky zoocenosis). The most significant increase (over 3 times) was observed in the crustaceans at the bank; these taxa are typical for the *Mytilus* rocky zoocenosis and show preference to favorable environmental conditions. The higher density of Mollusca representatives in the groin area was mainly due to the dominance of the small-sized *M. lineatus*, which occupied 91% of the total number of this group, while on the bank the distribution was more uniform (Fig. 6).

Regarding the biomass, the bank was characterized by more than five times higher values (42 882.42 g.m⁻² against 7838.97 g.m⁻², respectively), due to the much stronger presence (percentage cover) of the large-sized *M. galloprovincialis* which had a higher individual weight (Fig. 7).

Comparison between PCA groups

The macrozoobenthic communities were differentiated according to PCA multivariate method applied to samples from both sites, Gr and AB (non-transformed species density). The PCA matrix plot (Fig. 8) shows the groups of similar stations in

terms of the ecological classification of the species and their abundance. All LW stations from both sites are combined into one group (Group 1: Gr – Stations 1, 2, 3, 4, 8, 9; AB – Stations 1, 2), while the SW stations are combined into two groups: separately for each site Gr (Group 2: Gr – Stations 5, 6, 7) and AB (Group 3: AB – Stations 3, 4, 5, 6, 7). The epifauna in Group 1 (LW stations) and in Group 3 (AB – SW stations) along the PC1 axis was characterized with a high density of the crustaceans of class Amphipoda (*Melita palmata* MONTAGU, 1804) and Decapoda (*Pilumnus hirtellus* LINNAEUS 1761, *Athanas nitescens* LEACH 1813, *Pisidia longimana* RISSO 1816) in the Aladzha Bank area. These species develop under favorable environmental conditions, they have been classified as “sensitive to pollution” and belong to the ecological group I (BORJA *et al.* 2000). After these authors the benthic species are classified into five ecological groups. The classification is adjusted to the Black Sea benthic fauna according to the expertise of the Bulgarian team of zoobenthologists (TODOROVA *et al.* 2008). The ecological groups in consideration encompass: I – „sensitive to pollution”, II – „indifferent to pollution”, III – „tolerant to pollution”, IV – „second order opportunists”, V – „first order opportunists”. The two groups of stations separated along PC1 axis (LW and SW – AB) were also characterized with low density of Mollusca and Loricata species at the AB – SW stations, these species are typical for calmer and

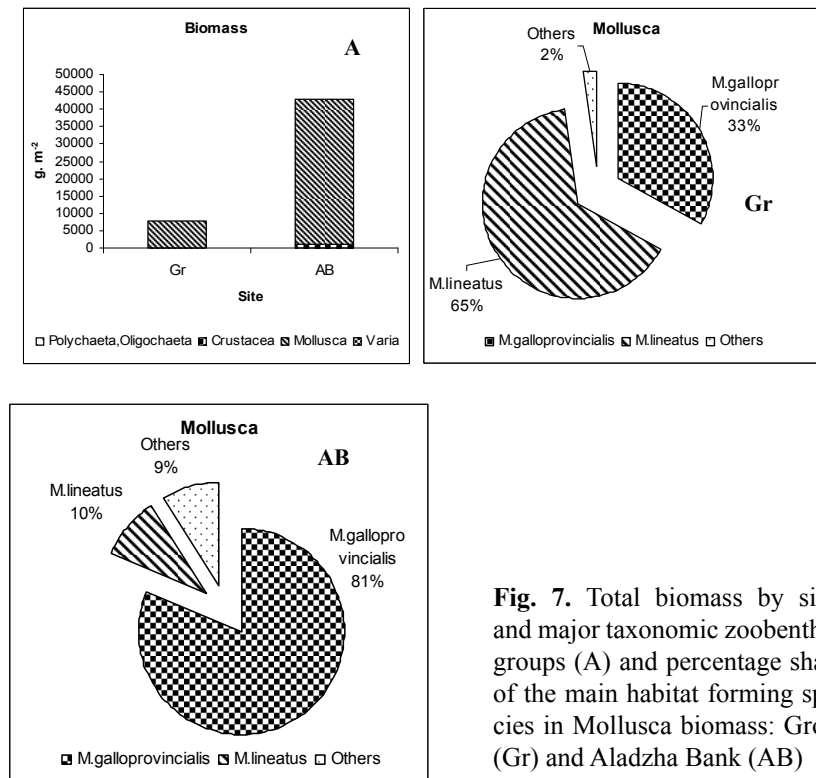


Fig. 7. Total biomass by sites and major taxonomic zoobenthos groups (A) and percentage share of the main habitat forming species in Mollusca biomass: Groin (Gr) and Aladzha Bank (AB)

