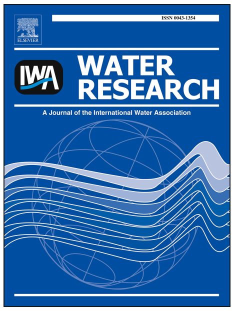

Benthic community recovery from brine impact after the implementation of mitigation measures

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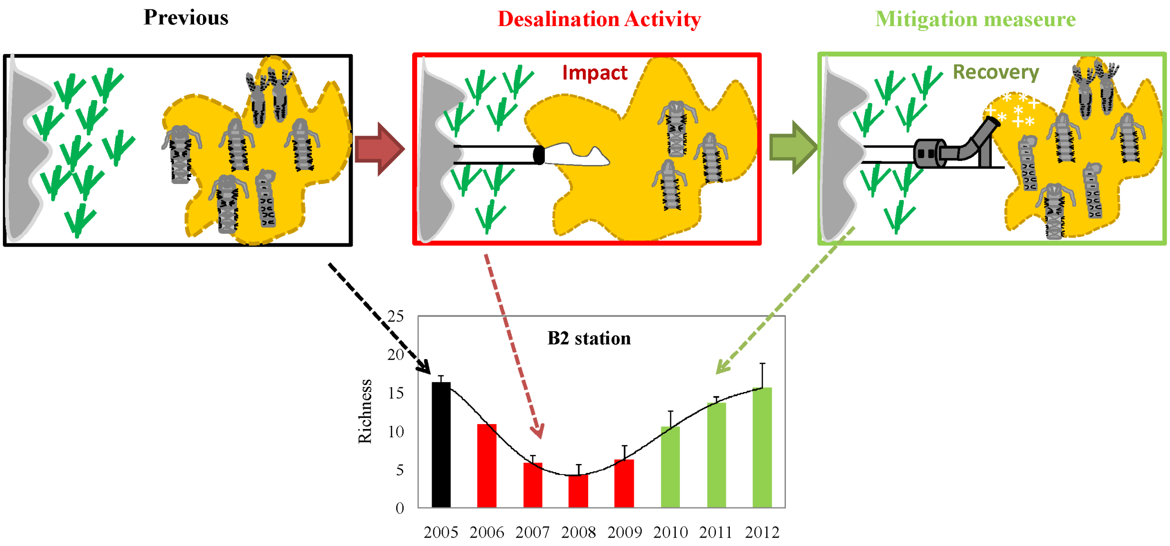

Richness changes at B2 station related to salinity changes due to desalination activity and mitigation measures

Benthic community recovery from brine impact after the implementation of mitigation measures.

Del-Pilar-Ruso, Yoana*, Elena Martínez-García[1], Francisca Giménez-Casalduero[1], Angel Loya-Fernández[1], Luis Miguel Ferrero-Vicente[1], Candela Marco-Méndez[1], Jose Antonio De-la-Ossa-Carretero[1] and Jose Luis Sánchez-Lizaso[1]

[1]*Dpto. de Ciencias del Mar y Biología Aplicada, Universidad de Alicante, Campus de San Vicente del Raspeig, Ap. 99 E-03080 Spain

*Corresponding author. Tel. +34 965 903400 Ext. 2916 Fax: 965 909897
E-mail address: yoana.delpilar@ua.es (Y. Del-Pilar-Ruso)

Abstract

In many regions, seawater desalination is a growing industry that has its impact on benthic communities. This study analyses the effect on benthic communities of a mitigation measure applied to a brine discharge, using polychaete assemblages as indicator. An eight-year study was conducted at San Pedro del Pinatar (SE Spain) establishing a grid of 12 sites at a depth range of 29-38 m during autumn. Brine discharge started in 2006 and produced a significant decrease in abundance, richness and diversity of polychaete families at the location closest to the discharge, where salinity reached 49. In 2010, a diffuser was deployed at the end of the pipeline in order to increase the mixing, to reduce the impact on benthic communities. After implementation of this mitigation measure, the salinity measured close to discharge was less than 38.5 and a significant recovery in polychaete richness and diversity was detected, to levels similar to those before the discharge. A less evident recovery in abundance was also observed, probably due to different recovery rates of polychaete families. Some families like Paraonidae and Magelonidae were more tolerant to this impact. Others like Syllidae and Capitellidae recovered quickly, although still affected by the discharge, while some families such as Sabellidae and Cirratulidae appeared to recover more slowly.

Key words: Polychaete assemblage, Brine discharge, Mitigation measures, Recovery, Soft bottom, Mediterranean.

1. Introduction

Over the last few decades we have faced a global water crisis due to the increase in domestic, industrial and agricultural water demand. The rapid growth in human population and industrial-scale activities has contributed to this water scarcity (Medina, 2001). As a result many countries have pursued alternatives to conventional resources to supply the additional water (Zhou et al., 2013). Desalination of seawater is predominantly used for alleviating the problem of water scarcity in dry coastal regions. It accounts for a worldwide production capacity of 24.5 million m^3/day (IDA, 2006; Lattemann and Höpner, 2008). In the Mediterranean Sea, the total production from seawater is about 4.2 million m^3/day (17% of the worldwide capacity) (Lattemann and Höpner, 2008). Spain is considered a water-stressed country (European Environment Agency, 2005); with 7% of the worldwide capacity it is the largest producer in the region, with about 70% of its desalting plants located on the Mediterranean coast (Lattemann and Höpner, 2008). Among the different technologies used, reverse osmosis is the most common, mainly due to its low energy and space consumption and the reduction in the cost of producing potable water (Einav et al., 2002). Nevertheless, such facilities may give rise to several potentially adverse environmental impacts (Höpner and Windelberg, 1996; Fernández-Torquemada et al., 2005; Sadhwani et al., 2005; Del-Pilar-Ruso et al., 2009). The main impact of seawater reverse osmosis (SWRO) desalination plants on marine communities is caused by the discharge of high salinity effluent (Einav et al., 2002). This brine, characterised by high salt concentration and low nutrients (Fernández-Torquemada et al., 2004), is usually returned to the sea. It can have a detrimental effect on the marine environment, mainly on benthic communities that are not adapted to these high salinities (Sanchez-Lizaso et al., 2008; Gacía and Ballesteros, 2001). The high-salt effluent remains on the bottom due to its greater density and principally affects marine benthic communities adapted to a lower or more stable salinity environment (Lattemann and Höpner, 2003). The magnitude of the impact reached in an area close to the discharge will depend on the salinity, speed of dilution and sensitivity of the ecosystem that receives it (Höpner and Windelberg, 1996; Fernández-Torquemada et al., 2009). To protect the environment, most countries tend to assess the environmental impacts produced by desalination activities (Sadhwani et al., 2005), and attempt to minimise such impacts through mitigation measures. Brine disposal impact may be reduced by the dilution of the effluent, either using diffusers or by flushing with normal seawater added to the flow (Fernández-Torquemada et al., 2009). At the San Pedro del Pinatar desalination plants, Environmental Impact Assessments (EIAs) were carried out from the beginning of the activity and some correction measures applied. Firstly, to avoid the impact on sensitive habitats (seagrass meadows), since January 2006 the discharge has been carried via a pipeline to a deep zone. However, due to the low levels of hydrodynamic activity there, salinity reached higher values close to the discharge point and its effect on benthic communities was detected, particularly on polychaete assemblages. Therefore, aimed at decreasing its salinity, a diffuser was added at the end of the pipeline in May 2010 to facilitate the mixture of the effluent with the ambient water (Loya-Fernández et al., 2012).

