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Effect of brine discharge from Al-Dur RO desalination plant on the infauna species composition in the East Coast of Bahrain

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ABSTRACT

The GCC countries have been experiencing an accelerated socio-economic development process since 1970s, resulting in rapid demographic and urbanization growth and associated with rapidly increasing municipal water demands. To meet these demands' quantity and quality, the GCC countries resorted to desalination. Currently, the GCC countries collectively possess the largest desalination capacity in the world (~45%), and based on the current urbanization trends, it is expected that current rates in desalination capacity growth will continue in the future. However, desalination has a number of environmental externalities on the marine, and their severity will depend on various factors (i.e., site-specific). As a pre-requisite for designing and implementing programs to minimize these environmental externalities, the impact of desalination has to be investigated and characterized. The study objective is to investigate the impacts of Al-Dur RO desalination plant on the coastal infauna benthic species composition on the east coast of Bahrain. The in situ measurements over high and low tide cycles in winter and summer were conducted at 42 selected locations for surface and bottom waters. Sediment samples were collected from 10 locations selected at different distances from the discharge outlet. The species composition of infauna was investigated using the univariate analysis (number of species and individuals, species richness, evenness index and diversity index). The results showed an extreme elevation in temperature (>38°C) and hypersaline waters (>55‰) at locations nearby the discharge outlet, and also at bottom waters of depths more than 3 m during the high and low tide cycles in both seasons with exceptional levels in summer. Four main groups of benthic infauna identified are represented by polychaetes (12 taxa), bivalves (4 taxa), Gastropoda (2 taxa) and Amphipoda (3 taxa) including 256 specimens. The univariate analysis indicated spatial variations in infauna species composition where the lower diversity indices were found at locations close to the discharge outlet and at station 5 at which noticeable vertical differences were observed indicating exceptional elevation of temperature and hypersaline waters at bottom layer. However, the highest species diversity indices characterized the most offshore stations. Polychaetes are considered as the most useful bio-indicators to reveal any contamination from desalination brine discharge, due to their sensitivity and their capability to adopt to any environmental alteration.

Keywords: RO desalination; Univariate analysis; Infauna; Species diversity; Bahrain

1. Introduction

The GCC countries are located in an arid or semi-arid region characterized by low rainfall, high temperature (high evaporation), and limited conventional water resources. This region experienced rapid demographic and urbanization along with social and economic development. Population growth, increase in standard of living, reliance on desalination to meet urban rate demand, which is made possible due to the availability of financial and energy resources in the country. In any desalination technology, the process generates two main types of effluents; the first is a stream used as fresh water and the second is a stream represents high concentration of salt called brine water.

The Arabian Gulf area is distinguished as having the highest number of desalination plants and largest desalination

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capacity worldwide, where it accounted for more than 64% of the world's total production capacity from 2000 to 2010. In all the GCC countries, the desalination capacity has been increased substantially during the last three decades. This trend is expected to be continued in the coming decades (Al-Jamal and Schiffler, 2009). Desalination water production is expected to increase from about 8,000 Mm^2 per year to about 41,000 Mm^3 per year 2050 (AGEDI, 2016).

Due to a rapid population growth synchronized with industrial development in Bahrain, a rapid increase in water consumption reliance on desalination is being of great importance to meet urban rate demand facilitated by the availability of financial and energy resources in the country. Bahrain has introduced desalination in 1975 by establishing Sitra MSF desalination plant and moved steadily toward constructing further five desalination plants located on the eastern coastline of Bahrain including 1 MSF (Al-Hidd), 2 MED (Al-Hidd and Alba) and 3 RO (Ras Abu Jarjur and Al-Dur) (Al-Zubari, 2014). Al-Dur desalination plant is designed to produce 220,000 m^3/d. The plant was developed as a build-own-operate (BOO) project basis, which consist of a combined power plant and an RO desalination plant (Suez, 2012).

Despite the socioeconomic benefits, which desalination plants offer and the key role it plays in sustainable development (Dawoud, 2005), the potential negative impacts associated with desalination plant operation as a land-based source of pollution have been of concerted international attention (UNEP, 2006).

Generally, the impacts on coastal and marine environment derived from desalination plants are mostly due to routine discharge of brine water. The discharged brine water probably includes additional chemical pollutants, which potentially affect the chemical properties of both water and sediment quality as well.

