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Full Length Research Paper

The impact of industrial pollution on macrobenthic fauna communities

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Mossa creek is a long, deep, tidal canal in Iran. The creek stretches almost 56 km along the northwestern edge of the Persian Gulf. The creek contains numerous sources of organic pollution including industrial sewage effluent. A survey of the creek was performed assessing organic pollution, water properties, and the macrobenthic community. The need to assess the environmental status of marine and coastal waters encouraged the design of specific biotic indices to evaluate the response of benthic communities to human-induced changes in water quality. In this study of the benthic community structure in two creeks surrounding an industrial sewage discharge, water and sediment samples were collected at eight sites in the warm season (September) and cold season (February). Environmental data on physical and chemical variables were also collected from each site and a multivariate analysis was carried out to determine the effect of environmental factors on the biodiversity distribution. The result indicated that: Shannon's-weaver index has significant correlate with dissolved oxygen (DO) and organic matter (OM). In addition, in station near of the swage pollution biodiversity index, water quality and DO decreased and organic matter increased. However, very heavy pollution was observed according to the biodiversity index value in both seasons. The results showed that in both seasons 1, 2, 3 and 5 stations (which are located near the sewage output) in pollutant confine, 4 station in moderate confine and 6, 7, 8 stations located in un pollutant class. Also the results of water quality determine base on Welch index indicated that 1, 2, 5 stations in both season, 362.95 ha (7%) and other stations in moderate pollution load, 4885.73 ha (93%) located in high and moderate pollution load, respectively. Also, the results indicated that stations around the sewage outlet had less macrobenthic species and higher organic matter. On the contrary, the station furthest from the petrochemical industries (station located in Ghanam creek) had higher species diversity and consequently a higher value for the Shannon-Weaver diversity index. The present study also showed that Polychaetes, a biotic index of pollution biotic, were more abundant. Although Polychaetes were also recorded at all the other stations, these stations had greater biodiversity with different numerically dominant species such as: Isopoda, Decapoda, Gastropoda, Copepoda, Bivalvia, Pennatulacea, and Crustaceastations. Consequently, it was established that macrobenthic biodiversity was related to dissolved oxygen and the percentage of organic matter in the sediment.

Key words: Biotic indices, pollution, macrobenthos.

INTRODUCTION

Macrobenthos such as Polychaeta, Decapoda and Mollusca are important sea-bed fauna. Some species of this group are considered to be useful biological indicators for aquatic ecosystems. The macrobenthos are mostly non-migrant inhabitants, and can be used as indices of ecological changes in the sea water environment. Creeks are considered to be amongst the most complex and richest locations in terms of the biodiversity of aquatic ecosystems. They are also some of the most environmentally disturbed areas. Human activities associated with industries, cities and farming

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Abbreviations: PCA, Principle components analysis; **DO,** dissolved oxygen; **OM,** organic matter.

have adversely affected aquatic ecosystems. Detrimental effects include high organic matter (OM) in the water and the loss of habitat for aquatic organisms. Mossa creek stretches almost 56 km along the northwestern edge of the Persian Gulf. It connects with Mahshahr Port and the Shadegan watershed (the largest in Iran). The mouth of the creek is 37 - 40 km wide where it meets the Persian Gulf. Water depth at the western end is 80 m, but it decreases at the eastern end to 5 - 18 m. Tidal movements in the tidal zone cause mixing between the waters of the creek and the Persian Gulf. The water depth changes seasonally by about 4 m. The Mossa creek is of immense importance to regional trading, commercial development, and an increasing number of petrochemical industries. However, large quantities of pollutants from industrial and non-industrial sources are entering the aquatic ecosystem.

In this study, environmental conditions in Ghanam creek (a relatively unpolluted river) were compared with those in the region of Mossa creek around the Bandar Imam Petrochemical Company (BIPC) sewage outlet. Previous pollution surveys of Ghanam creek (Nabavi and Savari, 2002; Madhavi, 2007) showed moderate pollution loads in the area. However, a new and more comprehensive assessment on the influence of organic pollution should more accurately reflect the current ecological health of the ecosystems within these creeks. Moreover, information on benthic macrofauna will help provide an integrative measure for assessing and improving the ecological health of the ecosystem (Pearson and Rosenberg, 1978). This paper reports on this baseline survey of benthic macrofaunal community within the Mossa and Ghannam creeks. Water quality measurements were also compared so as to assess the impacts of existing industrial pollution in this area.

MATERIALS AND METHODS

Sampling stations

Mossa creek and Ghanam creek are situated in the northwestern Persian Gulf (30 21′ to 30 31′ N, 48 52′ to 49 15′ E). The BPIC, which is the largest petrochemical company in Iran covering about 450 ha, is located in the Northern side of Mossa creek. For the purposes of this study, eight sites along Mossa creek and Ghanam creek were selected. Stations 1, 2 and 5 were situated nearer the sewage discharge. Stations 3 and 4 were 500 m from the sewage discharge point; whereas stations 6, 7 and 8 were located in Ghanam creek, away from the sewage discharge (Figure 1). The precise location of each station was determined using a portable GPS unit.

Water sampling

Water samples were taken in three Nansen water samplers (transparent polyethylene bottles) from each sampling station. The creeks were sampled on September 8, 2007 and February 8, 2008. Samples were taken from water near the bottom of the creek to give the best indication of benthic conditions and to avoid problems of stratification. On- site measurements of water temperature and DO were carried out *in situ*. The salinity and pH of the water were determined using a salinity meter (ATAGO S/Mill-E) and pH meter (HORIBA F-11), respectively.