During the past ten years, studies have been conducted to assess the impacts of desalination effluent on soft-bottom benthic communities (Raventos et al., 2006; Shute, 2009; Del-Pilar-Ruso et al., 2009; Riera et al., 2012). However, to date, few studies assess benthic community recovery after the implementation of corrective measures. One study conducted by Fernandez-Torquemada et al. (2013) showed the recovery of echinoderm densities when the brine was diluted with seawater prior to discharge. In the same area we also detected a recovery of polychaete assemblage after the dilution (Unpublished data). The aim of the present study was to analyse the effectiveness of the mitigation measure applied, using a polychaete assemblage as bioindicator of benthic community status (Pocklington and Wells, 1992). Due to their ecological flexibility, since this group present a wide geographical range and contains both tolerant and sensitive species, they show an extraordinary ability to adapt to a whole range of habitats and environmental variations (Fauchald and Jaumars, 1979). This taxonomic group is therefore considered one of the best indicators of changes in environmental disturbances (Pocklington and Wells, 1992). They can also be considered as an alternative to studying the whole community (Olsgard et al., 2003; Martínez-García et al., 2013; Del Pilar-Ruso et al., 2014).

2. Material and Methods

2.1. Study area and desalination plants

The present study was focused on the San Pedro desalination plants located in southeast Spain (37º50´34.5´´N, 0º46´15.6´´W) (Fig. 1), where two facilities are operating with a maximum production capacity of 65,000 m^3/day each. This output involves a high volume of effluent water with a high salinity (around 70), from both plants via a 5 km pipeline (1293 mm diameter) into a deep zone around 33 m in depth. The main chemical discharged with the brine is the antiscalant PermaTreat® PC-1020T that is used at a concentration of 1.1 ppm. The prevailing currents in the area run parallel to the shoreline. Near the bottom, currents move mainly in a southerly direction but surface currents move mainly northwards, with an average speed of 10.03 cm/s (Del-Pilar-Ruso et al., 2009). A diffuser was added at the end of the pipeline in May 2010 to facilitate mixture and dispersal (Supplementary material).

The study area was characterised by the heterogeneity of the sediments where two anthropogenic impacts merge (a sewage outfall being the other effluent factor) (Fig. 1). The sediment types remained consistent throughout the study period and a previous investigation showed no synergic effects of both impacts together (Del-Pilar-Ruso et al., 2009).

2.2. Sampling method

To monitor the brine plume (Fig. 2), the vertical distribution of salinity was measured using a RBR XR-420 CTD sensor, range 0-70 and resolution ± 0.01. The spatial data was represented by means of the Surfer v9 program. The data was previously interpolated using the kriging technique as a gridding method in each campaign (Fernández-Torquemada et al., 2009). Two salinity surveys, one during the activity (autumn 2008) and the other after the diffuser was installed (autumn 2010) were represented to show the difference in plume extent before and after implementing the mitigation measure.

To assess the polychaete assemblage, an eight-year study was conducted at 12 stations with a depth range of 29-38 m during autumn 2005-2012, in the surroundings of a brine discharge outfall (at station B2). One sampling period (T1 = 2005) took place prior to the desalination activity (Previous), four during the activity (T2 = 2006; T3 = 2007; T4 = 2008 and T5 = 2009) (Activity) and the last three (T6 = 2010; T7 = 2011 and T8 = 2012) corresponding to the period after the diffuser piece installation (Mitigation measure). Four replicates were taken using a Van Veen grab (0.04 m^2), three for biotic analyses and one for the analyses of environmental features. The biotic analysis samples were sieved through a 0.5 mm mesh screen and fixed in 10% buffered formalin, then preserved in 4% formalin for later sorting and identification of the polychaete assemblage to the family level. The additional sample was used for granulometric analyses following Buchanan´s methodology (1984). Bottom salinity values were also obtained by means of a CTD at each station and in each of the eight sampling periods.

2.3. Spatial analyses

Permutational multivariate analysis of variance (PERMANOVA) was used to analyse changes in the structural parameters of the polychaete assemblage, such as total abundance, family richness and diversity. The family richness was expressed as the number of families found in each sample and the diversity index of each sample was determined using the Shannon-Wiener index (H´ ($\log_2$)) (Shannon and Weaver, 1963).

Changes in these parameters were evaluated between two fixed factors: 1) the level of Exposure (EL) to the plume with two levels: Exposed (E) (B2, based on the measure plume area) and Not Exposed (NE), and 2) Period of the activity, with three levels: Previous to the activity (Pre), during the Activity (Act), and once the mitigation measure was implemented (Mm). Pairwise comparisons were performed whenever significant differences were detected among the interaction terms or the main factors (Anderson et al., 2008). All PERMANOVAs were performed on untransformed data and similarities among samples were calculated using the normalised Euclidean distance (Clarke and Warwick, 1994). To obtain sufficient statistical power, p-values were generated after 4999 permutations of residuals (Anderson, 2001). These analyses were performed using the PRIMER v.6 with the PERMANOVA+add-on (PRIMER-E Ltd., Plymouth, UK (Anderson et al., 2008).

Additionally, graphical representation of multivariate patterns of the polychaete assemblage was obtained by non-metric multidimensional scaling (nMDS), to help detect any possible change in composition of the assemblage in relation to the activity. Similarity percentage (SIMPER) procedure was used to determine the percentage contribution of each polychaete family implicated in assemblage changes. Triangular similarity matrices were calculated using the Bray-Curtis similarity coefficient on untransformed abundance data for all taxa identified throughout the study period. All multivariate analyses were performed using the PRIMER statistical package (Clarke and Gorley, 2006).

A PERMANOVA was also applied to test differences in abundance of the polychaete families involved in the changes detected at the station close to the brine discharge thorough the three periods of the activity: (Previous, Activity and Mitigation measure).

Pairwise comparisons were also performed whenever significant differences were detected.

3. Results

3.1. Salinity campaigns related to the desalination activity and the corrective measures.

The highest bottom salinity values were obtained around the discharge station (B2) during autumn 2008 (Fig. 3), while the extension of the brine plume did not affect the stations located 2 km away from the discharge, to both the North and South. Bottom salinity values close to the pipeline outfall decreased significantly and the brine dispersion was also reduced during autumn 2010, once the diffuser was installed (Fig. 3). Therefore, the initial impact of the desalination plant on the soft-bottom community was confined to a very small area, since no impact was observed at stations at 250 m.

3.2. Polychaete assemblage

A total of 16069 individuals were counted at all the stations during all the surveys. They were grouped into 47 families. The polychaete assemblage was mainly dominated by the families Paraonidae (17.85%), Lumbrineridae (11.6%), Syllidae (9 %), Magelonidae (7.6%), Cirratulidae (6.5%) and Nephtyidae (5%). A high percentage of rarity (57%)

was detected in the study area. Twenty seven families were represented by less than 1% of the total abundance.

PERMANOVA of the total abundance data (including rare families) revealed significant differences for the factor Exposure level ($p = 0.044$) and for the factor Period of the activity ($p = 0.047$) (Table 1). A significant decrease in abundance took place in the stations exposed to the discharge plume due to the desalination activity. Although the recovery was not significant, a trend towards increase was observed (Fig. 4) (Table 2). With respect to family richness and diversity, significant differences for the interaction between two factors (EL X P) ($p = 0.0004$ and $p = 0.002$, respectively) were detected (Table 1). The significant differences were mainly due to the decrease in these parameters at station exposed to the plume during the desalination activity (Act), but no differences were detected between the previous (Pre) and mitigation (Mm) periods. No statistical differences were seen between the stations not exposed to the plume during the three periods of the activity (Table 2, Fig. 5 and 6).

Temporal differences in these structural parameters (abundance, diversity and family richness) showed inter-annual changes with similar distribution patterns for all the stations. This pattern was interrupted at the station close to the discharge (Fig. 4, 5 and 6).