The brine discharged into the sea induce the formation of a stratified system, with the brine forming a bottom layer that can affect the benthic communities habituated to stable salinity environments. The magnitude of this impact depends not only on the characteristics of the desalination plant and its reject brine but also on the nature of the physical and biological conditions of the receiving marine environment (Fernandez Torquemada et al., 2005). Khordagui (2002) reported the impingement biological effects and entrainment effects caused by desalination plants taking into consideration the role of inflow rate, intake design, and seasonal changes impacts on seawater temperature and species behaviour. Osmotic regulation is well known as the most response to salinity variation. This relationship has been investigated by Einav et al. (2002). Macpherson et al. (2006) assessed the impacts of desalination on macro benthic assemblages during pre and post of desalination plant commissioned. The study revealed that the variations in benthic species richness largely attributed to the brine discharged particularly within the surrounding environment.

The territorial waters of Bahrain cover sensitive marine habitats such as seagrass beds, coral reefs and mangroves, in addition to intertidal mudflat, which substantially support the marine biodiversity by providing nursery, spawning, and feeding grounds for broad scale of fishery species (Loughland & Zainal, 2009). However, these ecosystems are being heavily exposed to chronic anthropogenic impacts along the last few decades.

The seagrass bed nearby Al-Dur coast extends eastward to Hawar Islands. This vital sensitive habitat plays an important biological role as feeding, nursery, and spawning ground for broad-scale finfish and shellfish species and endangered megafauna species such as dugong, dolphins, and green turtles. Moreover, the Al-Dur coast representing a fishing ground for many fishermen using traditional fishing gears (wire metal and barrier traps), which more or less located within the vicinity of the desalination plant discharge. The brine water effect may extend to the bottom layer, which potentially reflect on species diversity of benthic community those comprise the base of marine trophic pyramid.

The aim of the study is to assess the impacts caused by the effluent discharged from Al-Dur desalination plant on the coastal species composition of benthic infauna.

2. Materials and methods

2.1. Study area

The present study is conducted on Al-Dur coast, east of Bahrain within the vicinity of the Al-Dur power and desalination plant (Fig. 1). Al-Dur reverse osmosis desalination plant is located in the south-east coast of the Kingdom of Bahrain commissioned in February 2012 and was designed with a daily capacity of 220,000 m^3/d to meet the growing demand of drinking water and electricity in Bahrain as well. The plant was developed as a BOO project engaged as a private sector.

The tidal regime circulation along the Bahrain coasts is diurnal twice a day with a depth range between 0 and 7 m. The water intake is located at a distance of 1.5 km and the pipe is supplemented by two subsurface intake filters each consisted of 4 units. A total of 20 barrier fishing traps (locally known as hadrah) are distributed along the Al-Dur coast. Further fishing activities are practiced by drift nets and wire metal traps (locally known as gargoor).

2.2. Sampling

Sediment samples were collected in May 2017 using Van Veen grab sampler. Ten stations were selected at different distances from the discharge outlet as illustrated in Fig. 2 associated with different depths to provide the opportunity for spatial variation in relation to distance, depth and sediment texture. The in situ water quality measurements including depth, temperature, and salinity were conducted during both high and low tide cycles at each location by using Pro DSS multi-meter probe. The parameters have been measured at surface and bottom layers.

2.3. Laboratory analysis

2.3.1. Grain size analysis

The sediment grain size analysis is conducted following the granulometry based on the median size of sediment particles. The procedure involved two steps, the first deals with determination of the distribution of the coarser, larger-size particles of sediments using sieve analysis. The second step