Macrofauna sampling

A stainless steel Van Veen sediment sampler was used to obtain samples of the bottom sediments. The grab collected a sample of sediment with a surface area of 250 cm^2. Four grab samples were taken at each sampling location. Samples were sieved through a 0. 5 mm mesh sieve. The retained macrofauna were then preserved in 5% buffered formalin with rose bengal solution. After 3 days the samples were transferred to 70% ethanol for subsequent sorting and identification. All fauna were identified according to the lowest reliable taxonomic level, with random specimens being verified by outside taxonomists. Granulometry of the sediment was determined using the method of Buchanan and Kain (1984). OM content in the sediment samples were analyzed using the method of El wakeel and Riley (1956).

Statistical analysis

Individual organisms and their species for each sampling date and location were enumerated, and their biodiversity calculated using the Shannon-Weaver Index (H') (Shannon and Weaver 1963, Wilhm and Dorris, 1968; Washington, 1984 and Adams, 2002).

$$\text{Thus } (H') = -\sum_{i=1}^{s} \frac{n}{N} \log_2 \frac{n_i}{N}$$

Where: (H') = the Shannon weaver index of diversity; n_i = total number of individuals of a species i; N = total number of individuals of all species.

A comparison of the data collected at the different stations was made using a one- way ANOVA and Turkey's *post hoc* test. Differences between seasons were tested using a t-test after verifying normality using the Kolmogorov-Smirnov test (Zar, 1999). The total number of species and values of H' (Shannon and Weaver, 1963) were calculated for all the samples using a Multiple Variate Statistical Package. Correlations between the diversity index and physiochemical parameters were calculated using the Pearson Rank Correlation Index. Macrofauna species collected at each station were assessed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm (Estacio et al., 1997, Garcia and Gomez, 2005). All the water quality parameters of the eight stations were compared using principle components analysis (PCA) in which the parameters best explaining the changes in macrofaunal assemblages were identified (Saunders et al., 2007). Relationships among the measured water quality parameters with reference to macrofaunal abundance and distribution for all the eight sampling stations were explained by normal ordination grouping of PCA categories using canonical community ordination (CANOCO) software. PCA is a technique that in this study selects linear combination of water variables to maximize description of the macrofaunal species scores. PCA also determines the best weights for each of the water variables, thereby providing the first PCA axis. In PCA, composite gradients are linear combinations of water variables, which can make the results more comprehensible. The non-linearity enters the model through a unimodal model for a few composite gradients, taken care of in PCA by weighted averaging. Principle Canonical Analysis (PCA) is easier to apply and requires less data than regression. It is a useful Aid to understanding and summarizing the most important