3.3. Polychaete distribution pattern

The nMDS plot also showed that the polychaete assemblage of the study area was mainly segregated into two groups; muddy and heterogeneous bottoms (Fig. 7). The SIMPER procedure indicated a 67.77 % dissimilarity between these groups. One group was established by the stations A1, A2, A3, B1 and B4 in most of the time periods (57.73 % similarity). This group, which corresponds with the area characterised as a muddy bottom, was dominated by the families Paraonidae, Lumbrineridae, Magelonidae and Cirratulidae (percentage of contribution higher than 5%). The other group, characterised by the heterogeneity of the sediments, was established by stations A4, B2, B3, C1, C2, C3 and C4 over most of the study time periods; except for station B2, which segregated from the main group in 2007, 2008, 2009 and 2010. The families Syllidae, Lumbrineridae, Paraonidae, Onuphidae, Eunicidae, Capitellidae, Cirratulidae and Nephtyidae were responsible for its similarity (45.47%) (see Supplementary data).

The nMDS also showed changes in the structure of the polychaete assemblage at the station closest to the brine effluent. Analysing the polychaete distribution pattern at this station throughout the sampling period, a temporal segregation was detected with respect to the pre-impact period (Fig. 7). This segregation appears to correspond to changes detected in salinity, since the bottom salinity was around 37.41 ± 0.04 at all stations except B2, where salinity exceeded 39 from 2006 to 2009 (reaching 49 in 2008). However these salinity values decreased once the diffuser was applied in 2010 (Fig. 3). Sabellidae, Syllidae, Cirratulidae, Capitellidae, Lumbrineridae, Paraonidae, Flabelligeridae, Scalibregmatidae, Nephtyidae, Magelonidae and Dorvilleidae are the families showing differences in B2 through time (Table 3). Examining Fig. 8 in more detail, some families like Magelonidae ($p = 0.339$) and Paraonidae ($p = 0.141$) showed a similar pattern to the rest of the stations (no differences between the periods of activity were detected). Syllidae (p = 0.002) and Capitellidae (p = 0.011) decreased in abundance during the activity, showing a recovery in abundance once the mitigation measure was implemented. However, some families such as Sabellidae (p = 0.001) and Cirratulidae (p = 0.002), which also decreased in abundance from the beginning of the discharge, later show an upward trend in abundance, but significant differences were still not detected between activity (Act) and mitigation (Mm) periods (Fig. 8).

4. Discussion

Brine discharge has been described as an activity that induces a pressure in a place where the salinity values were once stable (Garcia and Ballesteros, 2001, Lattermann and Höpner, 2003). This abrupt change in salinity is highest at the discharge outlet (Del-Pilar-Ruso et al., 2009). However, the impoverishment of the community, characterised by the dominance of a few opportunistic tolerant species, can extend to a larger area if the activity remains without any mitigation measures.

As one of their main objectives, management interventions attempt to restore the biodiversity of degraded ecosystems (Elliot et al., 2007). Possible mechanisms to reduce potential environmental effects of brine would be to select a suitable discharge site (Tsiourtis, 2008), to dilute the discharge (Baalousha, 2006) or to encourage more rapid mixing (Altayaran and Madany, 1992). The diffuser added at the end of the pipeline discharges the effluent at 60º to the horizontal, facilitating mixture of effluent, reducing its salinity and dispersion area (Loya-Fernández et al., 2012). This shows that the implementation of this corrective measure can lead to a recovery of the polychaete assemblage, previously affected by the discharge of a high salinity effluent from a SWRO desalination plant. The initial impact on the soft-bottom community seems to be confined to a very small area since only the closest station was affected.

The recovery in polychaete assemblage descriptors, such as family richness and diversity was notable, conforming a similar assemblage to that in the previous stage (Fig. 4, 5, 6). The improvement in these descriptors was observed from 2010 onwards, when the mitigation measure was applied. However, the recovery in abundance was not so evident, due to inter-annual changes at all the stations except the closest to the discharge (B2). Not only were the assemblage descriptors modified but also the polychaete assemblage structure, showing changes in the composition of polychaete families throughout the time (Fig. 7).

Benthic recovery processes vary considerably and are dependent on the type of stress, and the temporal and spatial scales of disturbances (Johnson and Frid, 1995; Karakassis et al., 1999; Gray et al., 2002). An understanding of the costs and trajectories of the environmental recovery of degraded aquatic systems is increasingly necessary to allow policy makers and regulators to formulate robust, cost efficient and feasible management decisions (Pascual et al., 2012). Smith et al. (2006) discussed in their survey how it took several years for the macrobenthos to recover from high pollution levels after the cessation of stresses such as sewage sludge, pulp mill effluent and fish-farming. Although in some cases substantial recovery has taken less than 5 years (Borja et al., 2010; Kelley et al., 2014), full recovery of coastal marine and estuarine ecosystems from over a century of degradation can take a minimum of 15-25 years to attain the original biotic composition. Karakassis et al. (1999) showed that compared with other studies the recovery from sediments left by fish farming is more rapid, as the spatial scales of their impact are smaller and the constituents (fish-feed and faeces) are more labile than most types of industrial or sewage waste. However, the recovery succession in the case of fish-farm waste is not necessarily simple or monotonic, since a complex of factors including different biogeochemical processes could be involved.

In this study, the benthic community improvement after the implementation of a corrective measure, appears to be relatively rapid and may take place over months rather than years. A recovery in polychaete assemblage parameters (abundance, family richness and diversity) was observed 5 months after the implementation of this mitigation measure. The reason may be because this effluent is characterized merely by high salinity and low nutrient content. Once the main pressure is reduced by simply improving its mixing with the surrounding water, the polychaete assemblage returns to the pre-impacted state faster than after the cessation of other kinds of discharge that potentially increase the long-term pollutants levels in the sediment. Fernández-Torquemada et al. (2013) also detected a rapid increase in echinoderm densities in seagrass meadows once the brine discharge was diluted.

In contrast to other types of pollution, the knowledge of the role of polychaetes as indicators of brine impact is scarce. A detailed description of the behaviour of those polychaete families involved in the structural changes of the community throughout the periods of the activity suggests they have different levels of tolerance/sensitivity to it, as well as different recovery rates. Families such as Syllidae and Capitellidae became less abundant from 2006 onwards, showing recovery once the mitigation measure was applied. However, other families such as Sabellidae and Cirratulidae, also decreasing in abundance from the beginning of the activity, only seem to increase in the 2012 survey. Contrastingly, families such as Paraonidae and Magelonidae seem not to be affected by this activity. These families maintained similar distribution patterns at the discharge point; even when the activity pressure was increased (Fig. 8).

Further experimental studies would be necessary to define the sensitivity levels of different polychaete families at different salinity values and their recovery capacity.

5. Conclusions

In our study a direct link between the implementation of corrective measures and the recovery of benthic community was detected. The deployment of a diffuser piece that increases the mixing of the effluent with seawater reduces the impact of a desalination plant and allows the improvement of the benthic community. Community recovery from this impact was relatively rapid and takes place over months rather than years. To reduce the impact of reverse osmosis desalination plants it is necessary to adopt the measures that maximize the mixing of the effluent during the construction or, like in this case, during the operation of the plant.

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Table 1.- Results of permutational multivariate analyses of variance (PERMANOVA) performed on the community structure measures parameters: total abundance, family richness and diversity of the polychaete assemblage between Exposure level to the plume, EL-(exposed (E) and not exposed (NE)) and Period of the activity, P- (Previous (Pre), Activity (Act) and Mitigation measure (Mm) (df: degrees of freedom; MS: mean squares, ns: no significant differences and significant results: * significant at p<0.05; ** at p<0.01; *** p<0.001).

		Abundance		Family richness		Diversity	
Factor	df	MS	F	MS	F	MS	F
EL	1	5.79x10^{6}	24.906*	37.335	2.1243^{ns}	2.02x10^{-2}	6.01 x10^{-2ns}
P	2	4.25x10^{6}	50.788*	156.68	8.915***	2.9019	8.6304**
EL x P	2	2.95 x10^{6}	17.278^{ns}	151.95	8.6455***	3.2338	9.6174**
Res	282			17.575		0.33624	
Total	287						

Table 2. PERMANOVA pair-wise comparisons summary. P = factor Period: Pre: previous, Act: activity, Mm: mitigation measure; EL = factor Exposure level: E: Exposed, NE: not exposed. (ms: marginal significance (p = 0.05), ns: no significant differences and significant results: * significant at p<0.05; ** at p<0.01; *** p<0.001). The significant results were highlighted to make it understandable.

