Evaluation of the impact of industrial sewage pollution on marine benthic communities

T. Tabatabaie and F. Amiri

ABSTRACT

A survey was performed to assess organic pollution, water properties and the marine benthic 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 Ghanam Creek surrounding an industrial sewage discharge, water and sediment samples were collected at eight sites in the warm season and cold season. 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 results indicated that 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 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 Crustacea. Consequently, it was established that macrobenthic biodiversity was related to dissolved oxygen and the percentage of organic matter in the sediment.

Key words | benthic community, biotic indices, human activity, macrobenthos, pollution

T. Tabatabaie (corresponding author)
Department of Engineering,
Group of Natural Resources and Environmental,
Islamic Azad University,
Bushehr Branch,
Iran
E-mail: *ttabatabaie@iaubushehr.ac.ir*

F. Amiri
Department of Engineering,
Group of Natural Resources,
Islamic Azad University,
Bushehr Branch,
Iran

INTRODUCTION

Macrobenthos such as Polychaeta, Decapoda and Mollusca are important seabed 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 seawater environment (Nabavi & Savari 2002).

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 (Abu-Hilal *et al.* 1994). Human activities associated with industries, cities and farming have adversely affected aquatic ecosystems. Detrimental effects include high organic matter (OM) in the water and the loss of habitat for aquatic organisms (Vaquer-Sunyer & Duarte 2008).

Ghanam Creek stretches almost 56 km along the north-western 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 are a result of mixing between the waters of the creek and the Persian Gulf. The water depth changes seasonally by about 4 m.

The Ghanam 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.

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In this study, environmental conditions in Ghanam Creek (a relatively unpolluted river) were compared with those in the region of Ghanam Creek around the Bandar Imam Petrochemical Company (BIPC) sewage outlet. Previous pollution surveys of Ghanam Creek (Nabavi & Savari 2002; Madhavi Soltani 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 & Rosenberg 1978).

This paper reports on this baseline survey of the benthic macrofaunal community within the Ghanam Creek. Water quality measurements and marine benthic communities were also compared in order to assess the impacts of existing industrial pollution in this area.

MATERIAL AND METHODS

Sampling stations

Ghanam Creek is situated in the northwestern Persian Gulf (30°21′ to 30°31′ N, 48°52′ to 49°15′ E). BPIC, which is the largest petrochemical company in Iran covering about

