www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 14: 155-164 (2014) DOI: 10.4194/1303-2712-v14_1_17

Do Cement Boulders Mimic Natural Boulders for Macro-Invertebrates in the Southern Caspian Sea?

Fatemeh Pourjomeh[1,2], Mohammad Reza Shokri[1,*], Bahram Kiabi[1]

[1] Shahid Beheshti University, Faculty of Biological Sciences, G.C., Tehran, Iran.
[2] Iranian National Institute for Oceanography and Atmospheric Science, Department of Marine Science, Tehran, Iran.

* Corresponding Author: Tel.: ; Fax: ;
E-mail: M_Shokri@sbu.ac.ir, Shokri.mr@gmail.com

Received 16 November 2012
Accepted 23 January 2014

Abstract

The macro-invertebrates on natural (rock) and artificial (cement) boulders were compared along the southern Caspian Sea and the effect of structural features of boulders (i.e. orientation, facing, surface complexity, the degree of exposure to the wave action) on macro-invertebrate communities were investigated. Ten locations with rock walls in the southern Caspian Sea were investigated in which the isolated boulders of natural and artificial types with similar dimensions were haphazardly selected for sampling from their macro-invertebrate communities. A total of 59120 individuals of macro-invertebrates were counted being represented by 5 species from 3 phyla (i.e., Arthropoda, Annelida, Mollusca). The average taxonomic richness on natural boulders was significantly higher than that of artificial ones, but no significant difference was found in average density of macro-invertebrates between two boulder types. A significant difference in density and taxonomic richness of macro-invertebrates was found among different spatial orientations (i.e. vertical, sloped, horizontal) within and between boulder types. Density and taxonomic richness of macro-invertebrates on natural and artificial boulders were not significantly affected by other structural features including facing, surface complexity and the degree of exposure to the wave action. The results indicate that artificial boulders may mimic natural boulders only for density of macro-invertebrates.

Keywords: Artificial reefs, macro-invertebrates, macrobenthos, macrofauna, surrogacy.

Introduction

Artificial reefs may mimic natural reefs by attracting benthic communities and fish leading to enhance the biodiversity in coastal waters (Carr and Hixon, 1997; Pickering and Whitmarsh, 1997; Rilov and Benayahu, 2000; Azim *et al.*, 2002; Pondella *et al.*, 2002; Perkol-Finkel and Benayahu, 2004; Burt *et al.*, 2009). Earlier studies have revealed that artificial structures may enhance the regional biomass and local biodiversity by creating new suitable habitats and attracting non-indigenous species (Badalamenti, *et al.* 2002; Bulleri and Airoldi, 2005; Tyrrell and Byers, 2007; Marchini *et al.*, 2007; Burt *et al.*, 2009). Yet, some studies have shown that community composition might be different between natural and artificial reefs (Perkol-Finkel and Benayahu, 2004; Bulleri and Airoldi, 2005). A suit of physical characteristics of artificial boulders may affect the settlement process of benthic organisms. These factors include size (Butler, 1991; Rilov and Benayahu, 2000; Field *et al.*, 2007), surface orientation (Oren and Benayahu, 1997; Rilov and Benayahu, 2000; Glasby, 2000; Falace and Bressan, 2002; Perkol-Finkel *et al.*, 2006; Perkol-Finkel and Benayahu, 2007), surface complexity (Walters and Wethey, 1996; Choi *et al.*, 2002), composition and facing (Spieler *et al.*, 2001; Freitas *et al.*, 2005; Burt *et al.*, 2009) and the degree of exposure to wave action (Vaselli *et al.*, 2008; Barber *et al.*, 2009). Understanding the efficacy of artificial reefs in enhancing costal biodiversity is of crucial importance because they are ever-increasingly established constructions in coastal areas. This is achievable by comparing benthic community structure on artificial reefs with natural reefs. This can lead to explore whether artificial reefs can act as suitable replacements for natural reefs.

The Caspian Sea is the largest enclosed body of water on earth and its coastal area is dominated by mudflats and sandy shores. The sea level for Caspian Sea has permanently fluctuated within decades. The most recent sea level rise occurred during a period of 1977-1995 in which sea level increased about 4 m leading to inundation of inland areas (Jafari, 2010). This led to a tremendous erosion of the coastal areas and associated infrastructures. To halt this problem, walls of rocks with natural and artificial origins were built along the southern coastal areas to prevent inundation of inland areas. The species richness and abundance of sandy shores and mudflats in the southern Caspian Sea are impoverished due to some reasons such as unstable sediment and low nutrient (Nybakken and Bertness, 2005). Therefore, the boulders placed in coastal areas can potentially enrich the sessile species diversity leading to attract more fish to coastal waters that feed on sessile organisms. One of the most valued fish in the Caspian Sea is sturgeon fish that is famous for its roe (Barannik *et al.*, 2004). Approximately 90% of the world's Caviar comes from the Caspian Sea (UNESCO, 2003). The sturgeon stocks have been decreasing since 1970s (IUCN, 2001) and some main reasons for this decline include over and illegal fishing, habitat destruction, invasion of alien species and environmental pollution (IUCN, 2001). Yet one solution can be restoration of food resources for sturgeon fish (IUCN, 2001).

Sturgeon fish feed on polychaete worms, mollusks, crustaceans and tiny fishes in particular Gobiid fish (e.g. *Neogobius gorlap, N. bathybius*) (Fishbase, 2011; Zander and Hagemann, 1989). Moghaddam (2005) found a high abundance of polychaetes in the stomach of sturgeons in different depths of the southern Caspian Sea. Thus, polychaetes are among the most important source of food for these fishes. Polychaeta (i.e. *Nereis diversicular*) as the dominant annelid worms in the Caspian Sea along with Gobiid fish are generally found on and around rocky substrates. The establishment of new hard substrates in coastal areas of the Caspian Sea may enhance the diversity and abundance of the organisms on which commercial fish feed.