Pair-wise	Factor	Level of factor	Abundance	
P	P	Previous_Activity	**(Pre ≠ Act)***	
		Previous_Mitigation	(Pre = Mm) ^{ns}	
		Activity_Mitigation	(Act = Mm) ^{ns}	
	Factor	Level of factor	Family richness	Diversity
EL x P	El (P)	Previous	(E = NE) ^{ns}	(E = NE) ^{ns}
		Activity	**(E ≠ NE) *** **	**(E ≠ NE) *** **
		Mitigation	(E = NE) ^{ns}	(E = NE) ^{ns}
	P (EL)	Exposed	**(Pre ≠ Act)****	**(Pre ≠ Act)***
			(Pre = Mm) ^{ns}	(Pre = Mm) ^{ns}
			(Act ≠ Mm)***	**(Act ≠ Mm)****
		Not exposed	(Pre = Act) ^{ns}	(Pre = Act) ^{ns}
			(Pre ≈ Mm) ^{ms}	(Pre = Mm) ^{ns}
			(Act = Mm) ^{ns}	(Act = Mm) ^{ns}

Table 3.- Summary of the results of SIMPER dissimilarities at the station B2 throughout the sampling periods: **Previous (Pre)** desalination activity T1 (2005); **during the activity** (**Act)** T2 (2006), T3 (2007), T4 (2008), T5 (2009) and once the **mitigation measure (Mm)** was implemented T6 (2010), T7 (2011) and T8 (2012). (Av. Abund: average abundance, Contrib. %: percentage of contribution; Cum. %: cumulative percentage, A.D = average dissimilarity).

	Av.Abund	**Av.Abund**	**Contrib%**	**Cum.%**
Time (A.D= 41.27%)	**T1_Pre**	**T2_Act**		
Sabellidae	275.00	0.00	21.15	21.15
Syllidae	241.67	41.67	15.38	36.54
Cirratulidae	233.33	75.00	12.18	48.72
Capitellidae	141.67	41.67	7.69	56.41
Lumbrineridae	275.00	183.33	7.05	63.46
Paraonidae	283.33	200.00	6.41	69.87
Flabelligeridae	75.00	0.00	5.77	75.64
Nephtyidae	183.33	116.67	5.13	80.77
Time (A.D= 76.70%)	**T1_Pre**	**T3_Act**		
Sabellidae	275.00	0.00	13.92	13.92
Syllidae	241.67	0.00	12.24	26.16
Cirratulidae	233.33	0.00	11.81	37.97
Lumbrineridae	275.00	58.33	10.97	48.95
Paraonidae	283.33	108.33	8.86	57.81
Nephtyidae	183.33	16.67	8.44	66.24
Capitellidae	141.67	25.00	5.91	72.15
Magelonidae	66.67	166.67	5.06	77.22
Time (A.D= 76.64%)	**T1_Pre**	**T4_Act**		
Sabellidae	275.00	12.53	13.88	13.88
Paraonidae	283.33	37.59	13.00	26.88
Syllidae	241.67	0.00	12.78	39.66
Cirratulidae	233.33	0.00	12.34	51.99
Lumbrineridae	275.00	75.19	10.57	62.56
Capitellidae	141.67	25.06	6.17	68.73
Nephtyidae	183.33	75.19	5.72	74.45
Time (A.D= 70.07%)	**T1_Pre**	**T5_Act**		
Sabellidae	275.00	0.00	15.29	15.29
Lumbrineridae	275.00	25.06	13.89	29.18
Cirratulidae	233.33	12.53	12.27	41.45
Syllidae	241.67	37.59	11.34	52.79
Paraonidae	283.33	125.31	8.78	61.58
Capitellidae	141.67	25.06	6.48	68.06
Nephtyidae	183.33	87.72	5.31	73.37
Time (A.D= 65.28%)	**T1_Pre**	**T6_Mm**		
Sabellidae	275.00	12.53	13.37	13.37
Paraonidae	283.33	25.06	13.16	26.54
Syllidae	241.67	0.00	12.31	38.85
Cirratulidae	233.33	12.53	11.25	50.10
Lumbrineridae	275.00	75.19	10.18	60.28
Scalibregmatidae	0.00	100.25	5.11	65.39
Time (A.D= 44.39%)	**T1_Pre**	**T7_Mm**		
Sabellidae	275.00	0.00	17.05	17.05
Cirratulidae	233.33	0.00	14.47	31.52
Paraonidae	283.33	87.72	12.13	43.65

Lumbrineridae	275.00	137.84	8.50	52.16
Magelonidae	66.67	175.44	6.74	58.90
Dorvilleidae	25.00	125.31	6.22	65.12
Time (A.D= 36.23%)	**T1_Pre**	**T8_Mm**		
Lumbrineridae	275.00	62.66	15.44	15.44
Sabellidae	275.00	75.19	14.53	29.97
Magelonidae	66.67	187.97	8.82	38.80
Cirratulidae	233.33	112.78	8.77	47.56
Paraonidae	283.33	175.44	7.85	55.41
Syllidae	241.67	137.84	7.55	62.96

Figure 1. Map of the study area showing the sampling stations around the brine discharge. The distances between 1 and 2 and between 2 and 3 were 250 m. The distance between 4 and 2 was 1 km. The distance between C3 and C4 was shorter due to sampling problems (UTM coordinate system. Grid zone 30S) (SO: sewage outfall; BD: brine discharge).

Figure 2. Spatial representation of the salinity distribution on the bottom, during the activity (A) and after the implementation of a mitigation measure (diffuser) (B) (UTM coordinate system. Grid zone 30S).

Figure 3. Salinity values at each station throughout the sampling period

Figure 4. Mean values of polychaete abundance (±SE) at all stations, throughout the three periods of the activity (Previous, Activity and Mitigation measure)

