Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2017.20812

76 (2017) 311–318
May

Environmental effects of brine discharge from two desalination plants in Algeria (South Western Mediterranean)

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Received 18 August 2016; Accepted 11 April 2017

ABSTRACT

One of the main concerns in the desalination industry is to relieve pressure on the marine environment caused by brine disposal. Its impact depends on effluent dilution, which may be increased by installing appropriate diffusers. We analysed the environmental effect of brine discharge from two Algerian desalination plants with a similar capacity (200,000 m^3/day), but different discharge technology, to explore the reduction in impact on the marine environment by using diffusers. Spatial distribution of the brine was extremely different at the two plants. This was a result of the different discharge technology installed and is reflected in the differences in impact observed on benthic communities. The impact of desalination activity on the marine environment can thus be mitigated and controlled by installation of multiport diffusers. These systems can enhance mixing and reduce the impact on the benthic community and area of influence of facilities as large as those described in this paper.

Keywords: Brine discharge; Diffusers; Algeria; Dilution; Benthic; Impact assessment; Mediterranean

1. Introduction

Several countries in recent decades have been faced with the problem of fresh water demand. The irregular frequency and volume of rainfall affects their water policies, which now have to focus on non-conventional water resources [1]. In any case, less than 1% of the total fresh water available in rivers, lakes and other supplies is within easy access for human use [2]. One of the alternatives for solving water shortage problems is seawater desalination [3]. This technique is in constant development worldwide, with an installed capacity that has grown at a compound average rate of 12% a year over 5 years [4]. Reverse osmosis (RO) is the most common process, due to the low energy and space it requires, and the reduced cost of producing potable water [5]. Among countries concerned over water scarcity, Algeria has suffered severe water stress [6]. In response to this, from 2002 on, thirteen Sea Water Reverse Osmosis (SWRO) plants were built there and overall production has reached about 2.3 million cubic metres of fresh water per day [7]. With this, Algeria now has one of the fastest-growing desalination capacities in the world, together with Australia and Spain [7].

One of the challenges of desalination is to produce water without increasing the pressure on the marine environment [8]. Since 2003, as have other countries, Algeria has put in place laws to preserve the marine environment and control

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Presented at the EDS conference on Desalination for the Environment: Clean Water and Energy, Rome, Italy, 22-26 May 2016

1944-3994 / 1944-3986

discharges (Law 03–10 of 19 Joumada El Oula 1424, Decree 06–141 of 20 Rabie el Aouel 1427, Law 05–12 of 28 Joumada Ethania 1426). The desalination process discharges a concentrated salt solution (brine) as effluent, with up to twice the salinity as the original seawater [9], which can have a detrimental effect on the marine environment [10,11]. It causes osmotic pressure changes in marine organism cells, leading to mortalities in those not adapted to these high salinities [12]. Since brine discharges tend to remain on the bottom, their effect is mainly on the benthic communities that are not adapted to these high salinities. For this reason, benthic organisms are useful ecological indicators because they are relatively sedentary, unable to escape from deteriorating water quality. They may show marked responses to stress, depending on their species-specific sensitivity/tolerance [13–15].

Without proper dilution, a high salinity discharge plume may spread out for a considerable distance [16]. The extent of this impact will depend on the characteristics of the desalination plant and its brine effluent [17,18]. Recent studies have shown that brine disposal impact may be reduced by the dilution of the effluent, either by-passing seawater [8] or using diffusers [19,20,21].

We analyse the environmental effect of brine discharge from two desalination plants in Algeria (Beni Saf and Mostaganem) with the same capacity of 200,000 m^3/d, but different discharge technology. The two plants are located 200 km apart. This study aims to evaluate the benefits in brine discharge dispersion for the installation of a diffuser on the end of the pipeline in order to reduce salinity concentration and consequently the impact on benthic communities.