No studies have been so far undertaken to assess the value of artificial reefs in enrichment of coastal areas in the Caspian Sea. The purpose of this study is to assess whether artificial reefs in form of man-made boulders (cement) can mimic artificial reefs in form of natural boulders (rocks) for macro-invertebrates in the southern Caspian Sea. This was tested by comparing the abundance and taxonomic richness of macro-invertebrates on natural boulders (rocks) with that on man-made boulders (cement). Further, in case of differences in community structure between artificial and natural boulders, the species responsible for these differences were determined. The effect of different structural features of natural and artificial boulders including orientation, facing, surface complexity, and degree of exposure to the wave, was explored with respect to community structure of their benthic organisms.

Materials and Methods

Study Area and Sampling

This study was carried out at an area covering 110 km of coastline in Mazandaran Province at southern shore of the Caspian Sea (Figure 1). Ten locations with rock walls being built up by compiling man-made (cement) and natural (rocks) boulders were haphazardly selected for sampling. These rock walls have been built up on southern coastline during a period of 1977-1995 to prevent inundation of inland areas. Sampling was conducted during day time in November-December 2010. In each location nine isolated boulders of similar dimensions (≈ 0.5-1 m wide × 0.5-1 m length × 0.5 m height) surrounded on each side by sea water were selected for sampling. Boulders were partially submerged in sea water; however their top-sides were exposed to sea water by wave action. In order to compare the macro-invertebrate assemblages on three different spatial orientations, macro-invertebrates on vertical, sloped and horizontal surfaces were separately sampled on each boulder. For each boulder, the level of surface complexity (i.e. smooth, rough), facing (i.e. east, north east, north, north west, west, south west, south, south east) and the degree of exposure to the wave (i.e. sheltered, exposed, partial exposure) were recorded. At each location three replicates of each

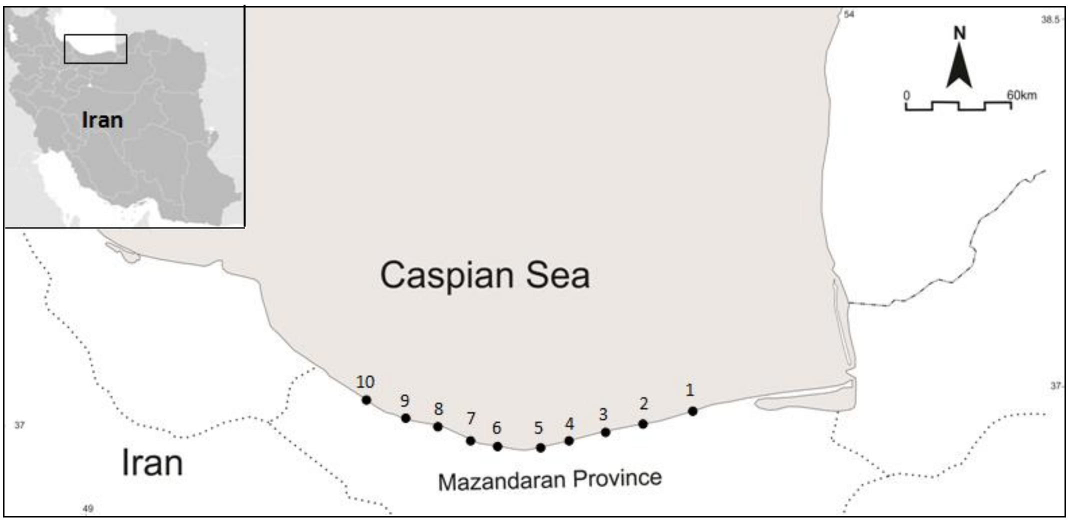

Figure 1. Sampling locations in southern Caspian Sea, Iran.

spatial orientation (i.e. vertical, sloped, horizontal) on each boulder type were haphazardly selected for sampling from sessile macro-invertebrates. In doing so, a total of 9 man-made boulders (cement) and 9 natural boulders (rocks) were sampled at each location. A 225 cm^2 (15 × 15 cm) quadrat (N = 3) was used for sampling. This size of quadrat was chosen relative to the size of boulders and density of macro-invertebrates. Macro-invertebrates were gently scraped into the net (0.05 mm mesh) attached to the quadrat using a metal brush and scraper. Net attached to the quadrat minimized the loss of macro-invertebrates due to the wave action. Macro-invertebrates retained in the net were preserved in 4% formaldehyde, followed by 70% ethanol for further sorting. Organisms were counted and identified to species-level where possible using available reference texts (e.g., Birshten *et al.*, 1968; Karaman and Pinkster, 1997; Stock *et al.*, 1998; Nasrolahi *et al.*, 2006; Taheri *et al.*, 2009) and all identifications were confirmed by specialist taxonomists at the Iranian National Center for Oceanography of Caspian Sea office and Tehran University. Voucher specimens of all species were deposited with Marine Biology Lab at Shahid Beheshti University, Tehran, Iran. The abundance of macroalgae in each quadrat was recorded in percentage cover of the area being sampled. Afterwards macroalgae inside each quadrate was scraped and transferred to the lab in paper bag. The biomass of macroalgae was estimated as dry weight after oven dried at 60°C for 50 hours.

Data Analyses

The species richness of each location was the sum of the number of species that were recorded on each boulder type (i.e. natural, artificial). The mean density of each species in each location was calculated from the estimates of total density on each boulder type in each location. Spatial variation in macro-invertebrate assemblages was depicted in non-metric multidimensional scaling (nMDS) ordination plots, based on Bray–Curtis dissimilarity matrices of square-root average density of each species. One-way analysis of similarity (ANOSIM) was derived from Bray–Curtis dissimilarity matrix based on square-root transformation to test the significance of differences in macro-invertebrate assemblages between natural and artificial boulders.