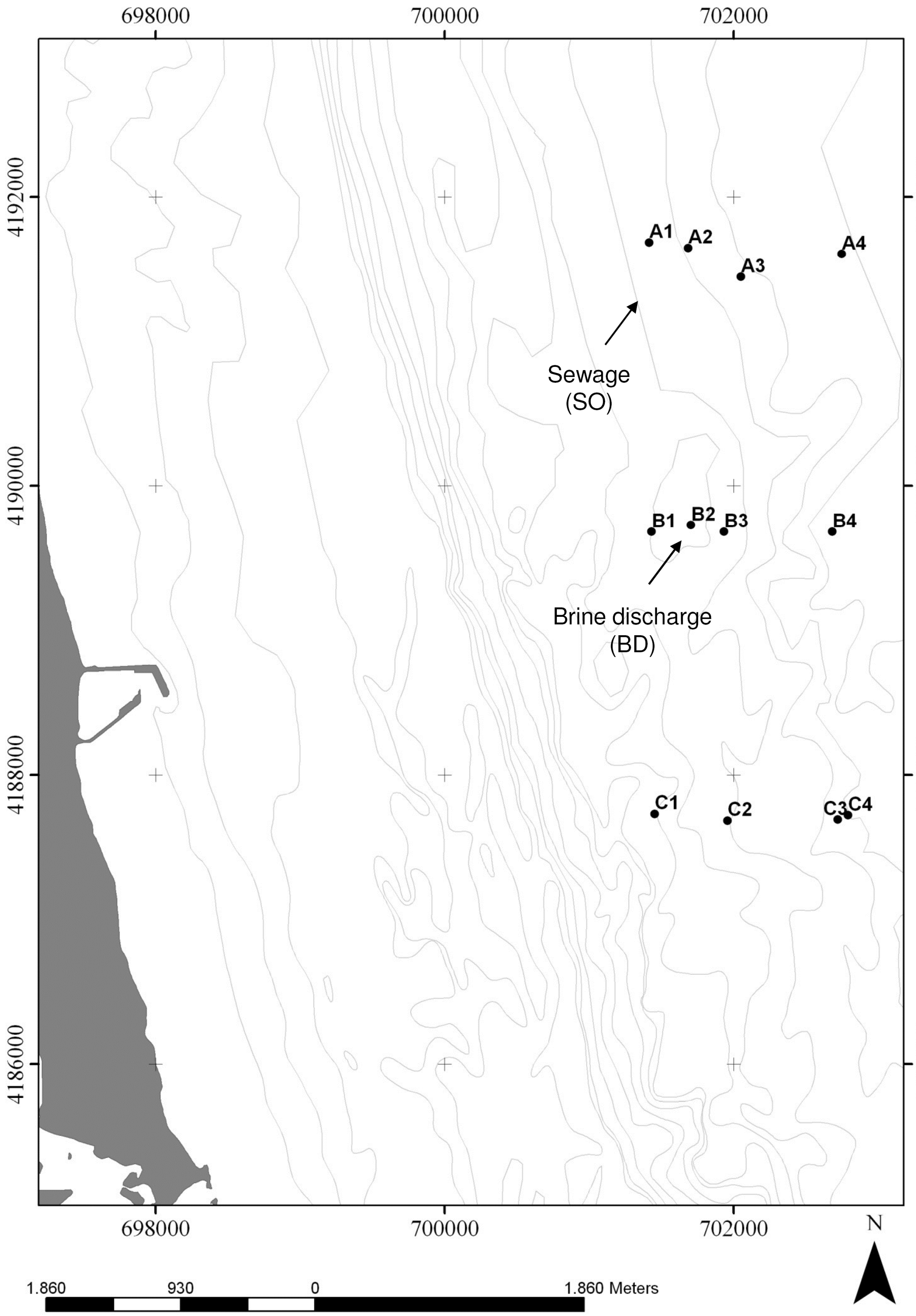
Figure 5. Mean values of polychaete family richness (±SE) at all stations, throughout the three periods of the activity (Previous, Activity and Mitigation measure)

Figure 6. Mean values of polychaete diversity (±SE) at all stations, throughout the three periods of the activity (Previous, Activity and Mitigation measure)

Figure 7. MDS analyses based on the Bray-Curtis Similarity of non-transformed abundance data at each taxonomic scale considered throughout the sampling period. The two main groups have been highlighted. Temporal changes in the polychaete assemblage have been highlighted.

Figure 8. Changes in abundance of indicative polychaete families at the discharge point (B2) through the three periods of the activity: Previous, Activity and Mitigation measure Pairwise summary was included: a and b indicate which stations are statistically similar (those with the same letter) or different (those with different letters).

Supplementary material. Schematic of the diffuser piece added at the pipeline end.