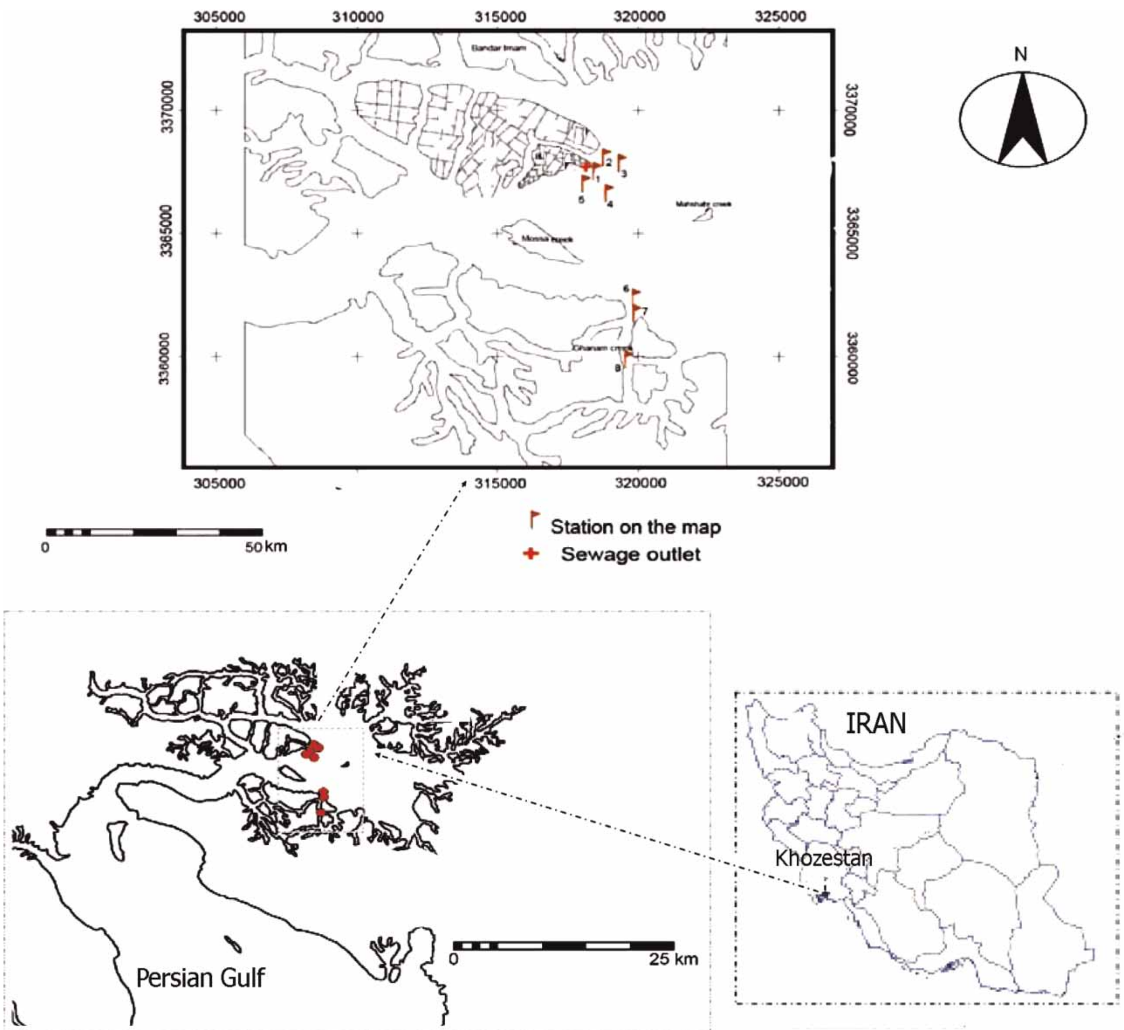

Figure 1 | Locations of sampling stations in Ghanam Creek. Stations 1, 2 and 5 were in the vicinity of the disposal outlet of sewage from BIPC, whereas stations 3 and 4 were 500 m away from the disposal outlet. Stations 6, 7 and 8 were located in Ghanam Creek.

450 hectares, is located on the northern side of Ghanam Creek. For the purposes of this study, eight sites along 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 (Table 1).

Water sampling

Water samples were taken in three Nansen water samplers (transparent polyethylene bottles) from each sampling station. The creeks were sampled on 8 September 2007 and 8 February 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. Onsite measurements of water temperature and dissolved oxygen (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 & Kian (1984). OM content in the sediment samples was analysed using the method of El Wakeel & Riley (1956).

Table 1 | Geographic position and water depth of stations

Station	Geographic position (UTM)	Depth of water (m)
1	39R 318995 3367945	4
2	39R 319276 3368509	5.3
3	39R 319717 3368360	6.2
4	39R 319306 3367292	6.5
5	39R 318572 3367638	4.2
6	39R 320161 3363525	7
7	39R320190 3362948	7.4
8	39R 319932 3361278	8.5

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 & Weaver 1963; Wilhm & Dorris 1968; Washington 1984; Adams 2002, 2003).

A comparison of the data collected at the different stations was made using a one-way analysis of variance (ANOVA) and Tukey'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 & Weaver 1963) were calculated for all the samples using a multiple variate statistical package. Correlations between the diversity index and physicochemical 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 & Gomez 2005).

All the water quality parameters of the eight stations were compared using principal 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. We used the principal canonical