A manual forward selection process in CANOCO was used to select the subset of environmental variables (i.e. orientation, facing, sheltered/expose, surface complexity, algal biomass) that best explained the spatial patterns in macro-invertebrate abundance between two boulder types. The abundance data were squared root transformed to reduce skewness and outliers and approximate normality. Environmental data were kept untransformed because they were categorical. CCA analyses were performed using CANOCO 4.5 (ter Braak and Smilauer, 2002).

The differences in abundance and taxonomic richness of macro-invertebrates among locations and between natural and artificial boulders were tested using univariate two-way ANOVA with two factors (Table 1). To compare the differences in abundance and taxonomic richness of macro-invertebrates among different spatial orientations (i.e. vertical, sloped, horizontal) within and between boulder types, a univariate three-way ANOVA was used with three factors (Table 1). The differences in abundance and taxonomic richness of macro-invertebrates among different facings on boulder types were explored using univariate two-way ANOVA with two factors (Table 1). The effect of surface complexity of boulders on abundance and taxonomic richness of macro-invertebrates was assessed by univariate two-way ANOVA with two factors (Table 1). Likewise, effect of wave action on abundance and taxonomic richness of macro-invertebrates was assessed by univariate two-way ANOVA with two factors (Table 1).

Table 1. The details of factors used in ANOVA analyses

Comparisons	Factor	Fixed/ Random	Orthogonal/ Nested	No of levels
Macro-invertebrates among locations and between natural and artificial boulders	Location	Fixed	Orthogonal	10 (10 locations)
	Type	Fixed	Orthogonal	2 (cement, rock)
Macro-invertebrates among different spatial orientations	Type	Fixed	Orthogonal	2 (cement, rock)
	Orientation	Fixed	Orthogonal	3 (vertical, sloped, horizontal)
	Location	Fixed	Random	10 (10 locations)
Macro-invertebrates among different facings of each boulder types	Type	Fixed	Orthogonal	2 (cement, rock)
	Facing:	Fixed	Nested	8 (east, north east, north, north west, west, south west, south, south east).
Effect of surface complexity on macro-invertebrates	Type	Fixed	Orthogonal	2 (cement, rock)
	Level of surface complexity	Fixed	Nested	2 (smooth, rough)
Effect of wave action on macro-invertebrates	Type	Fixed	Orthogonal	2 (cement, rock)
	Wave action	Fixed	Nested	3 (sheltered, exposed, partial exposure).

The normality of abundance data were tested using Cochran's test prior to ANOVA. When data were not normal, a square root transformation was applied to data to reduce the heterogeneity of variance. ANOVA analyses were performed using SPSS18 and GMAV5 (Underwood and Chapman, 1984). Significant interactions and differences between factors were explored by Student–Newman–Keuls (SNK) test (Sokal and Rohlf, 1995).

To determine the species that were more responsible for differences between two boulder types, a SIMPER (similarity percentage) analysis in PRIMER5 (Clarke and Warwick, 2001) was used.

Results

A total of 59,120 individuals were counted in total of 10 locations. The material represented by 5 species from 3 phyla of Arthropoda (i.e. *Amphibalanus improvisus* (Cirripedia), *Chironomus albidus* (Diptera), *Pontogammarus maeoticus* (Amphipoda)), Annelida (i.e. *Nereis diversicular* (Polychaeta)) and Mollusca (i.e. *Mytilaster lineatus* (Bivalvia)). The average density per location on both boulder types was 789.4±197.3 (mean±standard error), 96.6±26.8 and 5026±1934.5 for arthropods, annelids and molluscs, respectively. Assemblages were numerically dominated by molluscs (85.0% of total density), followed by arthropods (13.3%) and annelids (1.6%).

The non-metric multidimensional scaling (nMDS) ordination plots formed no clear groups based on similarities in macro-invertebrate assemblages on each boulder types (Figure 2). The result of CCA analyses based on manual forward testing found that different variables were responsible for variation in spatial pattern of macro-invertebrates on natural and artificial boulders. Three variables that best explained significant proportions of the total spatial variation on natural boulders were orientation (λ=0.33, P=0.01); facing (λ=-0.26, P=0.04); and levels of exposure to wave action (λ=0.25, *P*=0.04) (Table 2a). Values for the inter-set correlations of natural boulders (Table 2a) show that axis 1 (the horizontal axis) of the ordination plot in Figure 3a depicts (from left to right) a trend of alteration in orientation of boulders. Axis 2 (the vertical axis) depicts (moving upwards) a trend of alteration in levels of exposure to wave action of boulders. Further inspection of the ordination plot infers that algae coverage followed by *M. lineatus* are largely altered with different orientations.

Three variables that best explained significant proportions of the total spatial variation of artificial boulders were algal biomass (λ=0.39, P=0.002); surface complexity (λ=0.28, P=0.01); and orientation (λ=0.15, P=0.02) (Table 2b). Values for the inter-set correlations of artificial boulders (Table 2b) show that axis 1 (the horizontal axis) of the ordination plot in Figure 3b depicts (from left to right) an increasing trend in algal biomass on boulders. Axis 2 (the vertical axis) depicts (moving upwards) a trend of alteration in orientation of boulders. Further inspection of the ordination plot infers that *C. albidus* largely occurs at surfaces with highest algal biomass, and *M. lineatus* largely occurs at surfaces with lowest algal biomass.