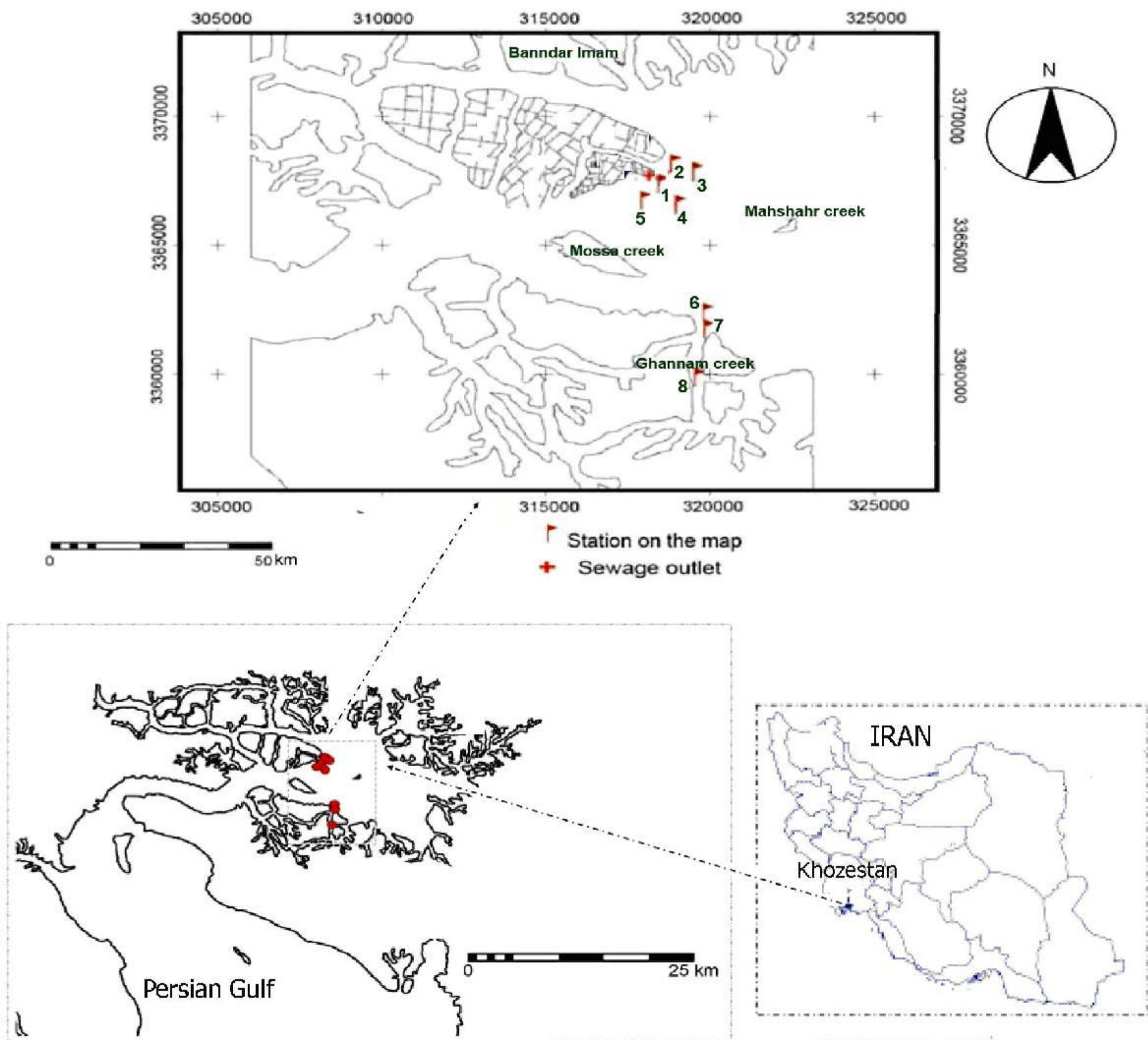

Figure 1. Locations of sampling stations in Mossa creek. Stations 1, 2 and 5 were in the vicinity of the disposal outlet of sewage from BIPC whereas stations 3 and 4 were 500 m away from the disposal outlet. Stations 6, 7 and 8 were located in Ghanam creek. The location of Mossa creek within the Persian Gulf is shown in the inset.

species- water relationships (Saunders et al., 2007).

RESULTS

Macrobenthic fauna

Species numbers of macrofaunal diversity were higher in stations 6, 7 and 8 than in the lagoon stations 1, 2 and 5. Species numbers of macrofaunal diversity were intermediate for stations 3 and 4. There was a significant difference in H' among stations; $p \leq 0.05$. H' was higher in stations 6, 7 and 8 than in the lagoon stations 1, 2 and 5. Species numbers of macrofaunal diversity were intermediate for 3 and 4 stations, this change being more significant in the cold season (Figure 2a and c). Numbers of individual organisms were also higher in stations 6 - 8 than in the stations nearer to the sewage discharge. However, station 4 had a significantly higher number of individuals than stations 1, 2 and 5, with more than twice the number of individuals being recorded (Figure 2b).

The samples from the three stations nearest to the sewage discharge were dominated by Polychaetes, *Lycastopsis sp* being most abundant in both the summer and winter seasons. Even though Polychaetes were also present at each of the other stations the samples were more diverse. The numerically dominant species included Isopoda, Decapoda, Gastropoda, Copepoda, Bivalvia, Pennatulacea and Crustacea. The least abundant species were *Apseudes sp*. and *Pyrene sp.* in the warm and cold seasons, respectively (Table 1). Values for the Shannon-Weaver diversity indices confirmed that each station has a unique community composition (Tables 2a and b). However, when data from the station samples were