2. Material and methods

2.1. Study area

The study was carried out in September 2014 in two areas on the west coast of Algeria affected by brine discharge from SWRO desalination plants at Beni Saf and Mostaganem (Fig.1). These desalination plants have respectively been in operation since 2009 and 2011 [4]. Each plant

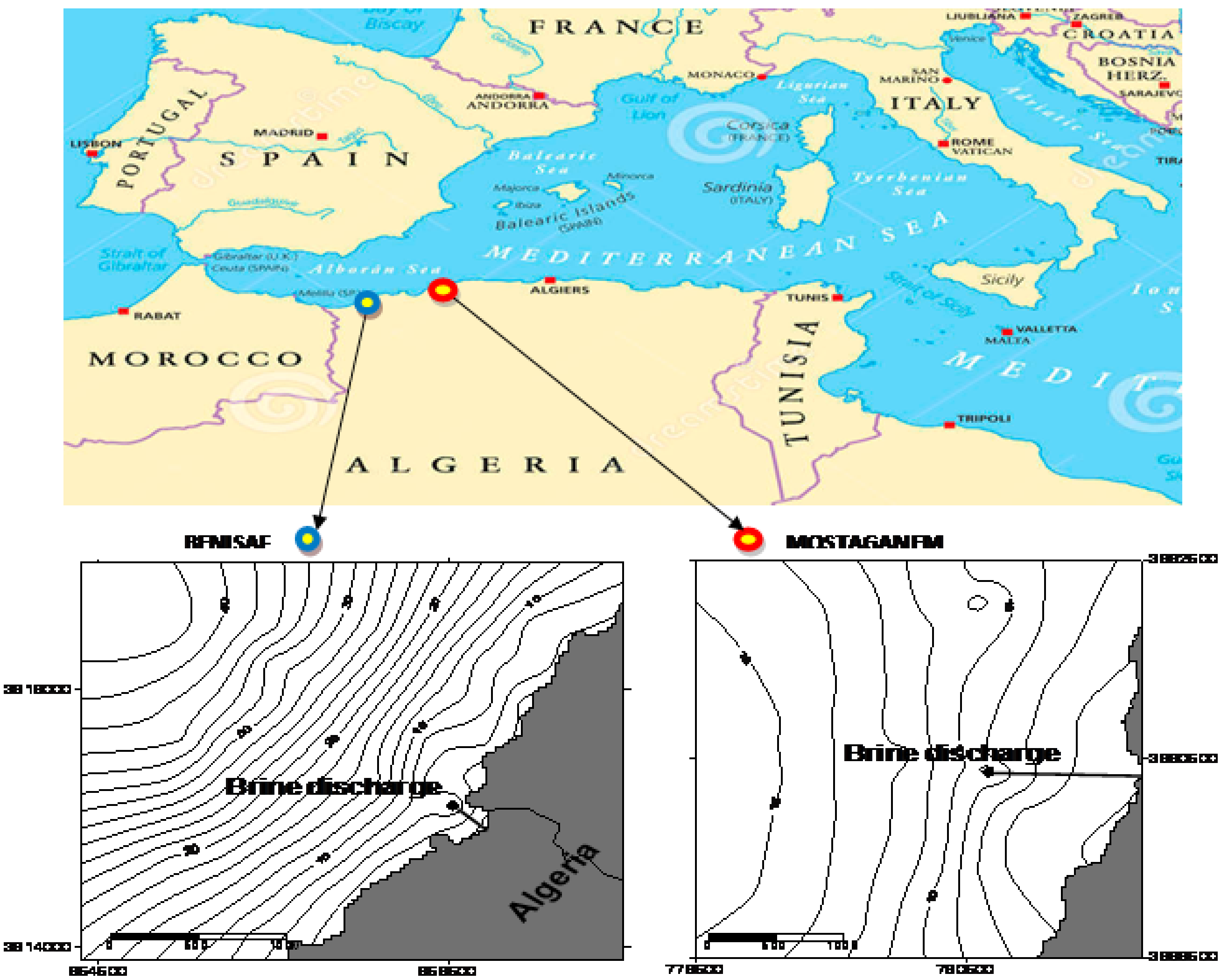

Fig. 1. Studied area showing brine discharge and bathymetry of both locations: Beni Saf and Mostaganem. (UTM coordinate system. Grid zone 30S).

has a potable water production capacity of 200,000 m^3/d. Brine discharge is 245,000 m^3/d with a conversion rate of 45%, at a salinity concentration of approximately 68.

The brine discharge from both desalination plants contains high salinity levels as well as concentrations of chemicals used in the pre-treatment stage [4], as shown in Table 1. The pre-treatment sludge from the two desalination units is discarded with the brine in the same single discharge.