Overall, natural reefs contained a higher average number of species but there was no significant difference in mean density between boulder types (cement, rock) (Table 3). Natural reefs contained a higher average number of species with 3.4±0.2 (mean±standard error) versus 3.0±0.1 for artificial reefs and a significant difference in mean species richness was found between habitat types (Table 3). Yet the result of one-way ANOSIM yielded no significant differences in assemblages between artificial and natural boulders (R=0.002; P=0.29) (Figure 2). In natural boulders, no significant differences were found in number of species among

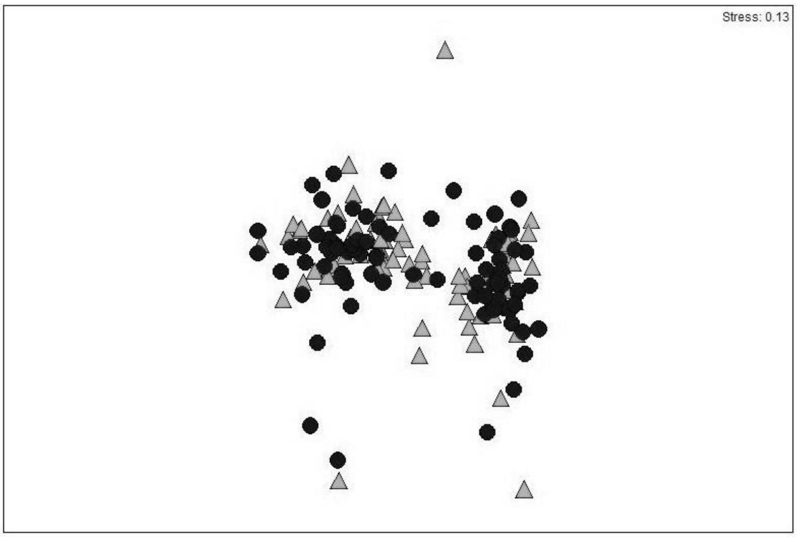

Figure 2. nMDS plot of macro-invertebrate assemblage structure based on Bray-Curtis indices of dissimilarity derived from square-root transformed means of abundance data of two boulder types.

Table 2. Summary results of partial canonical correspondence analysis (CCA) for macro-invertebrate species abundance on (A) natural and (B) artificial boulders

Variables included	Inter-set correlations		Eigenvalues		% variance explained		Total inertia	Canonical inertia	R^2
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2			
(A)									
Orientation (3.98*)	0.33	-0.07	0.05	0.01	66.80	85.20	0.76	0.07	7%
Facing (2.59*)	-0.26	-0.07							
Levels of exposure to wave action (2.50*)	0.25	-0.14							
(B)									
Algal biomass (6.70**)	0.39	-0.08	0.09	0.04	68.20	96.00	0.90	0.13	13%
Surface complexity (3.46*)	0.28	0.05							
Orientation (3.45*)	0.15	0.37							

Abundance data were square-root transformed prior to analysis. Variables included are those selected by manual forward selection to explain a significant amount (at P=0.05) of variation in the species data and only significant variables are shown. Conditional effect for each selected variable (in brackets) is the proportion of variation in the species data explained by each of the environmental variables selected in addition to the proportion explained by the first variable selected. The significance of conditional effects was determined by Monte Carlo test (999 unrestricted permutations) (* P<0.05, ** P<0.01).

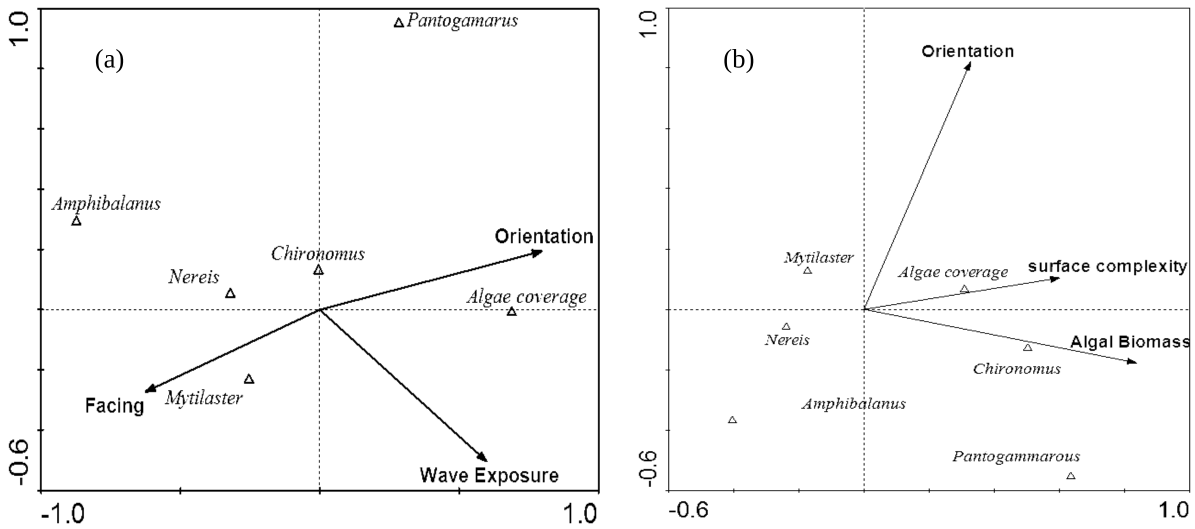

Figure 3. Canonical correspondence analysis (CCA) ordination diagram showing associations between environmental variables and spatial patterns in assemblages. The environmental variables (showing by arrows) that explained a significant proportion of the spatial variation in assemblages were selected by manual forward selection (a) in natural boulders: orientation (λ=0.33, P=0.01); facing (λ=-0.26, P=0.04); and levels of exposure to wave action (λ=0.25, P=0.04), (b) in artificial boulders: : algal biomass (λ=0.39, P=0.002); surface complexity (λ=0.28, P=0.01); and orientation (λ=0.15, P=0.02).

Table 3. Summary of two-way ANOVA testing the abundance and taxonomic richness of macro-invertebrates between natural and artificial boulders.