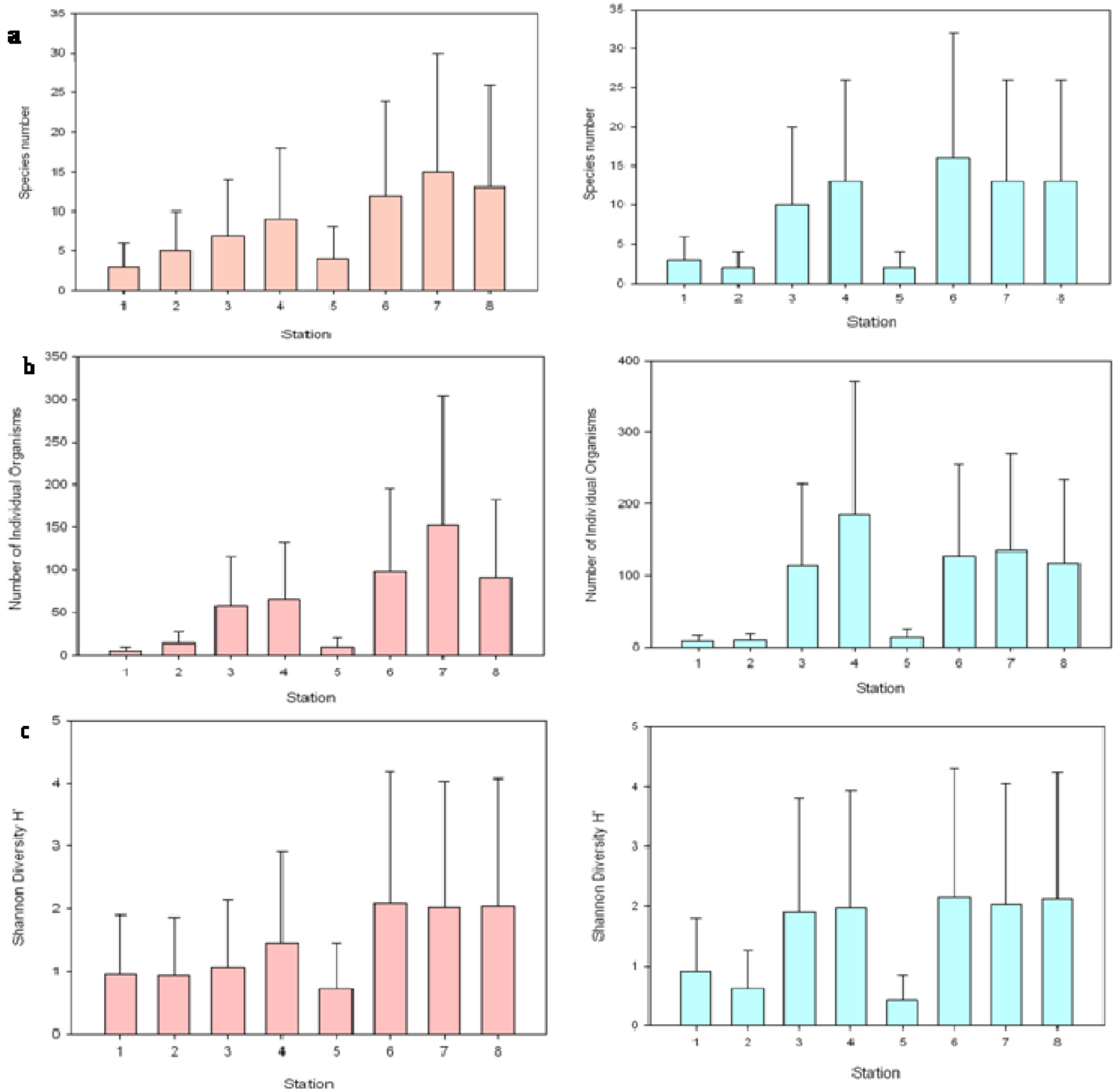

Figure 2. Number of species (a), individual organisms (b) and species diversity (c) within the eight sample stations in Mossa Creek averaged between the warm (figure in left) and cold (Figure in right) season dates. The number of macrofauna species (a), total number of individual macrofauna (b) and Shannon diversity index values(c) for the eight sampling stations in Mossa Creek are shown for the warm (left figures) and cold (right figures) seasons. The values are the average of 3 samples. (Error bars are SD).

divided into two groups according to the location of the stations from where they were taken, there was little similarity in biodiversity (less than 10%) between the group representing samples from Ghanam creek and that from regions nearer the sewage discharge. When data from the samples from the stations were divided into two groups representing the warm and cold seasons, respectively, and then aggregated within seasons according to their similarity, those from stations 1, 2 and 5 became allocated to one group and those from the

Table 1. Abundance of species (per 250 cm^2) at each station averaged over two sample dates.

A (warm season)									
		Station							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Polycheata	*Lycastopsis sp*	3	3	8	10	6	18	42	21
	Hemipodus sp		5	10	5		10	7	6
	Cossara sp			5		2		11	7
	Nephty sp.		4		1		3	5	
Isopoda	*Apanthura sp.*				5	1	1	2	4
Decapoda	*Grapsus sp.*			16	20	1	15	10	7
	Mud crab sp.			10	15		5	4	5
Gastropoda	*Hydrobia eglecta*	1					5	10	10
	Diala semistriata		1				4	6	4
Copepoda	*Cyclopoid sp.*	1						12	
Bivalvia	*Chama pacifica*						15	10	8
	Mcta aequisulcata						6	15	5
	Tivela ponderosa						14	15	7
Pennatulacea	*Sclerobelemnon sp.*			5	4			1	2
Crustacea	*Apseudes sp.*				3			2	
	Penaeus semisulcatus		1	3	3		2		5
B (cold season)									
		Station							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Polycheata	*Lycastopsis sp.*	5		17	21	11	21	40	18
	Hemipodus sp.		4	13	10		15	10	21
	Cossara sp				4		10		8
	Nephty sp.			12			6	8	
Isopoda	*Apanthura sp.*			2	4			7	6
Decapoda	*Grapsus sp.*			18	14		8	5	9
	Mud crab sp.		2		17		11	3	4
Gastropoda	*Hydrobia neglecta*			8	13		14	17	18
	Diala semistriata						3	9	11
	Pyrene sp.						1		
Copepoda	*Cyclopoid sp.*				1	2	2		1
Bivalvia	*Chama pacifica*	2		20	60		5	11	10
	Mcta aequisulcata	1		15	20		12	7	1
	Tivela ponderosa			5	14		6	9	4
Pennatulacea	*Sclerobelemnon sp.*		2		5		4	7	
Crustacea	*Apseudes sp.*		1				3		6
	Penaeus semisulcatus			4	3		5	2	

Only species contributing > 5% of the total individuals are shown.

other stations were allocated to a second group. The greatest similarity between stations in terms of biodiversity was for stations 7 and 8 in both seasons (Figure 3).

Water quality characteristics

Water temperatures were consistent along the length of the creek, varying between 24 and 26°C (warm season) and 13 to 15°C (cold season), with no significant difference between stations (ANOVA, P = 0.985 . The total measurements of water properties showed significant differences in DO and salinity between stations even though pH and OM remained constant along the creek (ANOVA, $p < 0.05$) (Figure 4).

Salinity percentage changed with season and bed topography. Salinity percentage increased in the warm season because evaporation increased and water depth decreased in Mossa creek. Rhoads (1974) showed that

Table 2a. R-values from pair wise UPGMA analysis of macrobenthic faunal communities between each station using dates as replicates.