The water treatment process at the Beni Saf plant consists of:

- a collection system and pumping of sea water through a single round plug connected to the seawater pump tank by a pipe 2.4 m in diameter, submerged at 1400 m from the coast at a depth of 18 m.
- pre-treatment by sand/anthracite filtration and microfiltration using polypropylene cartridge filters,
- followed by demineralization by reverse osmosis,
- and finally evacuation of brine and by-products through an outlet 1.8 m in diameter at 8 m depth below sea-level, discharging 2 m above the bottom through a single diffuser (1 m diameter at an inclination of 45º). The total terrestrial and submerged length of the duct is 1400 m.

Table 1
Chemicals used for processing at both desalination plants

Product	Symbol	Utilization
Sodium hypochlorite	NaOCl	Disinfection
Ferric chloride	$FeCl_3$	Coagulant
Sodium sulphite	Na_2SO_3	Remove residual chlorine
Dispersant	–	Anti-scale
Sulphuric acid	H_2SO_4	pH correction

The water treatment at the Mostaganem plant is composed of:

- seawater collection and pumping through two tap towers connected to the seawater pumping tank by two pipes 1.8 m in diameter. The catchment towers are submerged 2500 m from the coast at about 16.5 m deep,
- pre-treatment by sand/anthracite filtration and microfiltration,
- followed by demineralization using reverse osmosis,
- and finally, brine evacuation through an outfall equipped with 50 diffusers at the end of its submarine stretch, via a pipe 1.8 m in diameter and 1400 m in length, including the diffuser lengths of 130 m.

2.2. Monitoring of brine dispersion

In order to estimate dispersion of the brine plume at both locations, the spatial distribution of salinity was measured using a RBR XR-420 CTD (conductivity, temperature and depth) device with a measurement range of 0–70 and a resolution ± 0.01. All the stations were positioned using a GPS (precision ± 5m) based on UTM coordinates. Bottom salinity data was interpolated using the Kriging technique as a gridding method at each location [8], carried out and represented on contour maps using the Surfer v9 program.

2.3. Benthic fauna analysis

A benthos survey was performed by establishing two areas for each locality, based on the brine dispersion analysis: an impact area within the brine plume area where an increase in salinity was detected, and a control area where the brine plume did not reach (Fig. 2). Two depths were sampled in each area (8 and 15 m), establishing two sites