Comparisons	Source of Variation	df	MS	*F*
Abundance	Type	1	10.70	0.11 ns
Taxonomic richness	Type	1	0.42	4.48*

ns= (non significant) P>0.05

three spatial orientations (i.e. vertical, sloped, horizontal) ($P>0.05$). Horizontal orientation contained a higher density versus sloped and vertical orientations ($P\leq 0.05$) (Figure 4). In artificial boulders, vertical orientations contained a higher number of species with 2.3±0.04 (mean±standard error) versus 1.92±0.06 for sloped and 1.91±0.05 for horizontal orientations ($P\leq 0.05$) (Figure 5). Likewise, vertical orientations contained a higher density with 16.4±1.77 (mean±standard error) versus 5.58±0.97 for sloped and 4.76±0.83 for horizontal orientations ($P\leq 0.05$) (Figure 6).

When similar orientations were compared between natural and artificial boulders, vertical orientations for artificial boulders significantly contained a higher number of species than that of natural boulders ($P<0.01$) but no significant difference was found in density ($P>0.05$). No

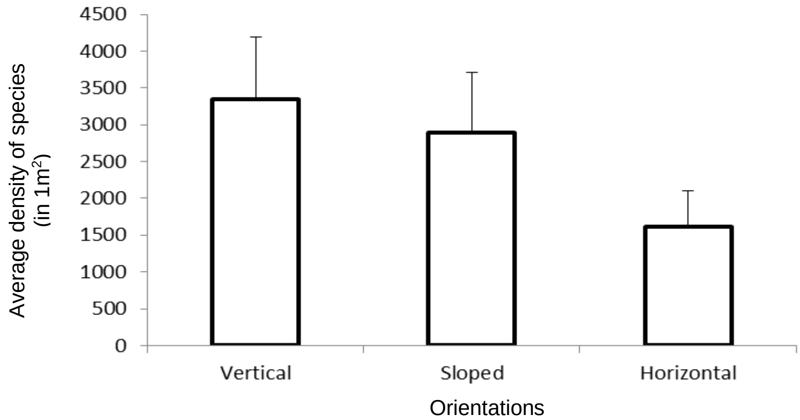

Figure 4. Density of macro-invertebrates on different orientations of natural boulders (Bars indicate standard error).

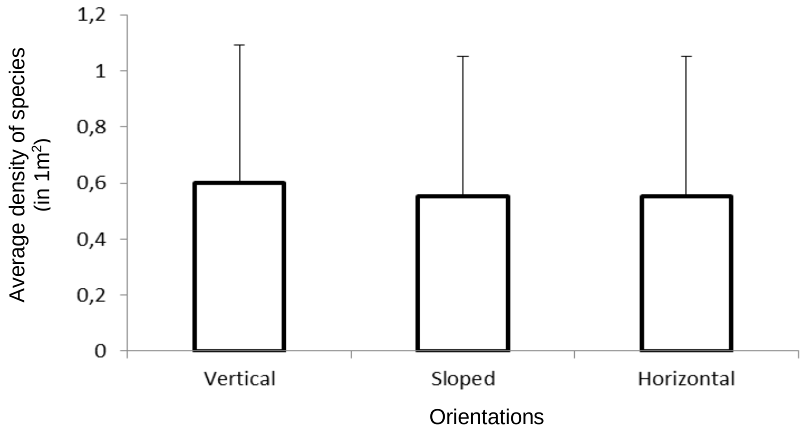

Figure 5. Average number of macro-invertebrate species on different orientations of artificial boulders (Bars indicate standard error).

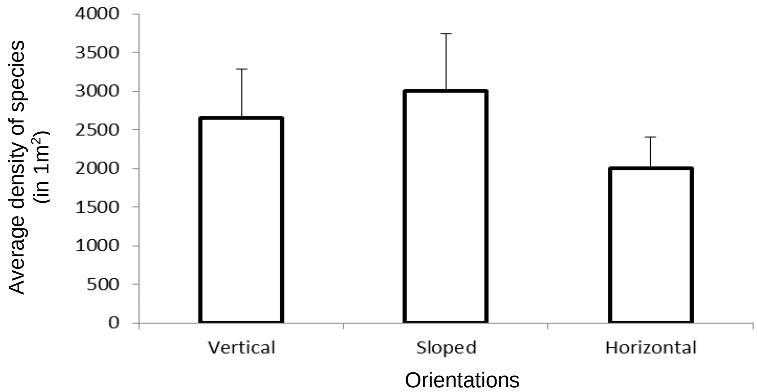

Figure 6. Density of macro-invertebrates on different orientations of artificial boulders (Bars indicate standard error).

significant differences were found in number of species between sloped and horizontal orientations for natural and artificial boulders (P>0.05).

Sloped and horizontal orientations for natural boulders significantly contained a higher density than that of artificial boulders (P≤0.05 for sloped orientation; P<0.01 for horizontal orientation).

The results of ANOVA analyses showed that abundance and taxonomic richness of macro-invertebrates on both natural and artificial boulders were not significantly affected by different facings (Table 4), levels of surface complexity (Table 5), and wave action (Table 6). According to the SIMPER analysis, dissimilarity between artificial and natural boulders is due to *M. lineatus* the highest ranked species followed by *A. improvisus* (Table 7). These two species accounted for one-second of the dissimilarity in abundance between two boulder types.