698000
700000
702000
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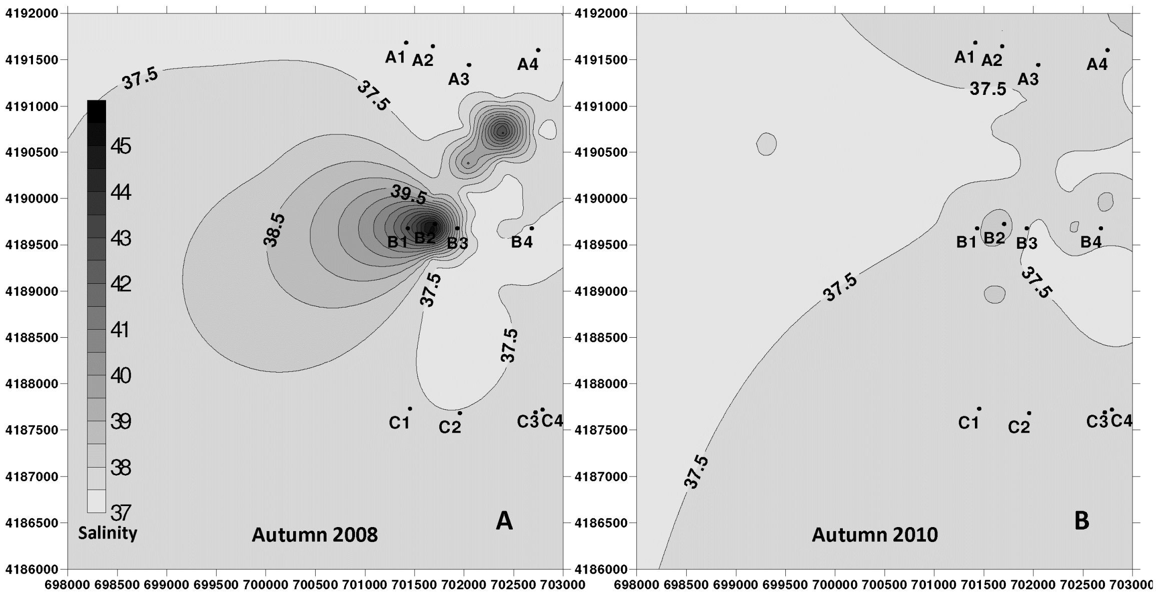
A1
A2
A3
A4
Sewage
(SO)
B1
B2
B3
B4
Brine discharge
(BD)
C1
C2
C3
C4
N
1.860
930
0
1.860 Meters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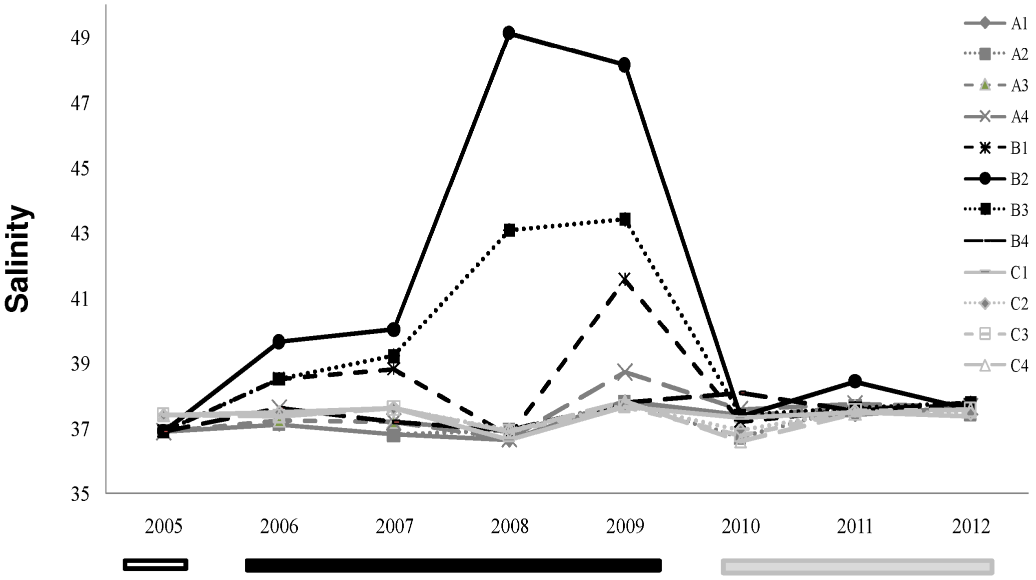
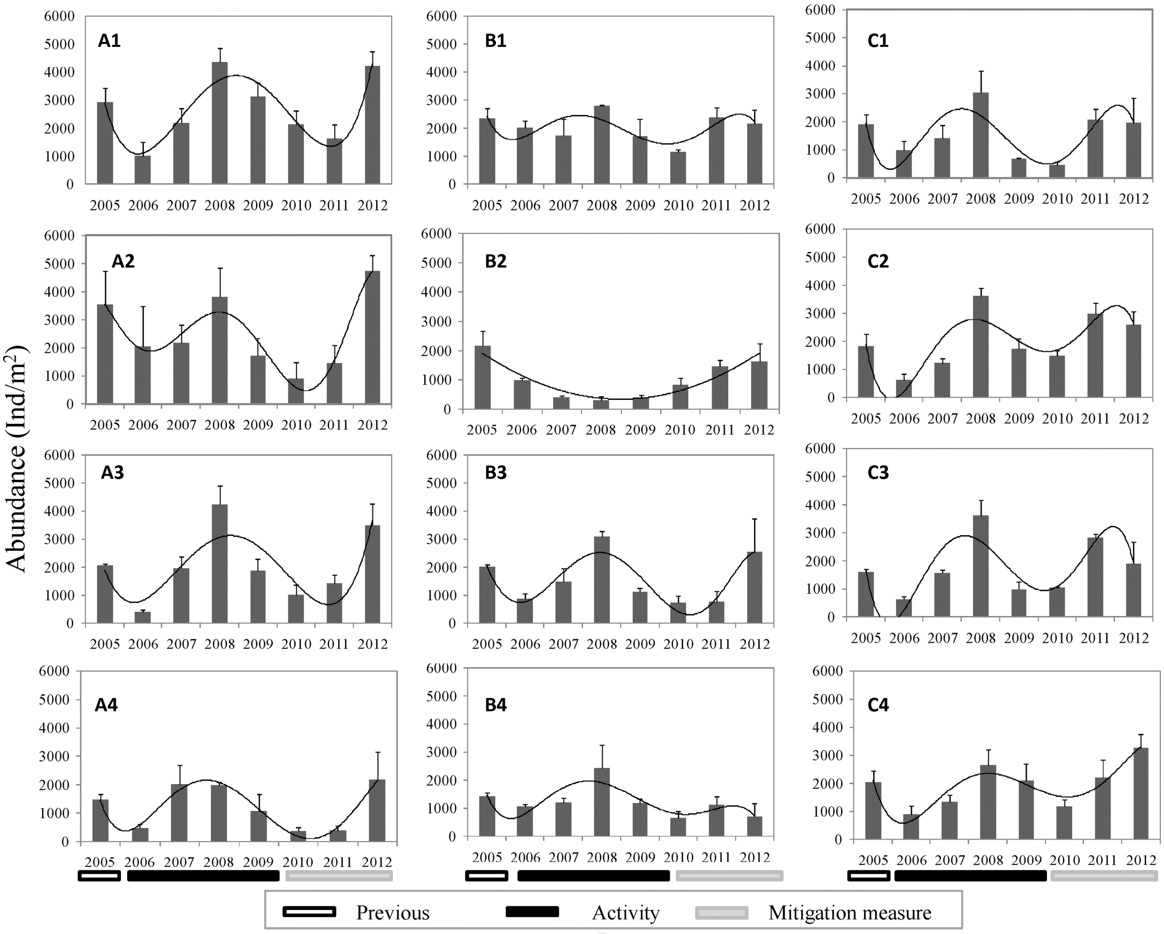