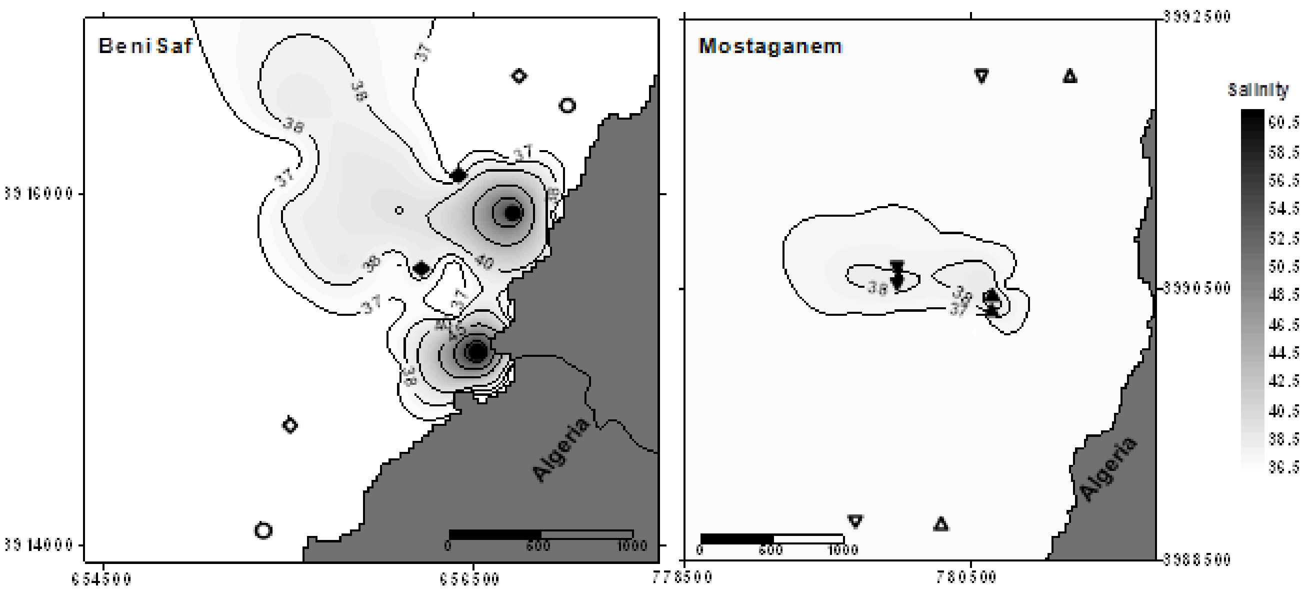

Fig. 2. Spatial representation of salinity distribution on the sea-bottom for both locations. Symbols indicate benthos sampling stations, Beni Saf: ○ Control 8 m depth, ◊ Control 15 m, • Impact 8 m, ◆ Impact 15 m, Mostaganem: △ Control 8 m, ▼ Control 8 m, ▲ Impact 8 m, ▼ Impact 15 m (UTM coordinate system. Grid zone 30S).

for each such that 8 stations were sampled at each locality (Fig. 2). At each site, three random replicates were collected using a Van-Veen grab with a surface area of 0.04 m^2 and a maximum penetration of 10 cm. Immediately after collection, the samples were sieved through a 0.5 mm mesh with seawater and the residues preserved in 4% buffered formalin. At the laboratory, benthic fauna were sorted from other material, preserved in 10% alcohol and identified to the closest taxonomic level possible. One additional replicate was collected at each site for sediment features. Granulometric fractions were determined by the wet sieving method and organic matter (OM) content by the loss on ignition method (LOI, 450º, 4h) [22].

2.4. Data analyses

To detect differences in abundance and Shannon-Wiener diversity of the benthic community, an analysis of variance (ANOVA) was used with three fixed factors: 1) Locality with two levels (Beni Saf and Mostaganem), 2) Treatment with two levels (impact and control), 3) Depth with two levels (8 m and 15 m) and one random factor nested in the others, 4) Site with two levels (1 and 2) [23]. Prior to ANOVA, the homogeneity of variance was tested using Cochran's test. Data were square-root transformed when variances were significantly different. Pairwise comparisons were performed whenever significant differences were detected between the interaction terms or the main factors. Multivariate patterns of the benthic community were represented graphically using non-metric multidimensional scaling (nMDS), to help detect any possible change in relation to the activity [24]. PERMANOVA [24] were performed on Bray-Curtis similarity matrices, to analyse spatial differences in composition of taxonomic groups between factors established in previous ANOVA. Similarity percentage (SIMPER) procedure was used to determine the percentage contribution of each animal group. All multivariate analyses were performed using the PRIMER statistical program [25]. Finally, in order to link benthic communities to sediment parameters, canonical correspondence analysis (CCA) was applied using the software CANOCO [26]. The output was displayed as a biplot, in which the plotted points for stations can be related to environmental gradients represented as arrows. The correlation strength of the environmental variables was reflected in the length of the arrow, and its association was reflected in the acuteness of the angle with the axis.

3. Results

3.1. Brine dispersion

Natural bottom salinity was around 36.5 in areas not affected by brine discharge. Sea-bottom salinity values reached 62.8 in areas close to the discharge at Beni Saf desalination plant, whereas the maximum value obtained at Mostaganem was 39.8. The increase in salinity over 38 due to brine discharge reached more than 1.5 km from the discharge point at Beni Saf, and only 200 m at Mostaganem (Fig. 2). Brine dispersion was guided by the direction in which the sea-bed depth increased most.

3.2. Benthic fauna composition

Sediments from sampled stations at Beni Saf were mainly sandy, with a higher percentage of fine sand, but also with medium sand and coarse sand in the 8 m depth control and impact stations. Mostaganem stations were characterised predominantly by fine sand (Table 2). Organic matter percentages were low, between 1.31% and 2.57% at both localities (Table 2).