Table 4. Summary of two-way ANOVA testing the abundance and taxonomic richness of macro-invertebrates on both natural and artificial boulders between different facings

Comparisons	Source of Variation	df	MS	*F*
Abundance	Facing	7	1.020	0.28 ns
	Type	1	0.208	0.05 ns
	Facing * Type	7	3.541	0.90 ns
Taxonomic richness	Facing	7	3.22	3.04 ns
	Type	1	7.28	5.56 ns
	Facing * Type	7	1.06	0.51 ns

ns= (non significant) P>0.05

Table 5. Summary of two-way ANOVA testing the abundance and taxonomic richness of macro-invertebrates on both natural and artificial boulders between different levels of surface complexity

Comparisons	Source of Variation	df	MS	*F*
Abundance	Surface complexity	1	3.77	3.96 ns
	Type	1	1.17	1.23 ns
	Complexity * Type	1	0.95	0.25 ns
Taxonomic richness	Surface complexity	1	7.97	13.51 ns
	Type	1	12.06	20.46 ns
	Complexity * Type	1	0.59	0.28 ns

ns= (non significant) P>0.05

Table 6. Summary of two-way ANOVA testing the abundance and taxonomic richness of macro-invertebrates on both natural and artificial boulders between different levels of exposure to wave action

Comparisons	Source of Variation	df	MS	*F*
Abundance	Wave exposure	2	5.41	3.3 ns
	Type	1	0.42	0.24 ns
	Wave exposure * Type	2	1.63	0.43 ns
Taxonomic richness	Wave exposure	2	0.31	0.11 ns
	Type	1	7.82	2.78 ns
	Wave exposure * Type	2	2.85	1.36 ns

ns= (non significant) P>0.05

Table 7. Percentage of average dissimilarities (δ) (i.e. 45.8) between two boulder types as calculated by the SIMPER analyses. Species appear in their order of their contribution to the overall differences between boulder types by SIMPER breakdowns and their mean abundance is shown for the two types of the boulders

Organism	Average abundance on natural boulders	Average abundance on artificial boulders	Average dissimilarity	Contribution percentage	Cumulative percentage
Mytilaster lineatus	276.08	288.78	15.43	33.67	33.67
Amphibalanus improvisus	36.51	32.30	8.51	18.57	52.25
Pantogammarous maeoticus	6.23	4.44	5.75	12.55	64.76
Chironomus albidus	4.71	4.43	5.70	12.44	77.23
Nereis diversicular	4.07	6.82	5.42	11.83	89.06
Algea coverage (%)	74.93	66.24	5.01	10.94	100

Discussion

The purpose of this study was to assess whether artificial boulders (cement) can mimic natural boulders (rock) for macro-invertebrates in the southern Caspian Sea. In general, the present study found that establishment of novel hard substrates in coastal areas in the Caspian Sea could enhance the diversity and density of the organisms on which commercial fish like Sturgeon feed. However, the results of present study demonstrated that unlike identical species density on artificial and natural boulders, taxonomic richness was not identical on natural and artificial boulders. Natural boulders harbored more species than artificial ones. The difference in taxonomic richness was mostly due to the presence of *M. lineatus* and *A. improvises* that were generally attracted to natural boulders. This result mirrors the findings of other studies (Carr and Hixon, 1997; Badalamenti *et al.,* 2002; Burt *et al.,* 2009) in which natural substrates accommodated more species than artificial substrates. However, in contrast with this study results from some studies were encouraging. For example, Pekrol-Finkel and Benayahu (2007) found more abundance and diversity of benthic organisms at the artificial reefs. Differences in the result of present study and those of Pekrol-Finkel and Benayahu (2007) might be driven by differences in the types of substrates and the target organisms. Pekrol-Finkel and Benayahu (2007) used a PVC net and metal pyramid as artificial substrate which attracted more epibenthic species than that by natural substrates. In the present study, artificial substrates were made of cement boulders (construction debris). Concretes may have mixed materials with pozzolanic reaction that may inhibit organisms from settlement (Lukens and Selberg, 2004) through changing ambient water acidity. In the present study, pozzolanic compounds in cement boulders might be the driven factor for reduced taxonomic richness on artificial boulders. To reduce such reactions, the boulders should not be treated with chemicals. Sanders and Ruiz (2007) found more fish species around artificial reefs than natural areas and further argued that this difference in fish density around artificial reefs might be due to the response of species investigated. Fishes are motile animals and may use artificial substrate as their nursery and shelter areas. In the present study, orientation of boulders was identified as controlling factor for differences in macro-invertebrate assemblages between natural and artificial boulders. Earlier studies have also shown that abiotic factors (e.g., current regime, shading, orientation of the surface, sedimentation, water quality) play an important role in settlement and recruitment of benthic organisms on artificial and natural substrates (Glasby, 2000; Pekrol-Finkel and Benayahu, 2007; Barber *et al.*, 2009).

Establishing a novel substrate creates an open space that usually results in colonization by a series of species (Nybakken and Bertness, 2005). Succession is a gradual process involving colonization and extinction of species. Through a three-year study, Carter and Prekel (2008) revealed that benthic communities change on an artificial reef system over time. The difference in taxonomic richness on artificial and natural boulders in the present study may also suggest that they differ in succession process, so that assemblages on artificial boulders may need more time to coincide with present status of assemblages on natural boulders.

Artificial boulders in the present study were made of construction debris (mixture of cement and rubbles) with complex surfaces, cracks and crevices. The complex surfaces, cracks and crevices on artificial boulders may have altered succession rate of organisms in comparison to natural boulders with smooth and exposed surfaces. Studies by Pekrol-Finkel *et al.* (2006) and Pacheco *et al.* (2010) found that hidden microhabitats, such as cracks and crevices (surface complexity), have a different succession rate from exposed substrates. This is because; they provide refuges for species that do not tolerate exposed surfaces in their primary life stages.

The result of CCA analysis showed that environmental variables that control macro-invertebrate assemblages, are totally different between natural and artificial boulders. The main controlling variable on natural boulders was orientation followed by levels of exposure to wave action and surface facing. Yet the main controlling variable on artificial boulders was algal biomass followed by orientation and surface complexity. The difference in environmental factors controlling macro-invertebrate assemblages might be regarded as driven factor for the differences in species diversity between natural and artificial boulders that is explicitly depicted in lower taxonomic richness on cement boulders.