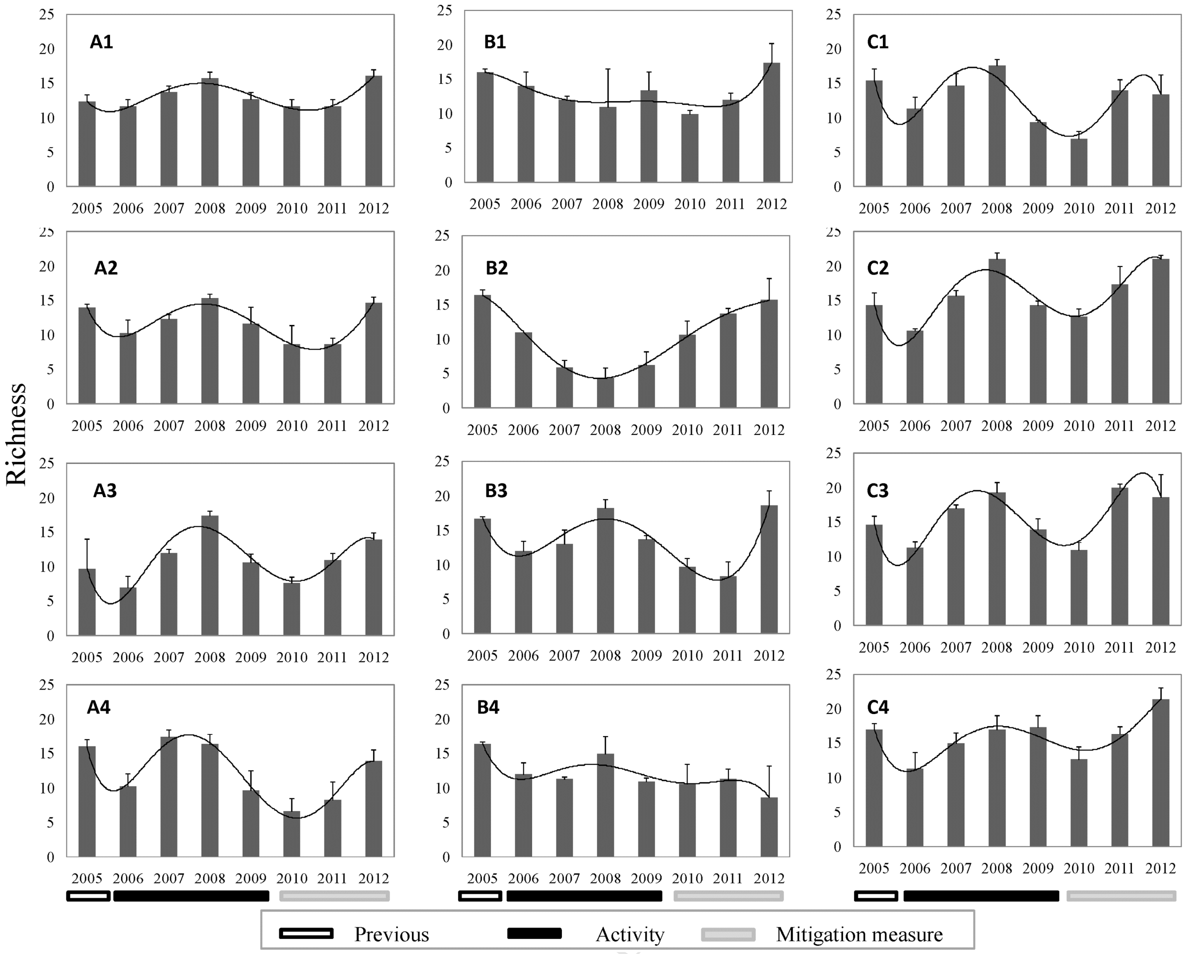
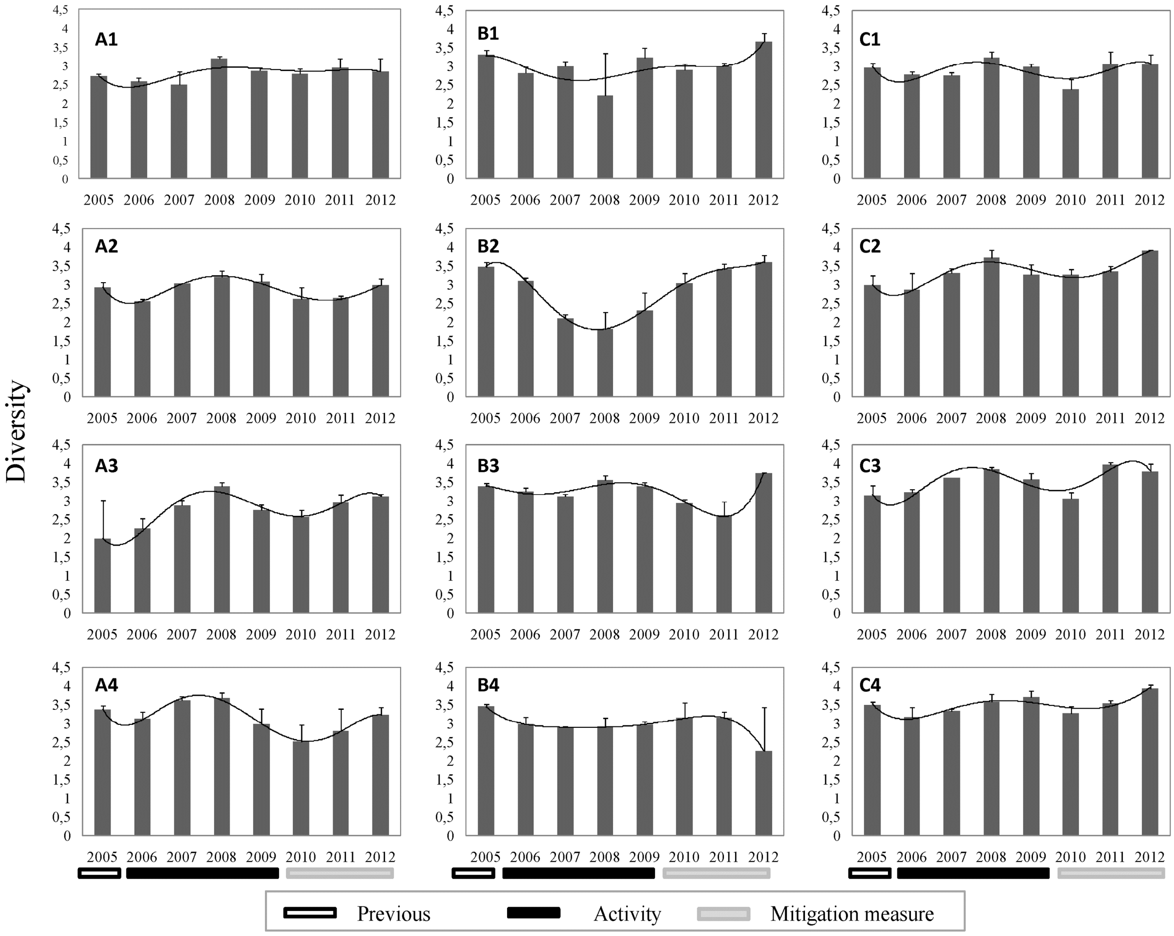
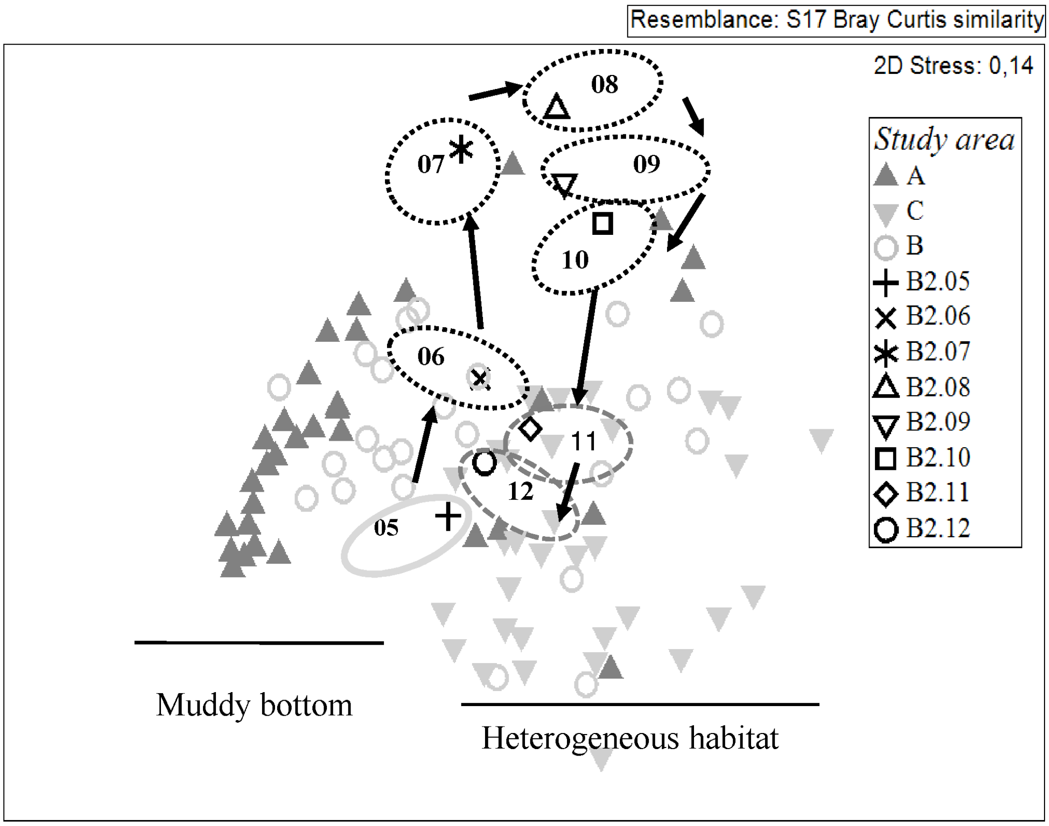
698000 698500 699000 699500 700000 700500 701000 701500 702000 702500 703000
A1 A2 A3 A4
B1 B2 B3 B4
C1 C2 C3 C4
37.5
38.5
39.5
45
44
43
42
41
40
39
38
37
Salinity
Autumn 2008
A
Autumn 2010
B