A (warm season)								
Station	1	2	3	4	5	6	7	8
1	100							
2	96.67	100						
3	93.49	94.61	100					
4	94.42	95.26	97.31	100				
5	97.16	96.82	94.12	95.46	100			
6	87.81	88.65	88.94	91.086	87.91	100		
7	95.41	96.21	95.03	96.37	94.81	90.54	100	
8	97.32	96.94	92.96	94.42	96.0	88.44	96.98	100

Global R = 0.866, all results significant to $p < 0.05$.

Table 2b. R- values from pairwise UPGMA analysis of macrobenthic fauna communities between each station using dates as replicates.

B (cold season)								
Station	1	2	3	4	5	6	7	8
1	100							
2	94.4	100						
3	92.51	94.90	100					
4	95.46	94.83	96.49	100				
5	96.09	95.83	95.44	97.33	100			
6	95.12	91.73	91.996	95.08	93.43	100		
7	92.83	88.62	88.59	91.77	90.64	95.61	100	
8	79.83	77.17	78.31	80.78	78.37	83.33	86.07	100

Global R = 0.866, all results significant to $p < 0.05$.

salinity was directly related to temperature. Salinity percentage was consistent between stations because the bed was silty. Gray (1981) showed that salinity percentage did not change in the granular sediment. OM was high in the whole zone. Susana Carvalho et al. (2006) showed that OM percentage increased in the granular sediment. Barnes and Hughes (1992) also explained that an OM value of 5 -10% is acceptable, but OM% was higher than that in samples from all the stations. Surveying water pH is important because heavy metals are dissolved in water when the pH decreases. PCA enables non-linear relationships between H' and physio-chemical properties to be identified so that the best weighting for the physio-chemical variables may be determined. The analysis of PCA showed that H' was significantly correlated with DO and OM. From the pattern of PCA it was evident that H' and DO were directly and positively related, whereas H' and OM were indirectly and negatively related (Figure 5).

Water quality characteristic and macrofouna distribution

The Pearson Rank Correlation analysis gave a correlation of -0.50 between DO and OM, and a correlation of 0.93 between change in the macro fauna community and a combination of DO.

DISCUSSION

This study provides new measurements of water properties and a baseline survey of macrobenthic fauna distribution within Mossa creek forming the basis of a two season term assessment. Carvalho et al. (2006) explained that survey of macrofauna is a useful guide to ecological condition. The results indicated that a high level of industrial pollution (OM) within the regions in the close vicinity of a sewage disposal point is already a significant problem in the area. Although pollution has been found previously in the creek (Mahdavi Soltani, 2007), with related changes in the benthic macrofauna community, the present study was more detailed, highlighting zones of high and low pollution impact on the macrobenthic fauna. Generally, organic pollution increased from the stations close to the sewage disposal point, with the opposite pattern for DO. BIPC is located near Mossa creek and the sewage effluent is discharged into this aquatic ecosystem.