Significant differences were detected in the interaction of treatment and depth factors for abundance and diversity of benthic fauna (Table 3). These differences were due to a decrease in abundance and diversity at 8 m-deep impact stations, while at 15 m deep the decrease at impact stations was not so high. These decreases were related with the highest salinities in impact treatments. Despite the decreases being greater at Beni Saf than Mostaganem (Fig. 3) no significant difference was detected due to location.

Analysing the MDS plot (Fig. 4), changes were observed in the benthic community. There was a segregation of stations sited at 8 m depth, close to outfalls, from control stations. Impact stations sited at 8 m in Beni Saf showed the

Table 2
Mean physicochemical parameters for each location, treatment (impact and control) and depth

Location	Beni Saf				Mostaganem			
Treatment	Impact		Control		Impact		Control	
Depth	8 m	15 m	8 m	15 m	8 m	15 m	8 m	15 m
Organic matter (weight %)	1.77	1.31	1.86	2.47	2.57	1.58	1.92	1.68
% Gravel	1.87	11.06	0.17	0.17	0.06	0.50	0.11	3.13
% Coarse sand	30.41	11.91	1.55	0.64	0.67	0.42	0.39	0.50
% Medium sand	24.29	32.18	41.57	3.53	18.71	0.47	6.84	24.89
% Fine sand	42.70	43.39	56.32	94.75	80.24	98.01	92.32	70.65
% Mud	0.73	1.46	0.39	0.91	0.32	0.60	0.35	0.82
Salinity	59.00	38.13	36.43	36.60	39.41	37.72	36.63	36.71
Temperature (°C)	25.23	24.36	24.70	23.75	25.04	24.95	25.15	24.76

Table 3
Results of ANOVA for square root abundance (individuals/m^2) and Shannon Wiener diversity index for the factors: Lo: location (Beni Saf and Mostaganem), Treat: treatment (impact-control), Dp: depth (8 m and 15 m) and site (1 and 2). Df: degrees of freedom, MS: mean squares, RES: residual, F of each factor, p value

Source		Abundance			Diversity		
	DF	MS	F	P	MS	F	P
Lo: location	1	305.58	4.27	0.0726	0.01	0.03	0.8662
Treat: treatment	1	1327.91	18.57	0.0026	1.30	7.66	0.0244
Dp: depth	1	801.41	11.21	0.0101	2.00	11.78	0.0089
Site (Lo × Treat × Dp)	8	71.52	1.31	0.2719	0.17	1.20	0.3305
Lo × Treat	1	117.26	1.64	0.2363	0.16	0.92	0.3665
Lo × Dp	1	238.30	3.33	0.1054	0.85	5.02	0.0553
Treat × Dp	1	469.79	6.57	0.0335	1.17	6.88	0.0305
Lo × Treat × Dp	1	123.10	1.72	0.2259	0.36	2.13	0.1827
RES	32	54.42			0.14		
TOT	47						