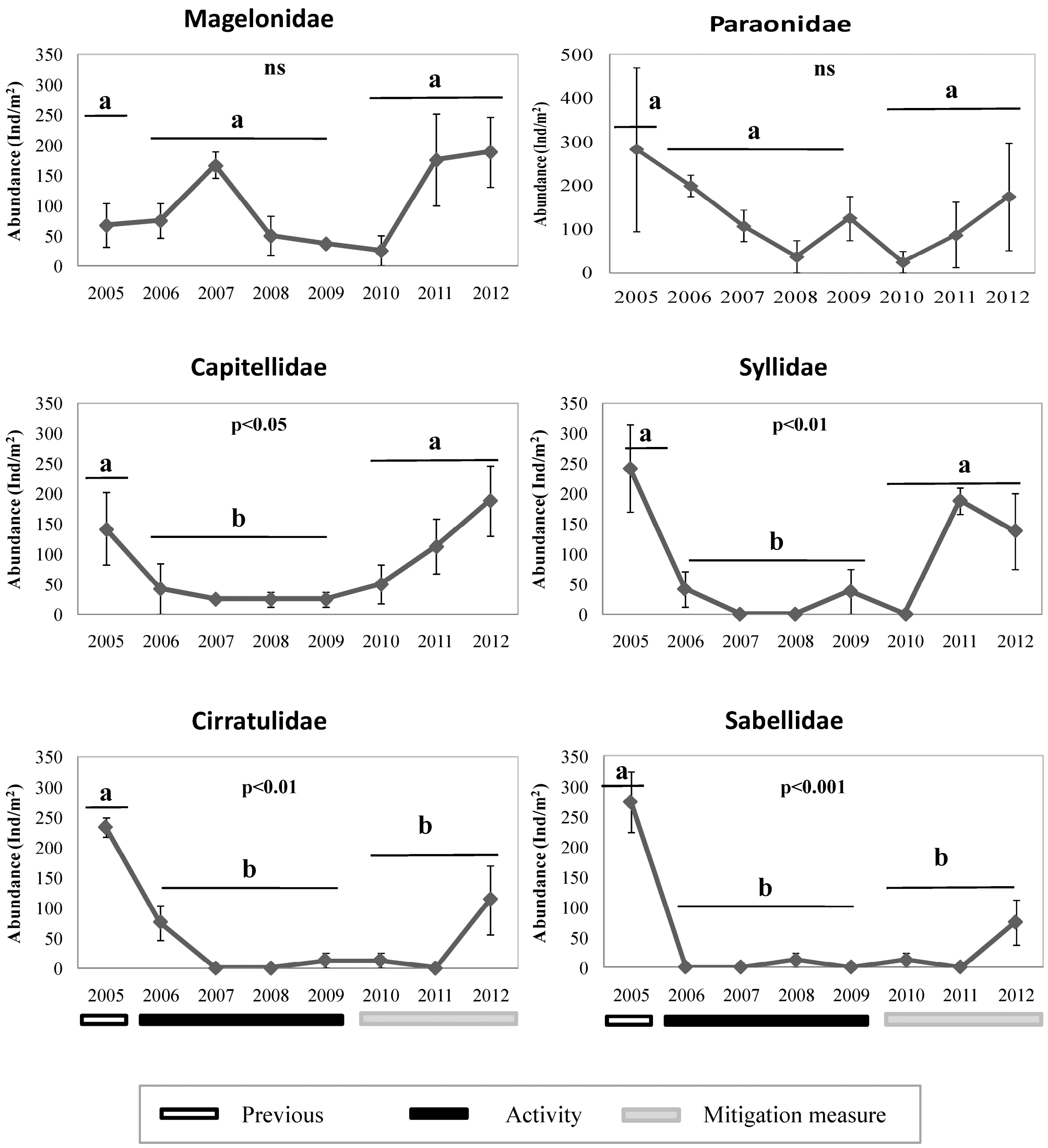

Salinity
35
37
39
41
43
45
47
49
2005
2006
2007
2008
2009
2010
2011
2012
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
C4


Abundance (Ind/m²)
A1
B1
C1
A2
B2
C2
A3
B3
C3
A4
B4
C4
0
1000
2000
3000
4000
5000
6000
2005
2006
2007
2008
2009
2010
2011
2012
Previous
Activity
Mitigation measure


Richness
A1
B1
C1
A2
B2
C2
A3
B3
C3
A4
B4
C4
0
5
10
15
20
25
2005
2006
2007
2008
2009
2010
2011
2012
Previous
Activity
Mitigation measure


Diversity
A1
B1
C1
A2
B2
C2
A3
B3
C3
A4
B4
C4
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
2005
2006
2007
2008
2009
2010
2011
2012
Previous
Activity
Mitigation measure


Resemblance: S17 Bray Curtis similarity
2D Stress: 0,14
Study area
A
C
B
B2.05
B2.06
B2.07
B2.08
B2.09
B2.10
B2.11
B2.12
05
06
07
08
09
10
11
12
Muddy bottom
Heterogeneous habitat


Magelonidae
Abundance (Ind/m²)
0
50
100
150
200
250
300
350
ns
a
a
a
2005
2006
2007
2008
2009
2010
2011
2012
Paraonidae
Abundance (Ind/m²)
0
100
200
300
400
500
ns
a
a
a
Capitellidae
p<0.05
a
b
a
Syllidae
Abundance(Ind/m²)
p<0.01
a
b
a
Cirratulidae
p<0.01
a
b
b
Sabellidae
p<0.001
a
b
b
Previous
Activity
Mitigation measure

Highlights

*Effect of brine discharge on benthic community was investigated.

*A mitigation measure was implemented to reduce the impact of a brine discharge.

* Recovery on polychaete assemblage parameters was detected after its implementation.

* The recovery process seems to be relatively rapid.

*Different recovery rates of polychaete families were detected.

Supplementary data. Summary of the results of SIMPER similarities for muddy and heterogeneous bottoms throughout the sampling periods (2005-2012). (Av. Abund: average abundance, Contrib. %: percentage contribution; Cum. %: cumulative percentage, A.S = average similarity).

Muddy bottom

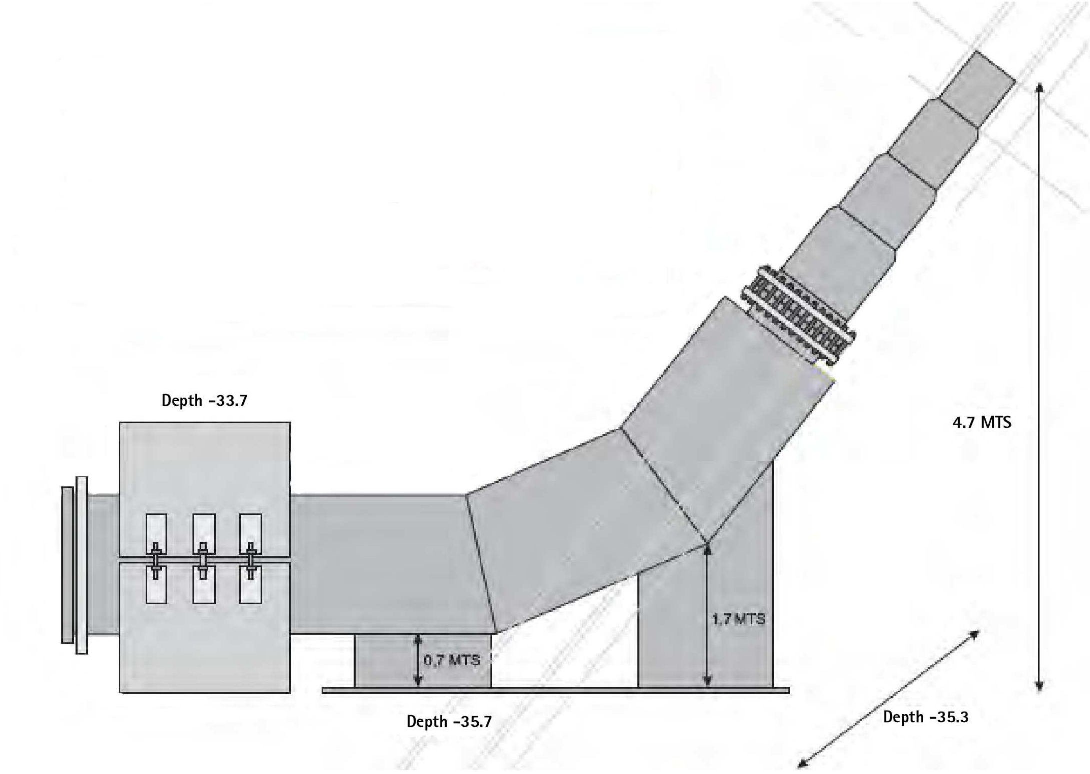
A.S: 57.73%

Families	Av. Abund	Av.Sim	Contrib.%	Cum.%
Paraonidae	671.86	18.53	32.09	32.09
Lumbrineridae	358.18	12.07	20.90	52.99
Magelonidae	261.39	7.93	13.74	66.73
Cirratulidae	175.97	4.07	7.04	73.77
Nephtyidae	110.12	2.85	4.94	78.71
Capitellidae	109.43	2.78	4.81	83.52
Cossuridae	98.44	2.49	4.31	87.84
Paralacydoniidae	69.14	1.64	2.84	90.68

Heterogeneous bottom

A.S: 45.47%

Families	Av. Abund	Av. Sim	Contrib.%	Cum.%
Syllidae	262.77	8.57	18.84	18.84
Lumbrineridae	122.99	4.53	9.95	28.79
Paraonidae	120.65	4.31	9.48	38.27
Onuphidae	116.27	4.08	8.98	47.25
Eunicidae	89.04	3.38	7.44	54.68
Capitellidae	72.58	2.63	5.77	60.46
Cirratulidae	82.65	2.50	5.49	65.95
Nephtyidae	79.14	2.32	5.10	71.05
Sabellidae	109.40	1.99	4.38	75.44
Magelonidae	80.13	1.87	4.12	79.56
Dorvilleidae	53.67	1.32	2.91	82.47
Maldanidae	51.20	1.27	2.78	85.25
Paralacydoniidae	36.04	1.02	2.25	87.49
Nereididae	33.97	0.82	1.80	89.29
Ampharetidae	33.98	0.65	1.44	90.73


Depth -33.7
4.7 MTS
1.7 MTS
0,7 MTS
Depth -35.7
Depth -35.3