protected water areas and are classified from I to IV ecological groups.

The groin seaward stations (Group 2) are discriminated along the second axis – PC2 (SW Groin 102 B) because of the high densities of Crustacea, Mollusca and Turbellaria species inhabiting the offshore natural rocks in Varna Bay, and exposed to wind wave impact (KONSULOV *et al.* 1989). These species are more tolerant to deteriorated environmental conditions of the habitat, e.g. the crustacean *Jassa oca* BATE 1862 is classified into ecological group V and the other species are mostly in group II – “indifferent to pollution”. The separation of the LW stations at both sites into one group was based also to the high number of “indifferent to pollution” Turbellaria (ecological group II) and “tolerant to pollution” crustaceans *Dexamine spinisa* MONTAGU, 1813 (ecological group III) recorded (Fig. 8).

The comparative analysis of different PCA groups of stations according to the univariate diversity indices of the epifauna community, J (PIELOU 1976) and H' (SHANNON-WEAVER 1949), shows high evenness and diversity indices at the SW stations (Fig. 9).

Conclusions

1. In general, the man-made shore protection structures, as well as the natural rocks are characterized as environmentally sound habitats that

contribute to the increase of biodiversity providing a hard substrate for the development of epifauna.

2. In terms of species richness of the epifauna, both sites do not differ significantly due to their close location in a coastal area with similar environmental conditions (Varna Bay and the adjacent area).

3. On the contrary, the percentage cover of the two major habitat forming species *M. galloprovincialis* and *M. lineatus* shows significant differences in these two sites: the Aladzha Bank is characterized by much higher values of percentage cover of *M. galloprovincialis*, while *M. lineatus* dominates in the epifauna on the groin. This is due to the mass development and wide distribution of the invasive alien predatory snail *R. venosa*, particularly pronounced in the area of the groin, which destroys the population of *M. galloprovincialis*, its main prey.

4. The results about the percentage cover of the two dominant Mollusk species regarding the position showed that *M. galloprovincialis* exhibited preference for the seaward positioned zones at both sites. The higher percentage cover of this habitat forming species is a prerequisite for better development of the concomitant zoocenosis and respectively higher biodiversity.

5. The quantitative characteristics of the epifauna at both sites are determined by the differences in the habitat forming species. The mussel *M. galloprovincialis* is more abundant on the natural rock bank because of its exposure to the wind

wave impact, and these conditions are not favorable to its enemy *R. venosa*.

6. The seaward positioned zones at both sites are characterized by better development of the habitat forming species and epifauna compared with the landward zones in terms of all parameters – percentage cover of the main species *M. galloprovincialis*,

which determines high numbers, biomass and epifauna biodiversity.

Recommendations

Due to the fact that the coastal area needs urgent protection, the shore protection structures should be designed in a manner that will minimize the negative