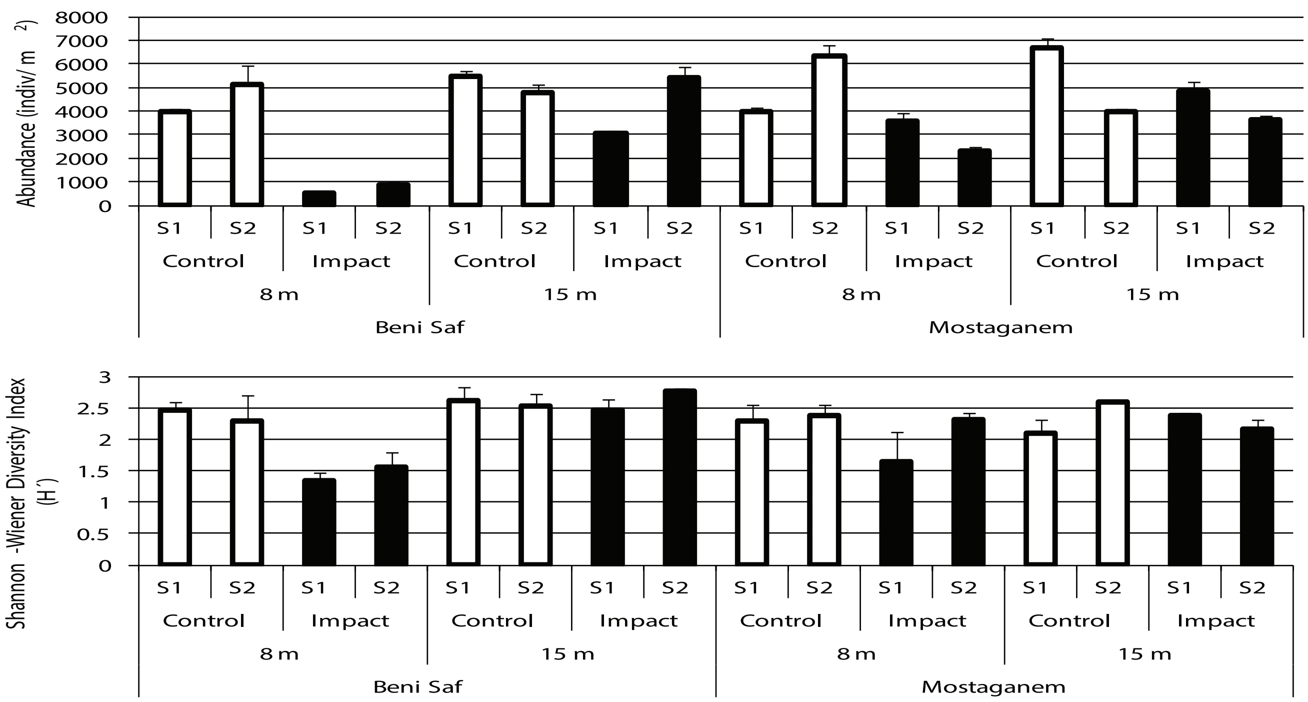

Fig. 3. Mean and standard error of benthic fauna abundances and Shannon-Wiener diversity index at each station. S1: Site 1, S2: Site 2.

highest dissimilarity, while those in Mostagenem at 8 m were more similar to control stations.

PERMANOVA results showed significant differences for each factor, detecting differences for location, treatment and depth (Table 4).

Based on similarity between plants, three main groups were established: groups A, B and C. Group A included a Beni Saf control at 8 m depth, Beni Saf 15 m control and one Beni Saf 15 m impact station. Group B included a Mostaganem 8 m control, Mostaganem 15 m control and Mostaganem 15 m impact. Group C included a Mostaganem 8 m impact and the other Beni Saf 15 m impact station. Group D and E were both Beni Saf 8 m impact stations.

SIMPER analysis highlighted the main changes in the benthic fauna structure among the groups established. Group A and B presented higher abundances. The species most abundant in group A were *Apseudopsis latreillii*, *Siphonoecetes dellavallei, Urothoe grimaldii, Scolpolos spp., Synchelidium haplocheles, Bathyporeia borgi, Perioculodes longimanus* and *Bathyporeia guilliamsoniana*. Polychaete families such as Spionidae, Paraonidae, Cirratulidae were abundant in group B, together with *A. latreillii*, *U. grimaldii, Scolpolos*

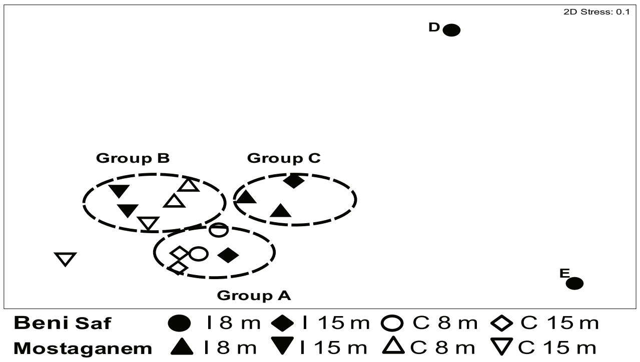

Fig. 4. MDS analyses based on the Bray Curtis Similarity of dispersion weighted abundance data. Established groups have been highlighted.