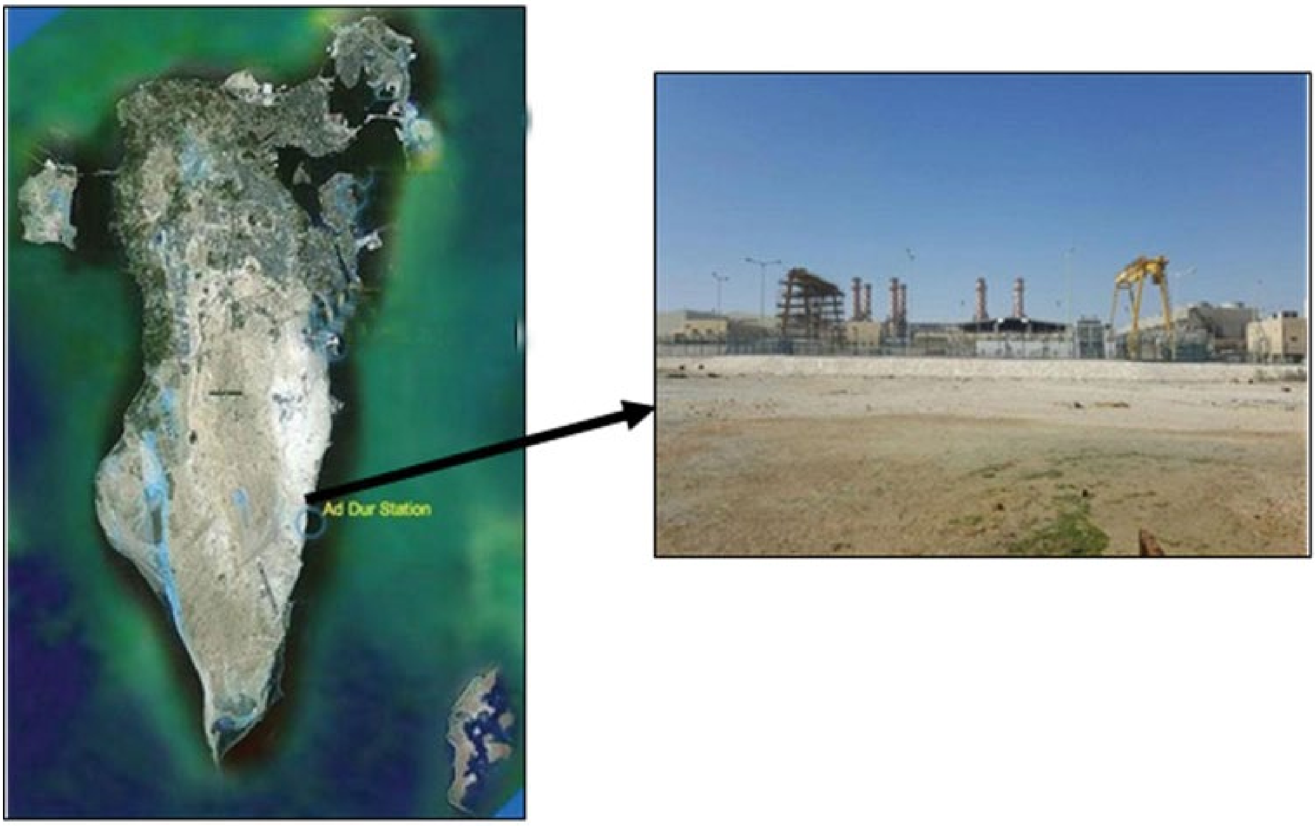

Fig. 1. Location map showing the site of the Al-Dur power and desalination plant.

Fig. 2. Locations of sediment sampling at Al-Dur Coast east of Bahrain.

is to determine the fine particles, which were obtained by applying the hydrometer.

The sediment samples collected for infauna identification were washed at boat using a sieve of mesh size 0.5 mm. Samples for infaunal benthic identification were divided into two jars for duplicate microscopic diagnosis. The samples have been preserved as soon as collected in a solution of dilute formalin (5%).

2.3.2. Identification of infauna

The samples were preserved with Rose Bengal prior to the normal sorting process by which specimens separated from the sediment. Sorting was carried out by placing a small quantity of sample in a petri dish and viewed under a dissecting stereomicroscope. Sorting was repeated three times for each petri dish to confirm that every single individual organism has been well diagnosed. The remainder residue was saved until the termination of the identification process.

2.3.3. Data analysis

The univariate analysis has been applied using PRIMER package Plymouth Routines in Multivariate Ecological Research V6 (Clark & Gorley, 2006). The raw data represented by a sum of duplicates of each species were imported from Microsoft Excel into the PRIMER work sheet and the following univariate ecological indices have been calculated:

- ***No. species (S)***: simply the number of species present in an ecosystem
- ***No. individuals (N)***: number of specimens belongs to *i*th species
- ***Richness (D)***: Margalef's index: $D = (S - 1)/\ln N$
- ***Diversity (H`)***: Shannon–Weiner index: $H` = -[\sum (\rho i \ln \rho i)]$

  where ρi is the proportion of individuals found in the *i*th species.
- Evenness (*J*): Pielou index $J = H`/H\text{max}$

where Hmax is the maximum possible diversity = ln *S*.

3. Results and discussion

3.1. Water temperature

A clear seasonal variation could be found between winter and summer temperatures. The measurements in winter were ranged between 17.0°C and 21.8°C, however in summer the readings varied between 35.4°C and 38.8°C (Table 1).