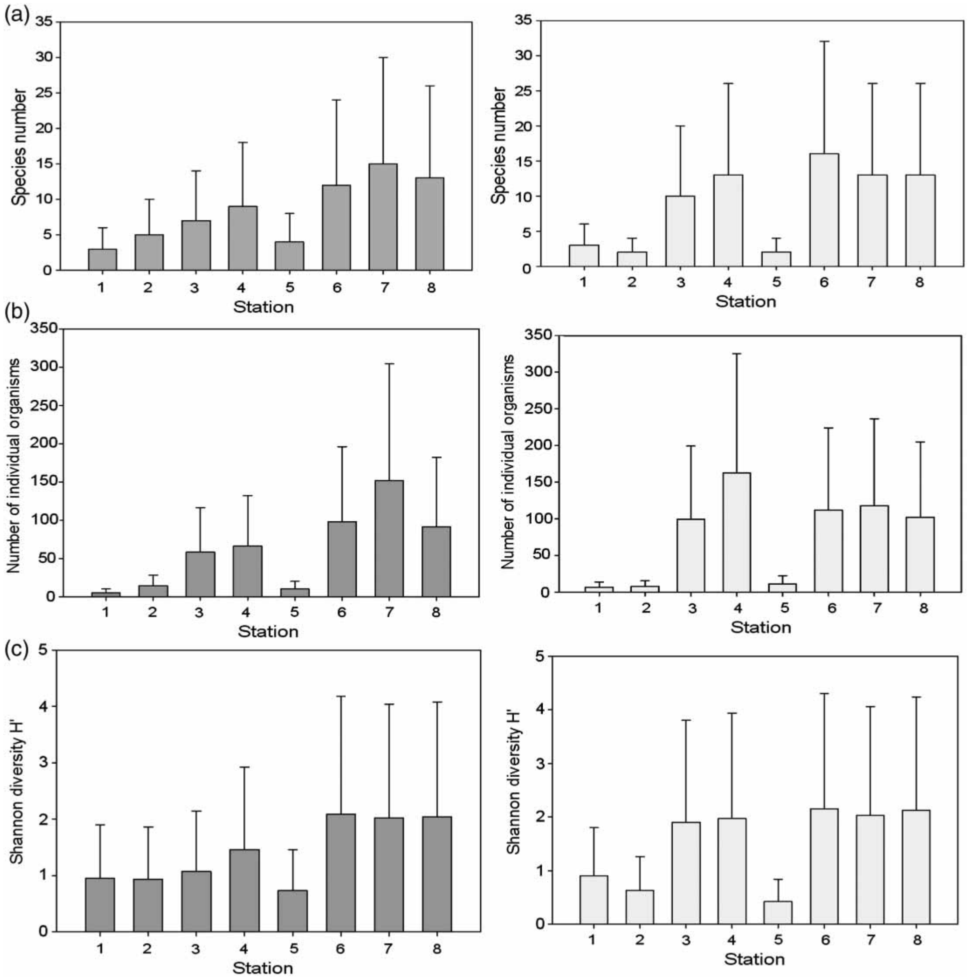

Figure 2 | (a) Number of species; (b) individual organisms; and (c) species diversity within the eight sample stations in Ghanam Creek averaged between the warm (left-hand side) and cold (right-hand side) season dates. The values are the average of three samples (error bars represent SD).

analysis technique to select a linear combination of water variables to maximize description of the macrofaunal species scores. Also, by using the first PCA axis the best weights for each of the water variables were determined.

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 stations 3 and 4, this change being more significant in the cold season (Figure 2(a) 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 2(b)).

The samples from the three stations nearest to the sewage discharge were dominated by polychaetes, *Lycastopsis* spp. being most abundant in both the summer and winter seasons. Even though polychaetes were also present at each of the other stations, there the samples were more diverse. The numerically dominant species included Isopoda, Decapoda, Gastropoda, Copepoda, Bivalvia, Pennatulacea and Crustacea. The least abundant species were *Apseudes* spp. and *Pyrene* spp. in the warm and cold seasons, respectively (Table 2).

Values for the Shannon-Weaver diversity indices confirmed that each station has a unique community composition (Tables 3(a), 2(b)). However, when data from the station samples were 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

Table 2 | Abundance of species (per 250 cm^2) at each station averaged over two sample dates: (a) warm season; (b) cold season