Table 4
Results of PERMANOVA of Bray Curtis Similarity of dispersion weighted abundance at each station for the factors Lo: location (Beni Saf and Mostaganem), Treat: treatment (impact-control), Dp: depth (8 m and 15 m) and site (1 and 2). DF: degrees of freedom, MS: mean squares, RES: residual, Pseudo-F of each factor, P (perm) permutation P value

Source	DF	MS	Pseudo-F	P (perm)
Lo: location	1	12480	2.9713	0.0067
Treat: treatment	1	9284.4	2.2105	0.0207
Dp: Depth	1	8082.3	1.9243	0.0428
Site (Lo × Treat × Dp)	8	4200.1	2.0386	0.0001
Lo × Treat	1	6916.1	1.6467	0.0969
Lo × Dp	1	5336.8	1.2707	0.2598
Treat × Dp	1	6760	1.6095	0.1015
Lo × Treat × Dp	1	6066.4	1.4444	0.1705
RES	32	2060.3		
TOT	47			

spp., and *B. guilliamsoniana*. Abundance was lower in group C, where the main taxa were *Scoloplos spp. Chamelea gallina, Spionidae, Tellina spp* and *Donax sp*. Most of the species in groups D and E disappeared. Only some individuals of *Donax sp,* Onuphidae, Paraonidae, *U. grimaldii, Periocùlodes longimanus* and *Ampelisca tenuicorni* appeared in group D. Spionidae, *Synchelidium haplocheles, Chamelea gallina* and Nemertea were the only taxa presented in group E (Table 5).

According to CCA, changes in benthic communities at Beni Saf impact stations were mainly related to the increased salinity and coarse sand, although other parameters such as temperature, depth and fine sand percentage also influenced benthic composition (Fig. 5).

4. Discussion

Spatial distribution of the brine was highly different between the two desalination plants under study, despite their similar production capacity. At the Beni Saf plant, although the shallow water should promote faster dilution of the brine discharge [27], the simple disperser design did not sufficiently favour mixing, producing a high salinity increase in areas close to the outfall and a brine plume extending for hundreds of metres. In contrast, the area affected by the Mostaganem discharge was much smaller than at Beni Saf. This was due to the multiple diffusers installed on the pipeline, which facilitate mixture of effluent [19].

Multiport diffusers employed at Mostaganem outfall increase flow velocity, boost dilution by turbulence in the vicinity, increase the volume of seawater in contact with the brine and push the concentrated brine in the direction of the sea surface. All these features improve the brine dilution process [16,28], whereas at Beni Saf the simpler diffuser system does not adequately promote dilution in the vicinity [29]. Since salinity increases in Mediterranean marine environments are rare under normal conditions, any changes could be expected to affect marine life. At both these desalination plants, brine discharge with high salinity levels has a detrimental effect on both the abundance and diversity of the benthic communities close to the outfalls, especially those communities not adapted to such salinity [29–34]. Despite the inclusion of multiport diffusers at the Mostaganem outfall, salinity values still exceeded 39 at the stations closest to the discharge. This induced a lower abundance of the benthic species that are especially sensitive to increased salinity. However, compared with Beni Saf, these diffusers greatly reduced the increase in salinity and the area of influence of the discharge, as reflected in the benthic communities. Such impact was higher at Beni Saf, where impact stations at 8 m depth were highly dissimilar in benthic community composition with respect to control stations because most species disappeared near the outfall. At this plant, depth has a strong influence on the observed salinity values and, consequently, benthic composition was also affected. Only some organisms were capable of surviving near the discharge (Spionidae, *Urothoe grimaldi,* Paraonidae, *Synchelidium haplocheles, Periculodes longimanus, Chamelea gallina*, Nemertea), but in very small abundances compared to control and impacted areas at 15 m depth. Paraonidae has been described before as a family tolerant to salinity, whereas Spionidae is described as sensitive in other parts of Mediterranean Sea [35]. Amphipoda show sensitivity to abrupt salinity increases from brine discharges from desalination plants [36], therefore the presence of some specimens of *Urothoe grimaldi*, *Synchelidium haplocheles* and *Periculodes longimanus* at the discharge stations may be due to individuals migrating from nearby stations where the brine plume did not reach.

It has been previously observed that benthic communities affected by brine discharge can recover very quickly after the implementation of mitigation measures that improve effluent mixing. These measures include by-passing seawater as at Alicante desalination plant [32] or installation of diffusers in the pipeline that favour mixing [19, 29]. Diffuser improvements at Beni Saf to raise the discharge velocity would enhance mixing, reduce the salinity increase in the environment and allow the recovery of benthic fauna around the discharge.