Relatively, the temperature was differed on spatial basis following to distance from the desalination plant outlet. The maximum values were found at station 10; the most close to the outlet at which the range of degrees varied from 21.2°C to 21.8°C in winter and from 37.4°C to 38.8°C in summer. The rest of the locations had an average of 18.5°C in winter and 36.5°C in summer.

Little variations could be noticed between temperatures during high tide and low tide cycle in summer, however no real variations were observed in winter. Thermocline (temperature stratification considered with temperature difference of >3°C) of difference slightly below 3°C was observed in winter where the bottom layers were characterized by higher temperature particularly at station 5 with a difference of 2.1°C–2.7°C between surface and bottom layer. The other sampling locations exhibited marginal fluctuations on vertical basis between surface and bottom layers mostly with less than 2°C. In summer, the water column seems to be thermally well mixed.

3.2. Salinity

The salinity levels throughout the study area were varied between 42‰ to 60‰ in winter and 44‰ to 59‰ in summer indicating slightly higher levels in summer (Table 2).

Spatially, the salinity showed obvious variations based on a distance from the desalination outlet. Extreme salinity levels (58‰–60‰) were found at station 10; the nearest

Table 1
Water temperature at sampling locations of Al-Dur coast east of Bahrain

Sampling locations	Winter				Summer			
	High tide		Low tide		High tide		Low tide	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Station 1	18.0	18.7	18.4	20.4	36.2	36.2	37.6	37.8
Station 2	18.0	18.7	18.2	20.4	36.2	36.2	37.6	37.8
Station 3	18.0	18.2	18.4	20.3	36.0	36.2	37.2	37.6
Station 4	18.0	18.4	18.6	20.4	36.2	36.2	37.6	37.8
Station 5	18.0	20.1	18.4	21.1	36.0	36.8	37.0	38.6
Station 6	18.0	19.0	19.0	20.4	36.2	36.2	37.6	38.0
Station 7	18.0	18.2	19.0	20.4	36.4	36.4	37.8	38.0
Station 8	17.5	17.5	19.8	19.8	36.4	35.4	37.8	37.8
Station 9	17.0	17.0	20.0	20.0	36.8	36.8	38.0	38.0
Station 10	21.2	21.2	21.8	21.8	37.4	37.4	38.8	38.8

Table 2
Salinity at sampling stations of Al-Dur coast east of Bahrain

Sampling locations	Winter				Summer			
	High tide		Low tide		High tide		Low tide	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Station 1	42.0	46.0	44.0	48.0	44.0	47.0	44.0	47.0
Station 2	42.0	47.1	44.0	48.0	45.0	48.0	44.0	47.0
Station 3	43.3	45.8	44.0	48.0	44.0	47.5	44.0	46.0
Station 4	42.0	46.0	44.0	45.7	44.5	48.0	44.0	47.0
Station 5	43.4	52.8	43.5	54.4	44.0	48.0	43.2	49.0
Station 6	42.0	46.0	43.7	45.7	45.0	45.0	46.0	46.0
Station 7	43.5	46.0	43.5	48.0	47.0	48.0	46.0	47.0
Station 8	44.7	43.3	47.3	48.0	46.0	46.0	47.0	47.0
Station 9	48.0	48.0	49.0	49.0	48.0	48.0	48.0	48.0
Station 10	58.8	59.3	60.0	59.5	58.2	58.2	59.0	59.0

sampling location to the outlet. The salinity levels at other locations were ranged between 42‰ and 49‰.

The salinity levels during high tide cycle were slightly higher than relevant ones during low tide cycle. Halocline (salinity stratification with difference >1‰) was observed at all sampling locations except stations 8, 9 and 10 which were located nearby the outlet associated with shallow depths (<1 m). Again, station 5 was found to be the most salinity stratified where the difference was 9.4‰ during the high tide and 11.9‰ during the low tide. More or less the vertical differences of salinity in summer were slightly lower than those occurred in winter.

3.3. Sediment texture

Generally, the sediments grain size analysis based on the 10 locations revealed that the sand fraction predominated the sediment types in the study area. As presented in Fig. 3, four sediment textures were obtained, which were categorized into sand (4 stations), sandy loam (3 stations), loamy sand (2 stations), and loam (1 station).

The fine sediment presented by silt fraction was noticeably occurred at stations 1, 2, 3, and 5 associated with 14%–16% clay. On the other hand, sand fraction represented the whole texture of four stations (6, 7, 9, and 10) by 100%. Moreover, the sediment texture at stations 4 and 8 is mostly composed of sand (>80%).