		Station							
Class	**Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
(a) Warm season									
Polychaeta	*Lycastopsis* spp.	3	3	8	10	6	18	42	21
	Hemipodus spp.		5	10	5		10	7	6
	Cossara spp.			5		2		11	7
	Nephty spp.		4		1		3	5	
Isopoda	*Apanthura* spp.				5	1	1	2	4
Decapoda	*Grapsus* spp.			16	20	1	15	10	7
	Mud crab spp.			10	15		5	4	5
Gastropoda	*Hydrobia neglecta*	1					5	10	10
	Diala semistriata		1				4	6	4
Copepoda	*Cyclopoid* spp.	1						12	
Bivalvia	*Chama pacifica*						15	10	8
	Mactra aequisulcata						6	15	5
	Tivela ponderosa						14	15	7
Pennatulacea	*Sclerobelemnon* spp.			5	4			1	2
Crustacea	*Apseudes* spp.				3			2	
	Penaeus semisulcatus		1	3	3		2		5
(b) Cold season									
Polycheata	*Lycastopsis* spp.	5		17	21	11	21	40	18
	Hemipodus spp.		4	13	10		15	10	21
	Cossara spp.				4		10		8
	Nephty spp.			12			6	8	
Isopoda	*Apanthura* spp.			2	4			7	6
Decapoda	*Grapsus* spp.			18	14		8	5	9
	Mud crab spp.		2		17		11	3	4
Gastropoda	*Hydrobia neglecta*			8	13		14	17	18
	Diala semistriata						3	9	11
	Pyrene spp.						1		
Copepoda	*Cyclopoid* spp.				1	2	2		1
Bivalvia	*Chama pacifica*	2		20	60		5	11	10
	Mactra aequisulcata	1		15	20		12	7	1
	Tivela ponderosa			5	14		6	9	4
Pennatulacea	*Sclerobelemnon* spp.		2		5		4	7	
	Apseudes spp.		1				3		6
Crustacea	*Penaeus semisulcatus*			4	3		5	2	

Note: only species that contribute >5% of the total individuals are shown.

Table 3 | *R*-values from pairwise UPGMA analysis of macrobenthic faunal communities between each station using dates as replicates: (a) warm season; (b) cold season

Station	1	2	3	4	5	6	7	8
(a) Warm season								
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
(b) Cold season								
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 $p < 0.05$.

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 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 and 15 °C (cold season), with no significant difference between stations (ANOVA, $p = 0.985$). Also, *t*-test analysis showed a significant difference between seasons based on water temperatures ($p < 0.05$).

The results of ANOVA analysis of water properties measurements are shown in Figure 4. There are significant differences in DO, salinity, pH and OM between stations and seasons along the creek (ANOVA, $p < 0.05$). Salinity percentage changed with season and bed topography. Salinity percentage increased in the warm season because evaporation increased and water depth decreased in Ghanam Creek.

Rhoads (1974) showed that 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 is increased in the granular sediment. Barnes & 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 physicochemical properties to be identified so that the best weighting for the physicochemical 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).

Physicochemical characteristics and macrofauna distribution

The Pearson's rank correlation analysis gave a correlation of −0.50 between DO and OM, and a correlation of 0.93 between change in the Shannon's index (H') and DO (Table 4).

DISCUSSION

This study provides new measurements of water properties and a baseline survey of macrobenthic fauna distribution within Ghanam Creek forming the basis of a two season term assessment. Susana Carvalho *et al*. (2006) explained that a 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