Sewage discharge causes a decrease in DO, species

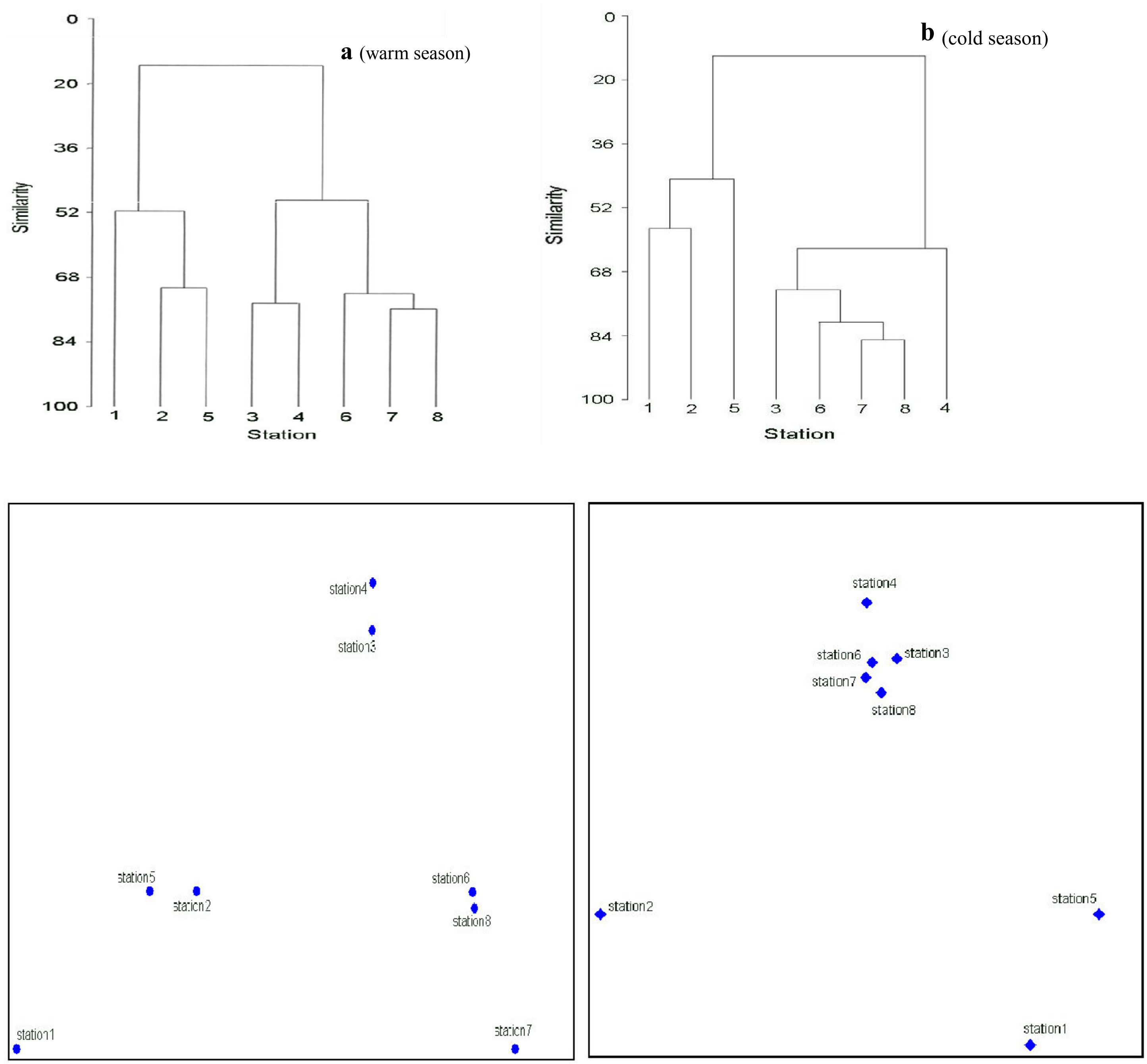

Figure 3. Group averaged dendrogram and n-MDS ordination of community similarity in the benthic macrofauna communities sampled within Mossa Creek. Numbers shown indicate station.

diversity, and an increase in the percentage of OM in the stations nearest the sewage outlet (Figure 6). Abu-hilal et al. (1994), Hassan et al. (1995) and EL-sammak (2001) established that high levels of organic pollution in Dubai creek cause decreases in DO and macrobenthic diversity. Johansson (1997), Flemer et al. (1999) and Wu (2002) explained that in response to decreasing DO, there are decreases in both species richness and diversity, and the species composition being largely determined by differences in the tolerance of the different species to oxygen deficiency.

The adverse biological effects on soft bottom communities are mainly due to reduced oxygen content of the water (Saiz-Salinaz, 1997). However, the interpretation of stress due to low DO is difficult because there is a lack of information about oxygen tolerances for most macrobenthic species (Dauer et al., 1993). The macrofauna within the creek showed a clear pattern of

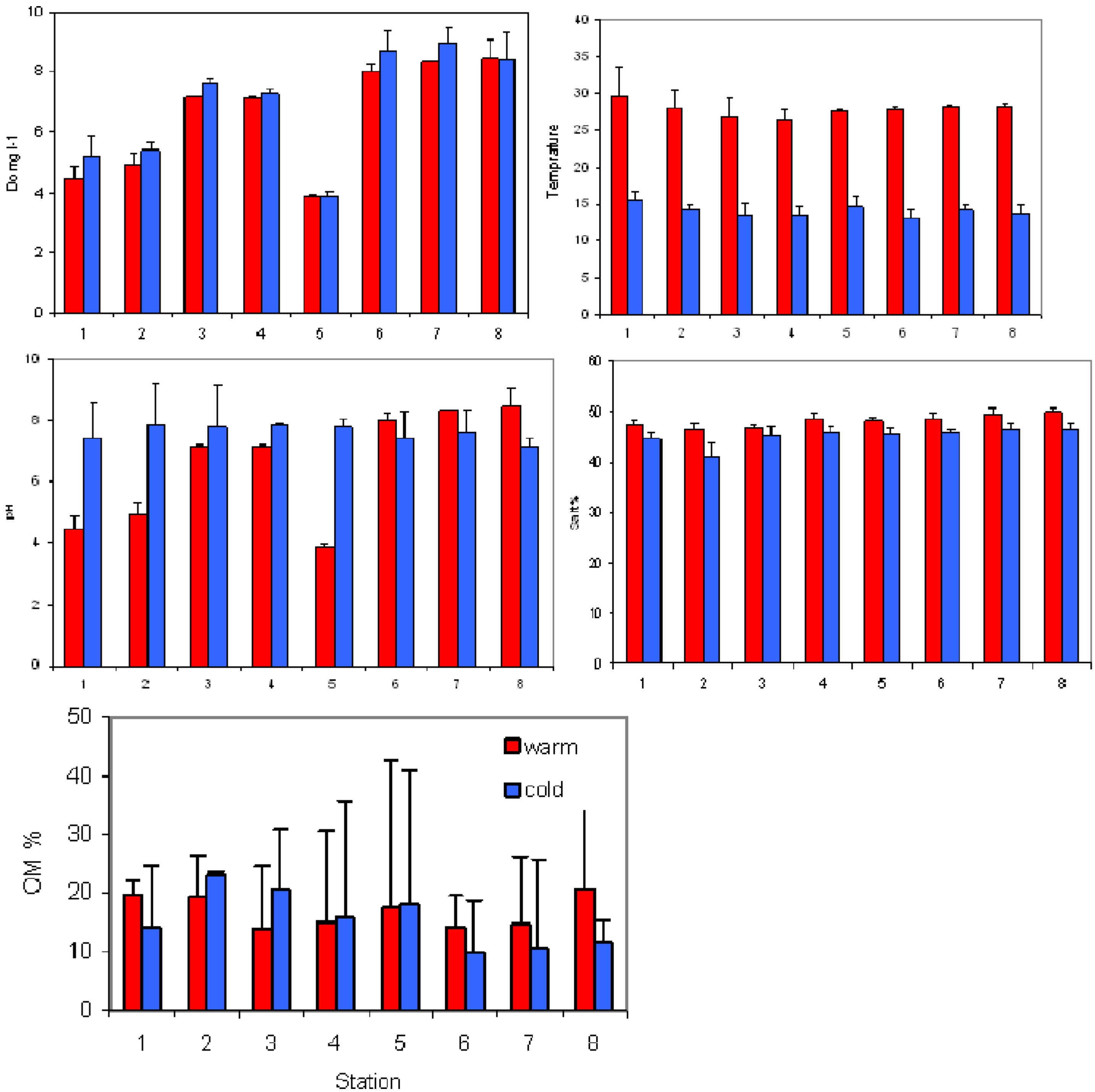

Figure 4. Physio-chemical properties of the water in Mossa Creek taken from the six sample stations averaged between the four sample dates.