Generally, the stations close to the outlet site are characterized by sand fraction; however the other stations more or less are composed of mixture sediments with tendency to sand fraction.

3.4. Infauna species composition

The species composition of infauna was investigated, and the univariate analysis was applied for sediment samples collected from the 10 stations. The infaunal organisms were diagnosed to possible identification of minor taxon for which four main groups were identified including Polychaeta (12 taxa), Bivalves (4 taxa), Gastropod (2 taxa)

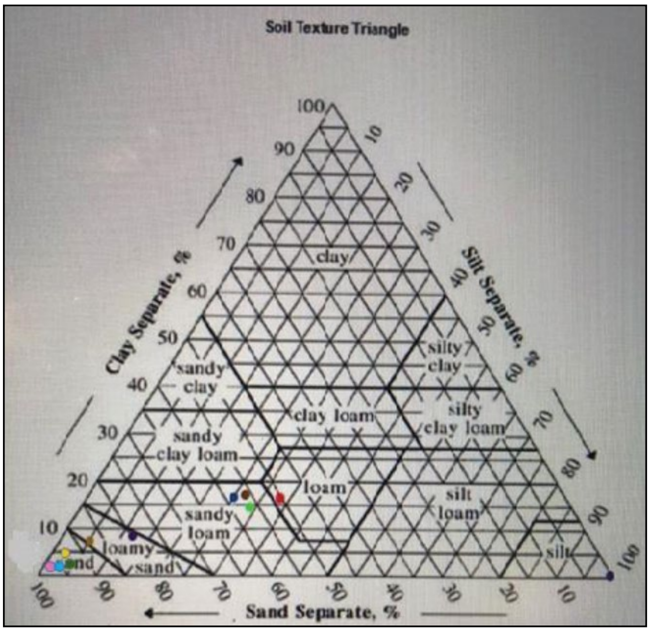

Fig. 3. Sediment texture of the sampling stations at Al-Dur coast.

and Amphipod (3 taxa) with a total of 21 taxa mostly at a level of family represented by 256 specimens (Table 3).

The percentages of the main infaunal groups are presented in Fig. 4. The results as an overall for the 10 locations showed that Polychaeta comprised the majority (91%) of the infaunal species composition; however the other three groups (amphipod, bivalves and gastropod) constituted minor portions by 7%, 1.5% and 0.5%, respectively.

Similar trends found individually at most of the monitoring stations (Fig. 5). Station 4 seems to be characterized by considerable percentages of amphipod and gastropod; however bivalves at station 7 represent the second main group.

Capitellidae was the most abundant taxa (45.7%) at most of the monitoring stations particularly at stations 9 and 10 those located close to the discharge outlet followed

Table 3
Species composition of infauna at Al-Dur coast east of Bahrain

Taxa	Stations										Total
	1	2	3	4	5	6	7	8	9	10	
Polychaetes											
Terebellidae	0	3	0	0	0	1	0	0	0	0	4
Capitellidae	9	14	15	2	1	0	1	11	38	26	117
Lumbrineridae	1	3	0	1	0	1	3	2	5	2	18
Maldanidae	1	6	0	0	0	0	0	0	0	0	7
Spionidae	1	3	0	1	0	1	1	0	0	0	7
Orbiniidae	3	1	4	0	0	2	0	0	0	0	10
Nereididae	16	1	7	5	9	4	10	1	9	0	62
Syllidae	0	2	0	0	0	0	0	0	0	0	2
Eunicidae	1	0	0	0	0	0	0	0	0	0	1
Opheliidae	0	0	1	1	0	0	0	0	0	0	2
Saccocirridae	0	0	1	0	0	0	0	0	0	1	2
Ampharetidae	0	0	1	0	0	0	0	0	0	0	1
Subtotal											233
Bivalve											
Diplodonta globosa	1	0	0	0	0	0	0	0	0	0	1
Antigona lamellaris	0	0	1	0	0	0	0	0	0	0	1
Atactodea glabrata (*bahreinenisis*)	0	0	0	0	0	0	1	0	0	0	1
Circe callipyga	0	0	0	0	0	0	1	0	0	0	1
Subtotal											4
Gastropoda											
Cerithium scabridum	0	0	0	1	0	0	0	0	0	0	1
Pirenella conica	0	0	0	1	0	0	0	0	0	0	1
Subtotal											2
Amphipoda											
Caprellidae	0	0	0	0	0	0	0	0	7	5	12
Maeridae	1	0	0	2	0	0	0	0	0	0	3
Aoridae	0	0	0	0	0	1	0	1	0	0	2
Subtotal											17
Total no. of individuals	34	33	30	14	10	10	17	15	59	34	2 256

by Nereididae (24.2%). However each of the rest of the taxa formed <7%.