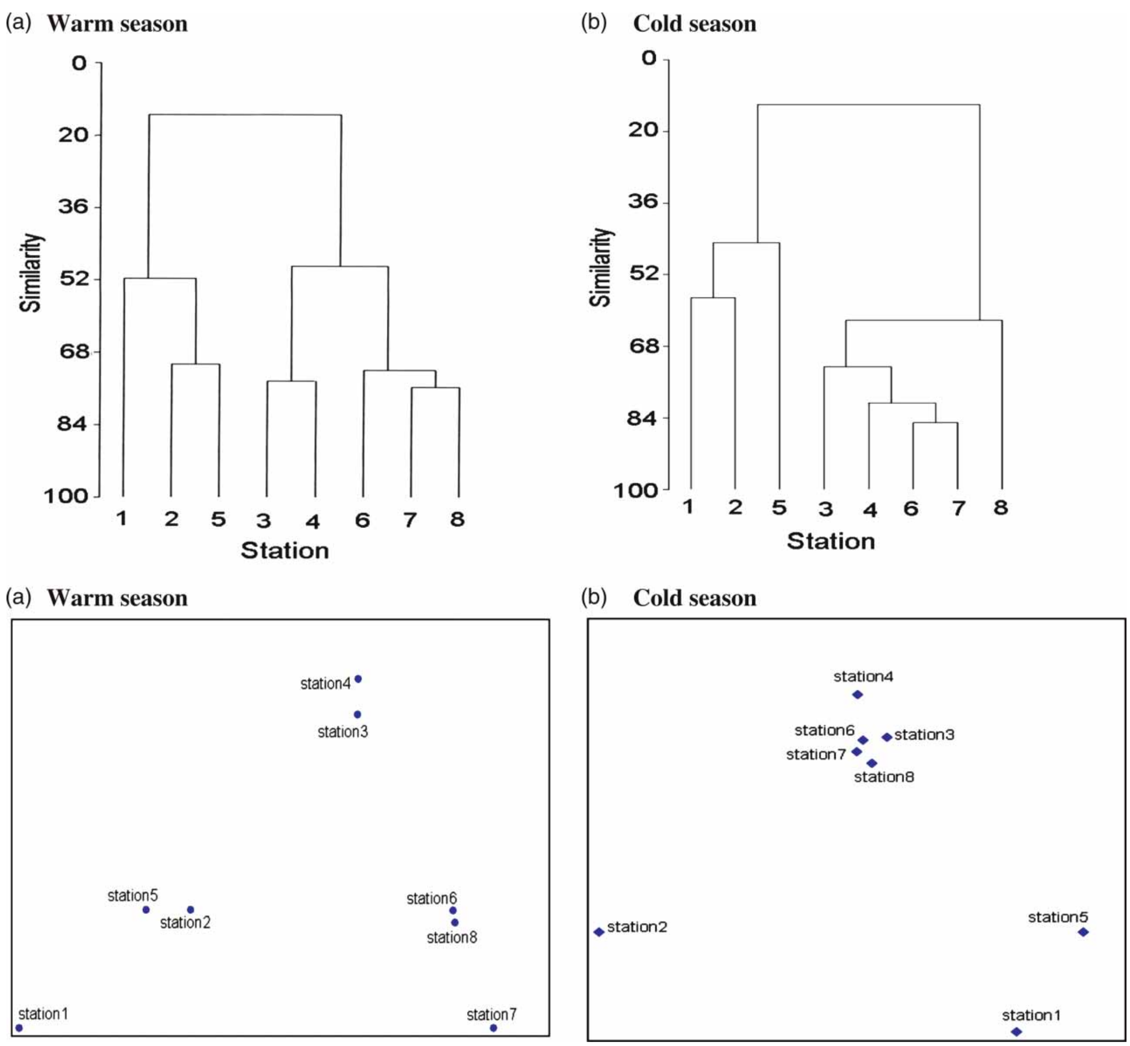

Figure 3 | Group averaged dendrogram and *n*-MDS ordination of community similarity in the benthic macrofauna communities sampled within Ghanam Creek.