Conclusion

Artificial boulders have been widely used as barriers to prevent inundation of inland areas due to sea level rise in the southern Caspian Sea. This is the first study assessing the surrogacy value of these boulders for macro-invertebrates in Caspian Sea. Our findings suggest that while artificial boulders (i.e. construction debris) can mimic natural boulders for density of macro-invertebrates, they are not surrogates of rock boulders for taxonomic richness of macro-invertebrates. Artificial boulders might be used instead of natural boulders when persistence of macro-invertebrate communities is a goal. To improve their role in attracting organisms, they should be built with a higher organized system. For example, there should be more concern about physical characteristics such as orientation, facing, levels of exposure to wave action and surface complexity of the boulders. We provided evidence that orientation plays a significant role in shaping community structure of macro-invertebrates on both natural and artificial boulders. However, further studies should consider other physical factors such as sedimentation, water quality, etc.

Acknowledgements

Thanks to Mohammad H. Pourjomeh, Mohsen Pourjomeh, Saloomeh Shoaei, Fatemeh Aghajanpour and Saeide Jolani for their assistance in the field sampling and laboratory works. This project involved an amount of species identification and this would not have been possible without the generous advice of Dr. Alireza Sari, Maryam Vafajoo and Mehrshad Taheri.

References

Azim, M.E., Verdegem, M.C.J., Khatoon, H., Wahab, M.A., van Dam, A.A. and Beveridge, M.C.M. 2002. A comparison of fertilization, feeding and three periphyton substrates for increasing fish production in freshwater pond aquaculture in Bangladesh. Aquaculture, 212: 227-243. doi: 10.1016/S0044-8486(02)00093-5)

Badalamenti, F., Chemello, R., D'Anna, G., Henriquez Ramoz, P. and Riggio, S. 2002. Are artificial reefs comparable to neighboring natural rocky areas? A mollusc case study in the Gulf of Castellammare. Journal of Marine Science, 59: 127–131. doi: 10.1006/jmsc.2002.1265

Barannik, V., Borysova, O. and Stolberg, F. 2004. The Caspian Sea Region: Environmental Change. Ambio, 33: 45-51. doi: 10.1639/0044-7447(2004)033%5 B0045:TCSREC%5D2.0.CO;2

Barber, J.S., Chosid, D.M., Glenn, R.P. and Whitmore, K.A. 2009. A systematic model for artificial reef site selection. New Zealand Journal of Marine and Freshwater Research, 43: 283–297. doi: 10.1080/00288330909510001

Birshten, Y.A., Vinogradova, L.G., Kondakov, N.N., Koon, M.S., Astakhova, T V. and Romanova, N.N. 1968. Atlas of Invertebrates of the Caspian Sea. Pishchevaya Promyshlennost, Moscow, 413 pp.

Bulleri, F. and Airoldi, L. 2005. Artificial marine structures facilitate the spread of a nonindigenous green alga, *Codium fragile* ssp. tomentosoides, in the North Adriatic Sea. Journal of Applied Ecology, 42: 1063–1072. doi: 10.1111/j.1365-2664.2005.01096.x

Burt, J., Bartholomew, A., Usseglio, P., Bauman, A. and Sale, P.F. 2009. Are artificial reefs surrogates of natural habitats for corals and fish in Dubai, United Arab Emirates? Coral Reefs, 28: 663–675. doi: 10.1007/s00338-009-0500-1

Butler, A.J. 1991. Effect of patch size on communities of sessile invertebrates in Gulf St. Vincent, South Australia. Journal of Experimental Marine Biology and Ecology, 153: 225–280.

Carr, M.H. and Hixon, M.A. 1997. Artificial reefs: the importance of comparisons with natural reefs. Fisheries, 22: 28–33. doi: 10.1577/1548-8446(1997)022%3C0028:ARTIOC%3E2.0.CO;2

Carter, A. and Prekel. S. 2008. Benthic colonization and ecological successional patterns on a planned near shore artificial reef system in Broward County. Proceeding of 11th International Coral Reef Symposium, SE Florida: 1215-1219.

Choi, C.G., Takeuchi, Y., Terawaki, T., Serisawa, Y., Ohno, M. and Sohn, C.H. 2002. Ecology of seaweed beds on two types of artificial reef. Journal of Applied Phycology, 14: 343-349. doi: 10.1023/A:1022126007684

Clarke, K.R. and Warwick, R.M. 2001. Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, UK, 144 pp.

Falace, A. and Bressan, G. 2002. Evaluation of the influence of inclination of substrate panels on seasonal changes in a macrophytobenthic community. ICES Journal of Marine Science, 59: 116–121. doi: 10.1006/jmsc.2002.1276

Field, S.N., Glassom, D. and Bythell, J. 2007. Effects of artificial settlement plate materials and methods of deployment on the sessile epibenthic community development in a tropical environment. Coral Reefs, 26: 279–289. doi: 10.1007/s00338-006-0191-9

Fishbase, 2011. http://www.fishbase.org/summary/Ponticola- gorlap.html (accessed July 20, 2011).

Freitas, C.E.C., Petrere, M. and Barrella, W. 2005. Natural and artificially-induced habitat complexity and freshwater fish species composition. Fisheries Management and Ecology, 12: 63–67. doi: 10.1111/j.1365-2400.2004.00420.x

Glasby, T.M. 2000. Surface composition and orientation interact to affect subtidal epibiota. Journal of Experimental Marine Biology and Ecology, 248: 177–190. doi: 10.1016/S0022-0981(00)00169-6

IUCN (International Union for Conservation of Nature) 2001. The Sturgeon. Commission on Environmental, Economic and Social Policy (CEESP), 28 pp.

Jafari, N. 2010. Review of pollution sources and controls in Caspian Sea region. Journal of Ecology and the Natural Environment, 2: 025-029.