The diversity indices obtained by the univariate analysis are illustrated in Fig. 6. The lowest number of species was recorded at S5 (Fig. 6a), that is located at depth 4 m in which the highest bottom salinity and temperature with lowest DO are noticed. The highest number of species (9) was collected at S1 representing the most offshore station at the intake site. The number of species exhibited a decrease trend toward the outlet site where the samples are collected from stations 8 to 10. The number of individuals showed different trend to that of number of species (Fig. 6b). The decrease trend toward the outlet was shifted to noticeable peak at station 9 where the highest number of individuals (59) was found represented by the dominance Capitellidae constituting 64.4%. The lowest number of individuals was recorded at stations 5 and 6 represented by 10 specimens.

The species richness index (*D*) seem to be of similar pattern of distribution to that found for number of species as presented in Fig. 6c. The highest value was 2.65 at station 4 and the lowest (0.43) at station 5. Stations 9 and 10 associated with the outlet were also distinguished by low species richness (<1).

The evenness index (*J*) showed no regular pattern, however the lowest value (0.47), as other previous indices, found at station 5 (Fig. 6d). Stations 4 and 6 characterized by the most proportional infauna species compositions indicating the highest evenness values (0.90). Most of the rest of stations found to be of moderate proportional of species composition in which the evenness index was over 0.70. The highest

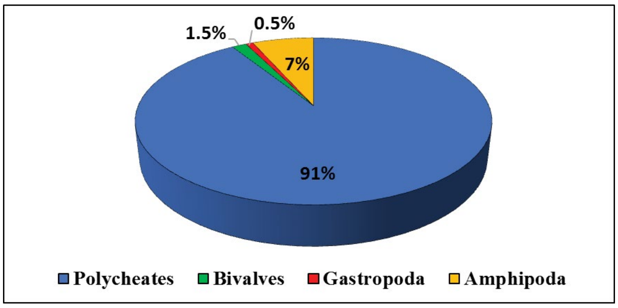

Fig. 4. Major groups of infauna collected from monitoring stations at Al-Dur coast.