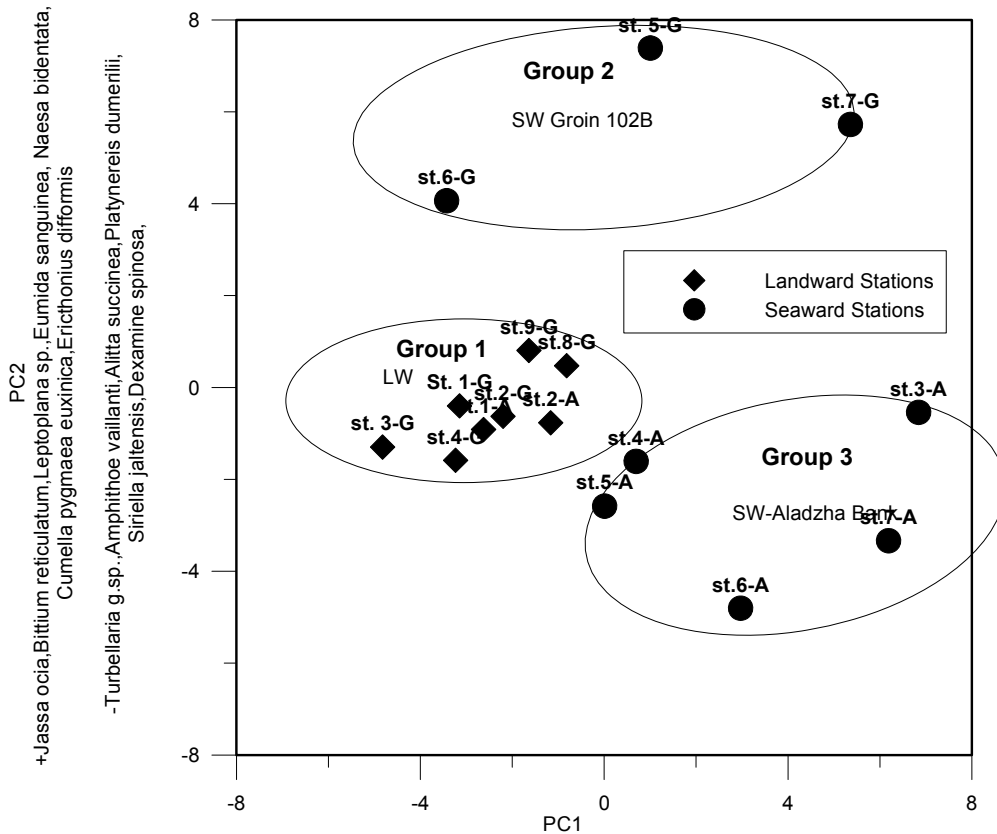


Fig. 8. PCA matrix plot of macrozoobenthos abundance at the Aladzha Bank and Groin Stations

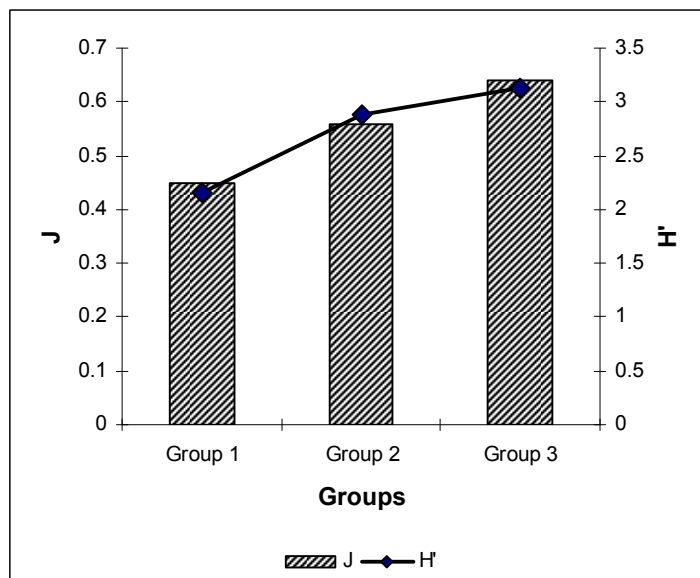


Fig. 9. Univariate diversity indices J and H' according to PCA groups

environmental impact of the formation of stagnant zones. Such zones create favorable conditions for development of the predatory snail *Rapana venosa* – a major threat to the habitat forming black-mussel *M. galloprovincialis* at present, which results in destruction of the epifauna, extinction of pollution-sensitive species and reduction of biodiversity.

An important task of the coastal engineering specialists is the optimization of the type and shape of the shore protection technical structures. In order to achieve maximum positive environmental effect,

we recommend the implementation of submerged breakwaters (SAITO *et al.* 2002) similar to the natural rocky Aladzha Bank, exposed to the prevailing in the region E-wind waves and NE winds.

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