Karaman, G.S. and Pinkster, S. 1997. Freshwater *Gammarus* species from Europe, North Africa and adjacent region of Asia (Crustacea-Amphipoda) PartI. Gammarus pulex group and related species. Bijdr Dierk, 47: 1-79.

Lukens, R.R. and Selberg, C. 2004. Guidelines for marine artificial materials. Atlantic and Gulf States Marine Fisheries Commissions, 205 pp.

Marchini, A., Sconfietti, R. and Krapp-Schickel, T. 2007. Role of the artificial structures on biodiversity: the case of arthropod fauna in the North Adriatic lagoons. Studi Trentini Di Scienze Naturali Acta Biologica, 83: 27-31.

Moghaddam, K.H. 2005. Aquatic invertebrates and their significance in sturgeon biodiversity on the continental shelf of Caspian Sea. Proceeding of 40th European Marine Biology Symposium, 21- 25.

Nasrolahi, A., Farahani, F. and Saifabadi, S.J. 2006. Effect of salinity on larval development and survival of the Caspian Sea barnacle, *Balanus improvisus* Darwin. (1854). Journal of Biological Sciences, 6: 1103-1107. doi: 10.3923/jbs.2006.1103.1107

Nybakken, J.W. and Bertness, M.D. 2005. Marine biology: an ecological approach. Pearson education, Inc, Publishing as Benjamin Cummings, San Francisco, 579 pp.

Oren, U. and Benayahu, Y. 1997. Transplantation of juvenile corals: a new approach for enhancing colonization of artificial reefs. Marine Biology, 127:

499-505. doi: 10.1007/s002270050038

Pacheco, A.S., Laudien, J., Thiel, M., Heilmayer, O. and Oliva, M. 2010. Hard-bottom succession of subtidal epibenthic communities colonizing hidden and exposed surfaces off northern Chile. Scientia Marina, 74: 147-154. doi: 10.3989/scimar.2010.74n1147

Perkol-Finkel, S. and Benayahu, Y. 2004. Community structure of stony and soft corals on vertical unplanned artificial reefs in Eilat (Red Sea): comparison to natural reefs. Coral Reefs, 23: 195–205. doi: 10.1007/s00338-004-0384-z

Perkol-Finkel, S. and Benayahu, Y. 2007. Differential recruitment of benthic communities on neighboring artificial and natural reefs. Journal of Experimental Marine Biology and Ecology, 340: 25-39. doi: 10.1016/j.jembe.2006.08.008

Perkol-Finkel, S., Shashar, N. and Benayahu, Y. 2006. Can artificial reefs mimic natural reef communities? The roles of structural features and age. Marine Environmental Research, 61: 121–135. doi: 10.1016/j.marenvres.2005.08.001

Pickering, H. and Whitmarsh, D. 1997. Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy. Fisheries Research, 31: 39–59. doi: 10.1016/S0165-7836(97)00019-2

Pondella, D.J., Stephens, J.S. and Craig, M.T. 2002. Fish production of a temperate artificial reef based on the density of embiotocids. ICES Journal of Marine Science, 59: 88–93. doi: 10.1006/jmsc.2002.1219

Rilov, G. and Benayahu, Y. 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. Marine Biology, 136: 931–942. doi: 10.1007/s002279900250

Sanders, I.M. and Ruiz, I. 2007. The impact of artificial reefs on fish diversity and community composition in Isla Ratones, western Puerto Rico. Proceeding of 60th Gulf Caribian Fish Institute, 407-411.

Sokal, R. R. and Rohlf, F.J. 1995. Biometry: the principles and practice of statistics in biological research. W.H. Freeman, New York, 887 pp.

Spieler, R.E., Gilliam, D.S. and Sherman, R.L. 2001. Artificial substrate and coral reef restoration: What do we need to know to know what we need. Bulletin of Marine Science, 69: 1013–1030.

Stock, J.H., Mirzajani, A.R., Vonk, R., Naderi, S. and Kiabi, B.H. 1998. Limnic and brackish water amphipoda (crustacea) from Iran. Beaufort, 48: 173-234.

Taheri, M., Seyfabadi, J., Abtahi, B. and Foshtomi, M.Y. 2009. Population changes and reproduction of an alien spionid polychaete, *Streblospio gynobranchiata*, in shallow waters of the south Caspian Sea. Marine Biodiversity Records, 2: 1-5. doi: 10.1017/S1755267208000201

ter Braak, C.J.F. and Smilauer, P. 2002. CANOCO reference manual and CanoDraw for windows user's guide: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca NewYork, 500 pp.

Tyrrell, M.C. and Byers, J.E. 2007. Do artificial substrates favor nonindigenous fouling species over native species? Journal of Experimental Marine Biology and Ecology, 342: 54–60. doi: 10.1016/j.jembe.2006.10.014

Underwood, A.J. and Chapman, M.G. 1984. *'GMAV-5'*. University of Sydney, Sydney.

Unesco, 2003. Caspian Sea regional country analysis brief: Environmental issues, 2003. http://www.unesco.org/mab/doc/mys/2002/ayati/ayati.pdf (accessed July 07, 2011).

Vaselli, S., Bulleri, F. and Benedetti-Cecchi, L. 2008. Hard coastal-defence structures as habitats for native and exotic rocky-bottom species. Marine Environmental Research, 66: 395–403. doi: 10.1016/j.marenvres.2008.06.002

Walters, L.J. and Wethey, D.S. 1996. Settlement and early post-settlement survival of sessile marine invertebrates on topographically complex surfaces: the importance of refuge dimensions and adult morphology. Marine Ecology Program Series, 137: 161-171. doi: 10.3354/meps137161

Zander, C.D. and Hagemann, T. 1989. Feeding ecology of littoral Gobiid and Blennioid fishes of the Banyuls area (Mediterranean Sea). III. Seasonal variation. Scientia Marina, 53: 441-449.