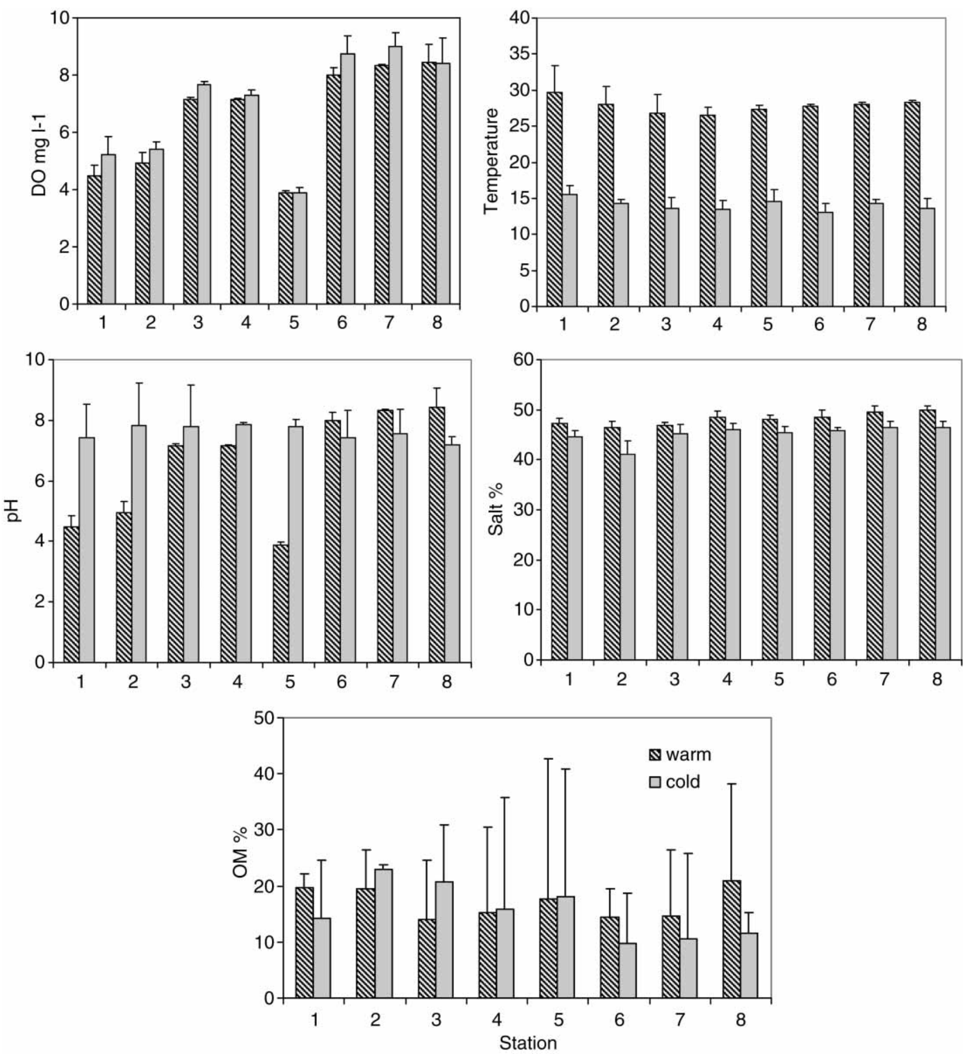

Figure 4 | Physicochemical factors of the water in Ghanam Creek taken from the eight sample stations averaged between the three sample dates. DO, dissolved oxygen; OM, organic matter.

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 at the stations close to the sewage disposal point, with the opposite pattern for DO.

BIPC is located near Ghanam Creek and the sewage effluent is discharged into this aquatic ecosystem. Sewage discharge causes a decrease in DO and species diversity, and an increase in the percentage of OM in the stations nearest the sewage outlet (Figure 6). The results of the study by Vaquer-Sunyer & Duarte (2008) show that the excessive production of OM increases the oxygen demand of coastal ecosystems. 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 is 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

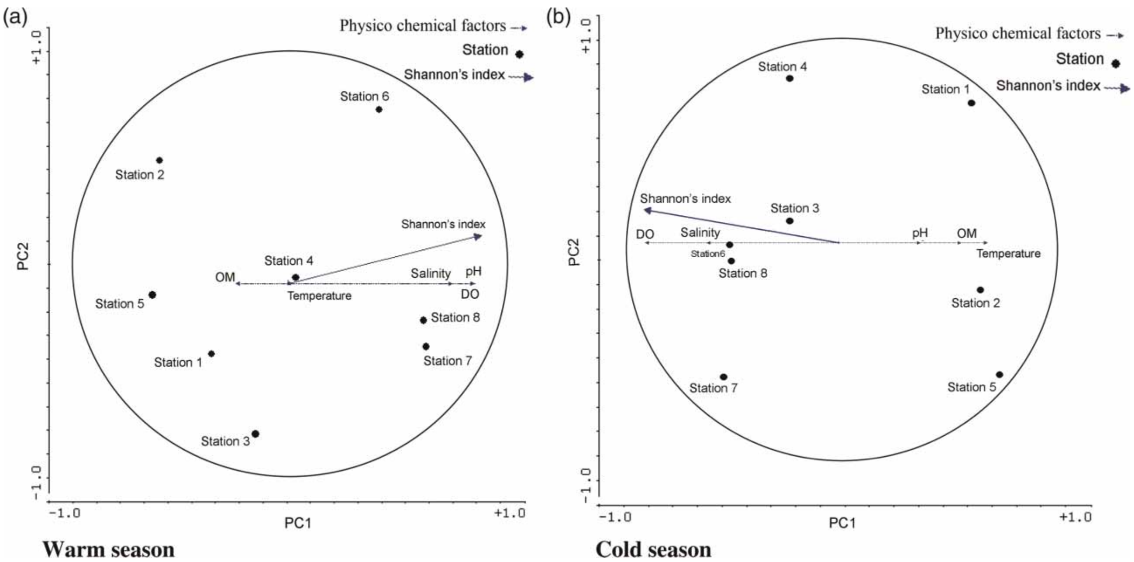

Figure 5 | Schematic PCA analysis of physicochemical factors and Shannon-Weaver Index (*H′*).