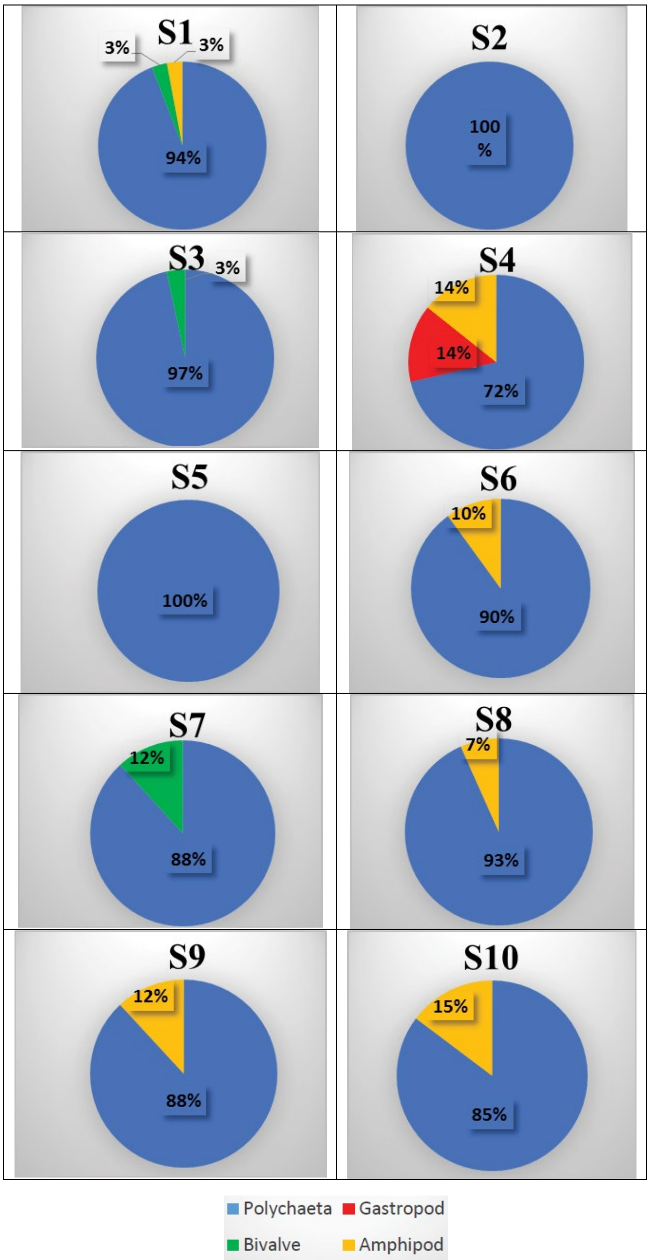

Fig. 5. Infauna species composition in the monitoring stations at Al-Dur coast.

diversity index (*H*) was found at station 4 (1.87) followed by station 2 (1.71) and station 6 (1.61). The diversity index showed a decrease pattern toward the outlet site with a noticeable low diversity at station 5 (0.33) as shown in Fig. 6e.

4. Conclusion and recommendations

The grain size analysis of sediments was investigated to sort out the factors that control the distribution of infauna species composition whether related to water quality or sediment texture. Benthic community structure and composition have a strong relationship with sediment structure. The macrobenthic communities reveal distinct relationship with sediment granulometry (Hyland et al., 2005).

To investigate the interaction of physical and biotic factors in an ecosystem, the species diversity is the most representative indicator. Diversity of the species is usually proportional to the stability of the ecosystem in question as the high number of species refers to the most stable community. In contrast an ecosystem beneath stress has few species, which is characterized by a dominance of few species.

Several studies have been carried out in order to determine how the distribution and abundance of marine flora and fauna species react to a change in temperature. The temperature of the brine discharge is one of the major concerns for any desalination plant project. Marine biologists indicated that a significant impact can occur to the natural balance and distribution of the marine life if a temperature alteration is applied to the ambient environment (Buros, 1994). A direct correlation can be determined between the temperature alteration and the behaviour of marine species. Sea temperature is one of the key variables to monitor and can play a great role in the marine flora and fauna's life.

The impact of desalination plant may extend to benthic community where these organisms are characterized either as sessile or of limited locomotion such as molluscs and echinoderms. The latter is well known as stenohaline organism, representing a bio-indicator for salinity effect (Fernandez-Torquemada et al., 2005). Naser (2013) investigated the impacts of MSF and RO desalination plants in Bahrain. The study revealed a reduction in biodiversity and abundance of microbenthic assemblages mostly at locations adjacent to the outlet of MSF desalination plant. As reported by Khordagui (2002) and Fernandez-Torquemada et al. (2005), several cases of fish kills and disappearance of marine benthic species such as echinoderms have been noticed at the vicinity of desalination plant due to slow growth rate, failure of the osmoregulatory mechanism, shrinkage of body cells, and malfunction of the endocrine system.

The univariate analysis indicated the variation of the species composition and species richness of benthic assemblages at the study area. The most diverse species was recorded in a family Capitellidae, where 12 species have been identified. Several reasons may justify the dominance of Polychaeta in the study area. Marine communities are impacted by the increasing human activities as reported by Del-Pilar-Ruso et al. (2008), indicating a reduction in abundance, diversity, and richness of the polychaete assemblages. Moreover, polychaetes are considered as the most useful bio-indicator to reveal any contamination from desalination brine discharge, due to their sensitivity and their capability to adopt to any environmental alteration.