change over a gradient of pollution (OM), following the Pearson - Rosenberg (PR) model of community change (Pearson and Rosenberg, 1978; Diaz and Rosenberg, 1995; Shin et al., 2006). Stations 6, 7 and 8, which were farther from the sewage outlet and with the lowest measurements of pollution, had communities high in species richness, diversity and individual numbers. Species richness, diversity and individual abundance were all very low at locations closer to the sewage disposal point; the organisms found being dominated by polychaetes, species symptomatic of high pollution and low DO (Pearson and Rosenberg, 1978; Ismail, 1992).

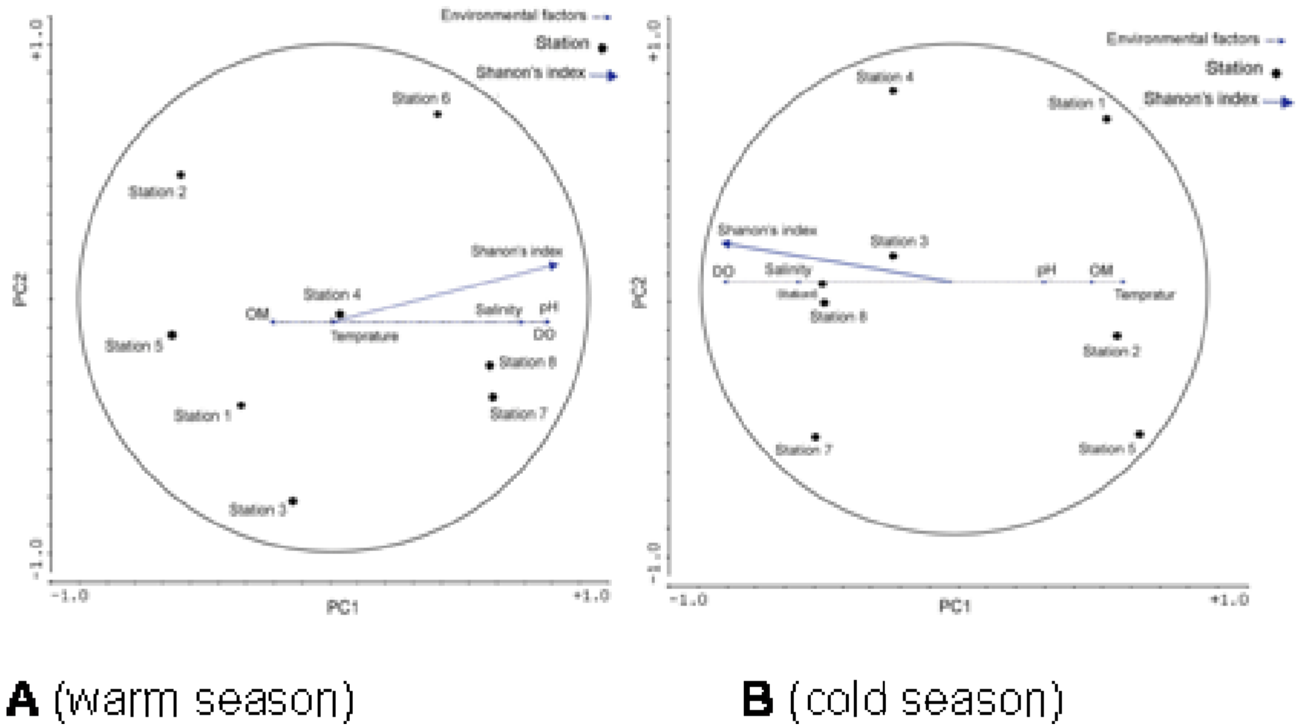

Figure 5. PCA of physio-chemical properties of the water from Mossa creek.