species (Dauer *et al.* 1993). The macrofauna within the creek showed a clear pattern of change over a gradient of pollution (OM), following the Pearson–Rosenberg (PR) model of community change (Pearson & Rosenberg 1978; Diaz & Rosenberg 1995; Al-Darwish *et al.* 2005; Shin *et al.* 2006). Stations 6, 7 and 8, which were further 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 were dominated by polychaetes, species symptomatic of high pollution and low DO (Pearson & Rosenberg 1978; Ismail 1992). Stations 3 and 4, situated between the Ghanam Creek and stations 1 and 2, had similar levels of diversity and species richness to the Ghanam 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 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 creek region. Our study provided evidence that pollution has spread to stations 1 and 2 because of the lack of natural flow out of the creek. Station 5 has the highest levels of OM within the creek and has an overall water

Table 4 | Coefficient correlation of Pearson's analysis between physicochemical variables, depth of water, DO, OM and the Shannon–Weaver index

	Shannon's index (*H′*)	DO	pH	Salinity	Temperature	OM	Water depth
Shannon's index (*H′*)	1.00						
DO	0.93	1.00					
pH	−0.33	−0.38	1.00				
Salinity	0.41	0.30	0.35	1.00			
Temperature	−0.12	−0.16	0.70**	0.71**	1.00		
OM	−0.50*	−0.50*	−0.23	−0.23	0.17	1.00	
Water depth	−0.17	−0.11	0.17	0.01	0.22	−0.01	1.00

*Significant difference ($p < 0.05$).

**Significant difference ($p < 0.01$).

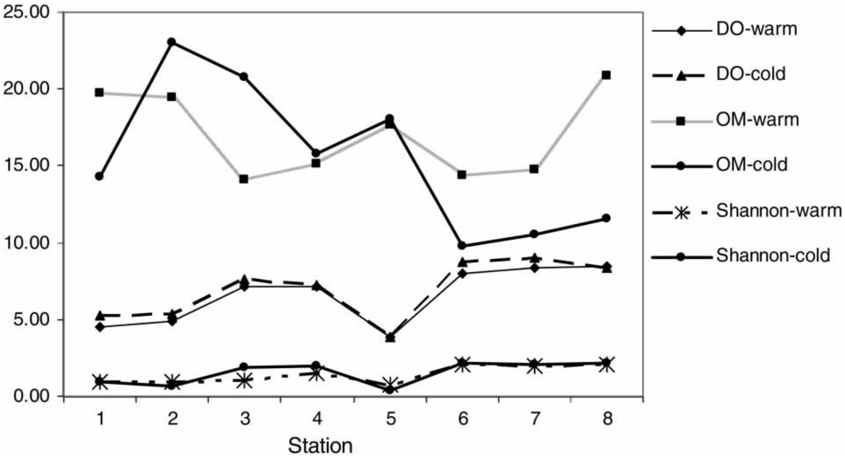

Figure 6 | Relationship between Shannon-Weaver Index (H'), dissolved oxygen (DO) and level of organic matter (OM).

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 Ghanam Creek, especially in the vicinity of the sewage disposal point, are already heavily affected by industrial pollution.

Consequently, the importance of oxygen in a water column and the percentage of OM in sediment as key factors for macrofaunal assemblage in sediment are now well understood. Figure 7 summarizes possible outcomes under different levels of OM and DO.

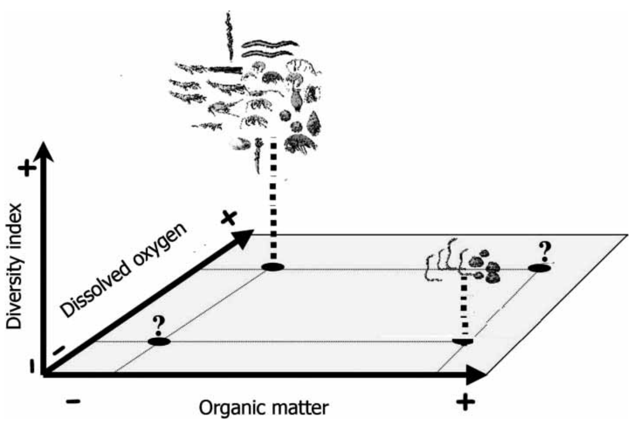

Figure 7 | Schematic model indicating how the diversity index responds to different levels of OM and DO.

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