Table 5
Average abundance of benthic taxa (indiv./m²) that contribute most to dissimilarity between the groups established

Taxa	Group A Av. Ab.	Group B Av. Ab.	Group C Av. Ab.	Group D Av. Ab.	Group E Av. Ab.
Spionidae	30.08	192.98	37.59	0.00	12.53
Apseudopsis latreillii	145.36	145.36	29.24	0.00	0.00
Urothoe grimaldii	120.30	75.19	29.24	12.53	0.00
Paraonidae	47.62	120.30	8.35	25.06	0.00
Scoloplos spp.	97.74	97.74	158.73	0.00	0.00
Cirratulidae	15.04	72.68	8.35	0.00	0.00
Bathyporeia borgi	82.71	5.01	4.18	0.00	0.00
Siphonoecetes dellavallei	125.31	2.51	20.89	0.00	0.00
Synchelidium haplocheles	87.72	5.01	8.35	0.00	12.53
Perioculodes longimanus	72.68	62.66	16.71	12.53	0.00
Micronephthys sp.1	15.04	47.62	12.53	0.00	0.00
Echinoidea	17.54	15.04	12.53	0.00	0.00
Nannastacidae	27.57	20.05	12.53	0.00	0.00
Chamelea gallina	42.61	37.59	137.84	0.00	25.06
Bodotriidae	47.62	35.09	16.71	0.00	0.00
Bathyporeia guilliamsoniana	65.16	67.67	0.00	0.00	0.00
Urothoe intermedia	30.08	50.13	4.18	0.00	0.00
Nemertea	52.63	27.57	0.00	0.00	12.53
Tellina spp	25.06	15.04	37.59	0.00	0.00
Spisula subtruncata	5.01	35.09	4.18	0.00	0.00
Donax sp	5.01	25.06	37.59	25.06	0.00
Pseudocumatidae	2.51	27.57	0.00	0.00	0.00
Paguroidea	20.05	7.52	20.89	0.00	0.00
Sabellidae	37.59	7.52	8.35	0.00	0.00
Nephthys sp.1	7.52	12.53	16.71	0.00	0.00
Onuphidae	12.53	7.52	12.53	25.06	0.00
Sigalionidae	5.01	12.53	20.89	0.00	0.00
Ampelisca tenuicornis	17.54	7.52	4.18	12.53	0.00

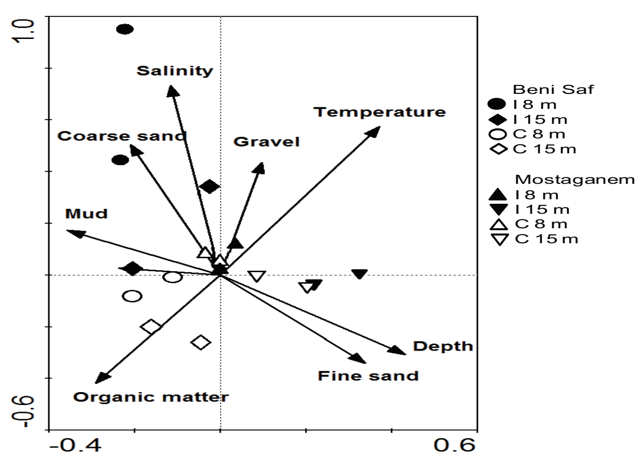

Fig. 5. Results of correspondence analysis biplot. Points correspond to stations and arrows indicate sediment characteristics, depth, salinity and temperature. Axis I and axis II had eigenvalues of 0.325 and 0.288, respectively.

5. Conclusion

We confirm that the impact of desalination activity on the marine environment can be mitigated and controlled by installation of multiport diffusers that are effective for plants as large as those studied here. These diffusers accelerate dilution, reducing the area affected by the hypersaline plume, subsequently mitigating the impact of brine discharge on the benthic community, as observed at Mostaganem, where the benthic community was only slightly affected. Updating the diffusers at Beni Saf and other desalination plants will improve dilution conditions with minimal financial investment, favouring benthic community recovery as achieved at some facilities [19].

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