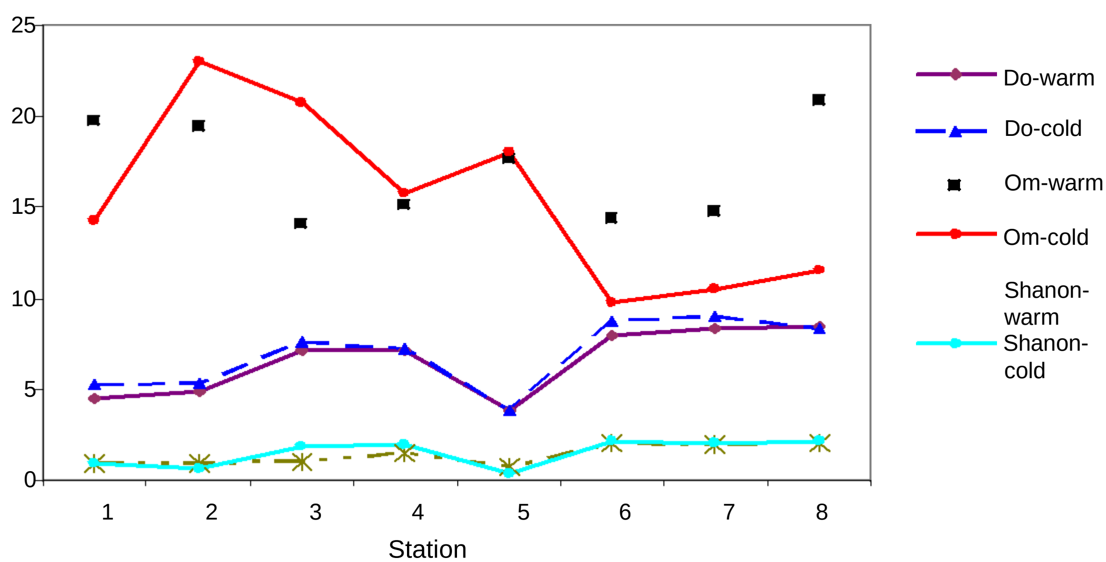

Figure 6. Relationship between (H'), DO and level of OM. Dissolved oxygen = DO, Organic matter = OM, Shannon weaver diversity index = H'.

Stations 3 and 4, situated between the Ghannam creek and stations 1 and 2 had similar levels of diversity and species richness to the Ghannam creek stations. Tidal flow within the creek is small with little net flow usually associated with systems such as estuaries. This means that water flux from the upper creek to the lower creek and ultimately the Persian Gulf is very small, so that the retention time within the creek is high. This research indicated that the input from the sewage outlet near station 5 is largely responsible for the pollution of the

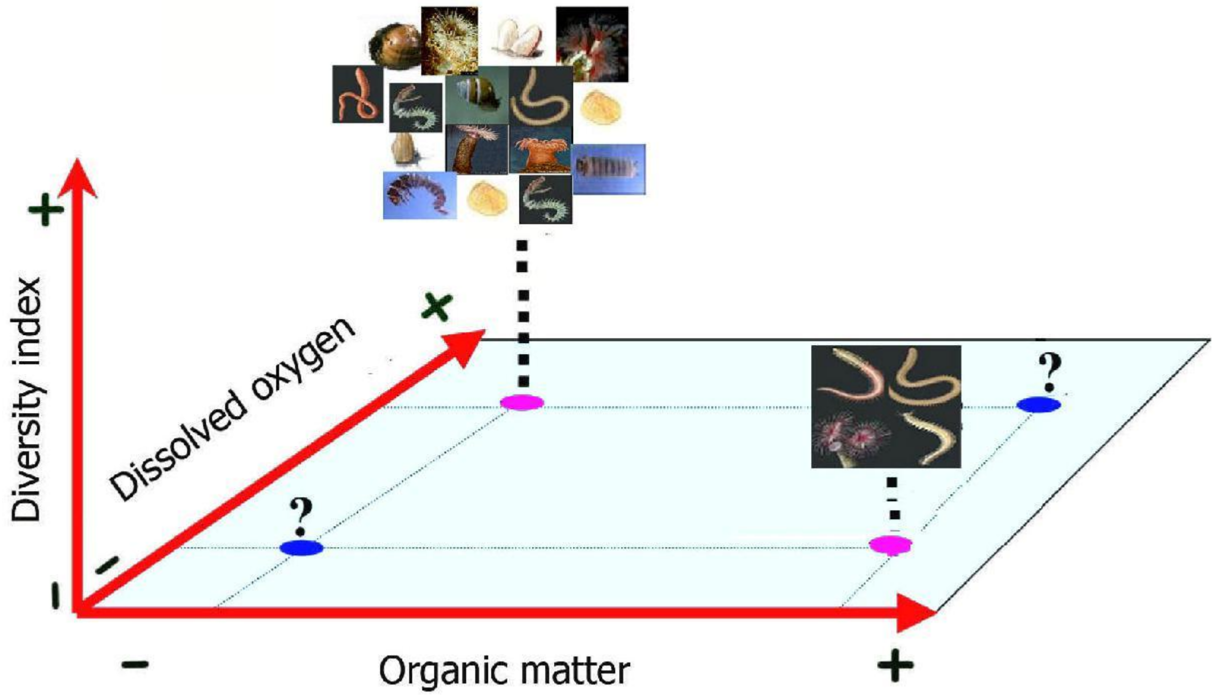

Figure 7. Schematic model indicating how the diversity index responds to different levels of OM and DO.

region creek. Our study provided evidence that pollution has spread to stations 1 and 2 due to lack of natural flow out of the creek. Station 5 has the highest levels of OM within the creek and has an overall water quality quite unlike the unpolluted water at stations 6, 7 and 8. Macrofauna communities are comparatively slow to respond to changing water conditions and are therefore a good indication of the state of a system over a prolonged time period (Bilyard, 1987). The results of this baseline macrofauna survey therefore highlight that sections of Mossa creek, especially in the vicinity of the sewage disposal point, are already heavily affected by industrial pollution. Given the rapidly increasing number of industries near the Mossa creek, including proposed developments around the creek, the results from our study highlight the need for this survey. Consequently, the importance of oxygen in a water column and the percentage of OM in sediment as key factors for macrofaunal assemblage in sediment is now well understood. Figure 7 summarizes possible outcomes under different levels of OM and DO.

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