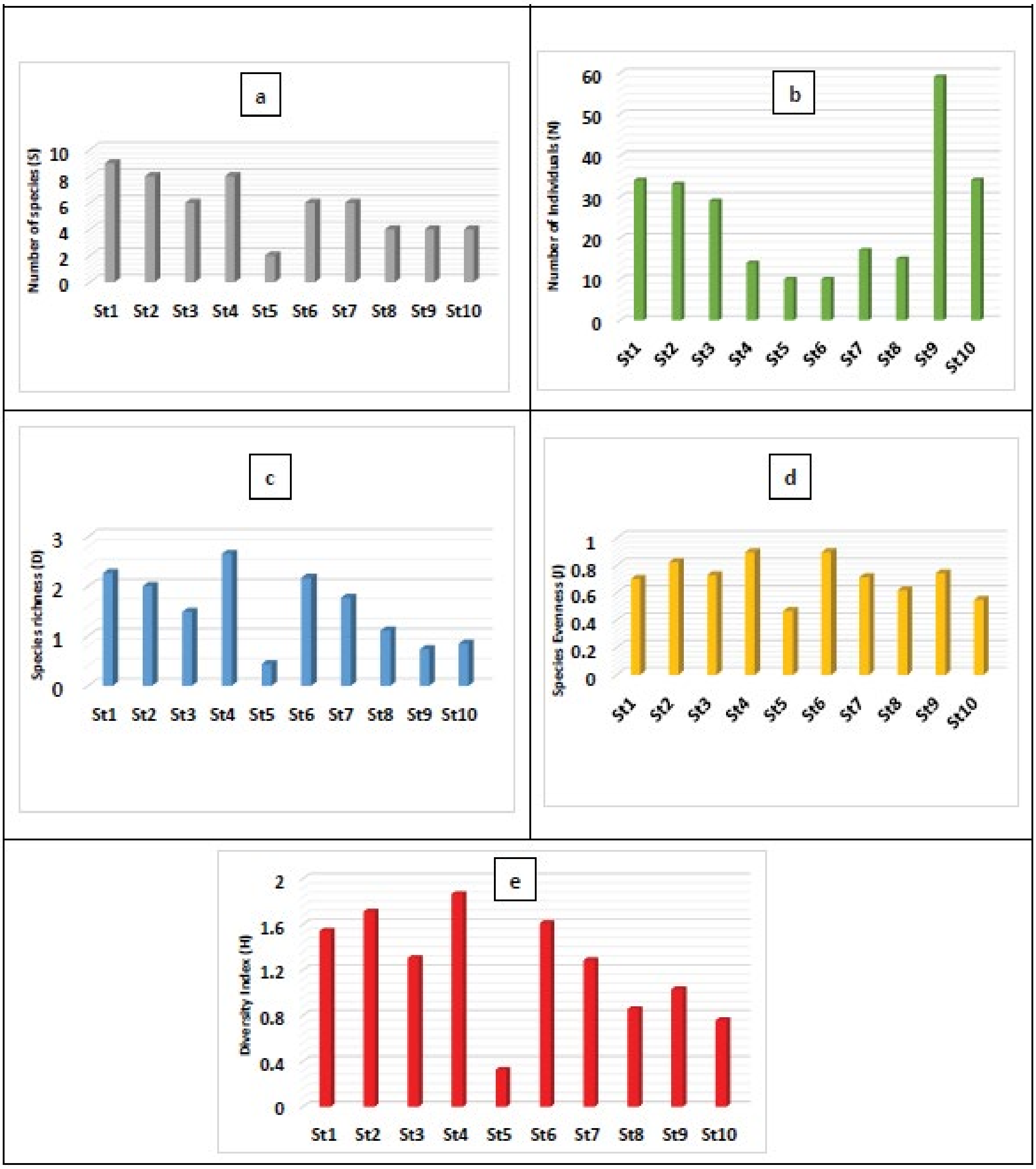

Fig. 6. Diversity indices of infauna species composition at Al-Dur coast.

Bivalves were present in 3% stations of all collected areas mostly represented by earlier stages where the sizes were too small. Amphipods as bivalves were present in 3% of the benthic assemblage in the study area notably in S9. This group contributes an important part of the base trophic level as other higher species preyed on. Gastropods were absent at all stations except S4 in which represented by small size (2 mm).

The benthic assemblage comprised the majority of fish food habit. The availability of benthic organisms by abundance and wide species diversity substantially contribute the fisheries status. This kind of sensitive marine species needs to be measured and monitored to mitigate any environmental effluence by making biotic indices (de-la-Ossa-Carretero et al., 2016).

No attempt has been made in the Bahrain marine environment to find out the discharge impacts of desalination plants neither on fish assemblage nor on benthic community. The exceedances noticed were restricted for salinity gradient at monitoring locations associated with the site nearby the outlet and bottom waters at locations associated with depths more than 3 m indicating the sinking of the hypersaline water mass at these depths. Consequently, the species composition of the benthic fauna was found to be largely related to the water quality rather than sediment texture. The lowest diverse composition found at locations was characterized by exceptional elevation of temperature and salinity in bottom waters such as those close to the outlet and station 5 as well. A pretreatment process needs to be implemented for brine waters of Al-Dur desalination plant before direct discharge to mitigate the impacts on physical, chemical and biological properties around the vicinity extent and buffer zone. Suggest passing the discharged waters through a long channel before releasing to natural coastal environment or extending the discharge pipe to deep water by diffuser lines", which promote better mixing of the brine and sea water where high current will improve the mixing process of the outlet.

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