Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Note

Bioindicators as metrics for environmental monitoring of desalination plant discharges

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A R T I C L E I N F O

Article history:
Received 24 September 2015
Received in revised form 14 December 2015
Accepted 17 December 2015
Available online xxxx

Keywords:
Desalination
Mediterranean
Brine
Benthos
BOPA index
Echinoderm
Salinity

A B S T R A C T

Development of desalination projects requires simple methodologies and tools for cost-effective and environmentally-sensitive management. Sentinel taxa and biotic indices are easily interpreted in the perspective of environment management. Echinoderms are potential sentinel taxon to gauge the impact produced by brine discharge and the BOPA index is considered an effective tool for monitoring different types of impact. Salinity increase due to desalination brine discharge was evaluated in terms of these two indicators. They reflected the environmental impact and recovery after implementation of a mitigation measure. Echinoderms disappeared at the station closest to the discharge during the years with highest salinity and then recovered their abundance after installation of a diffuser reduced the salinity increase. In the same period, BOPA responded due to the decrease in sensitive amphipods and the increase in tolerant polychaete families when salinities rose. Although salinity changes explained most of the observed variability in both indicators, other abiotic parameters were also significant in explaining this variability.

1. Introduction

During recent years, the desalination industry has expanded in countries suffering from water scarcity, becoming an important method for supplying potable water (Lattemann and Hopner, 2008). Development of desalination projects requires approval by the respective environment protection authorities, since this activity can lead to physicochemical and ecological impacts in the receiving marine environments. Desalination plants produce as waste a concentrated salt solution that can have twice the salinity of the source water (Younos, 2005). The main environmental concern is the impact of this hypersaline concentrate upon the salinity of seawater and its resultant effects on marine communities (Raventós et al., 2006; Sánchez-Lizaso et al., 2008; Roberts et al., 2010, Fernández-Torquemada and Sánchez-Lizaso, 2011, Riera et al., 2012; Garrote-Moreno et al., 2015). The discharged brine remains on the seafloor, because of its high density, and causes mortalities in benthic organisms that are not adapted to high salinities (Del-Pilar-Ruso et al., 2007). Without dilution of effluent, the brine plume may spread out for a long distance over the sea bottom (Einav et al., 2002). Cost-effective and environmentally-sensitive management of this concentrate can be a significant obstacle to implementing desalination (Younos, 2005).

Though benthic communities are one of the indicators most employed in marine environmental assessment (Dauvin, 2007), interpretation of changes in their constituent members can be complicated when the aim is to establish a quantified impact level. The development of simple techniques and tools to detect and evaluate such impact could solve this problem and facilitate interpretation by managing stakeholders. These methodologies should be easily applied and not costly. Among these the use of sentinel taxa could perform a 'warning' role pointing to possible imbalances in the environment due to brine impact (Bellan, 2008). Biotic indices are also useful tools because they reduce complex scientific data to a univariate value that can be easily interpreted from the perspective of environmental management (Chainho et al., 2007).

Among marine sentinel taxa, echinoderms are among the most frequently used organisms in the evaluation of marine pollutant toxicity (Dupont et al., 2010). They are abundant, widely distributed, ecologically important, highly sensitive to various contaminants and with a relatively sedentary lifestyle (Sugni et al., 2007). Moreover, echinoderms are strictly marine species and tolerate a narrow range of salinities, thus being very sensitive to salinity variations produced by brine. Indeed, a significant reduction in their abundance has been observed in water surrounding desalination discharges (Chesher, 1971, Gacia et al., 2007; Fernández-Torquemada et al., 2013). They have therefore been previously considered as potential taxa to indicate impact of brine discharge (Fernández-Torquemada et al., 2013).

Among biotic indices, application of BOPA (Benthic Opportunistic Polychaetes and Amphipods) requires less effort than other indices and is considered an effective tool for monitoring several kinds of impacts. It is based on the principle of antagonism between sensitive and

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http://dx.doi.org/10.1016/j.marpolbul.2015.12.023
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opportunistic species. Amphipods are highly sensitive to contaminated sediments, while opportunistic polychaetes are resistant, indifferent or favoured (Dauvin and Ruellet, 2007, de-la-Ossa-Carretero et al., 2009; Joydas et al., 2011; Ingole et al., 2009, Riera and de-la-Ossa-Carretero, 2014). While amphipods have shown high sensitivity to increased salinity produced by a brine discharge (de-la-Ossa-Carretero et al., 2015), some polychaetes seem not to be affected (Del-Pilar-Ruso et al., 2015).

The main objective of this paper is to evaluate the response of echinoderms and the BOPA index to brine discharge and their utility as indicators for environmental assessment of desalination plants.

2. Material and methods

Efficiency of both indicators was evaluated with data from the environmental monitoring programme at San Pedro desalination plants (SE Spain). These plants began operation in 2006 and discharge their effluent by means of a 5 km pipeline at 33 m depth. Both facilities are operating with a production capacity of 130,000 m^3/day. The raw water intake is around 270,000 m^3/day with a recovery ratio of 47%, producing an effluent flow of 140,000 m^3/day, characterised by its high salinity (around 70).

The brine plume was monitored every three months, measuring the vertical salinity profile with a RBR XR-420 CTD (conductivity, temperature, depth) sensor over a 65-point grid around the outfall. The spatial data was interpolated using the Kriging technique as a gridding method (Fernández-Torquemada et al., 2009) and represented using Surfer v9 software. This discharge caused a salinity increase from 2006 to 2010, reaching levels of 53 close to the outfall. However, in May 2010, a diffuser was installed at the end of the pipeline to discharge the effluent at 60° from horizontal, facilitating mixture with the surrounding seawater. Since then, salinities near the discharge returned to close to natural concentrations, around 37.5 ± 0.5 (Loya-Fernandez et al., 2012; Del-Pilar-Ruso et al., 2015) (Fig. 1).

A benthos survey was performed by establishing three transects perpendicular to the coast: one within the pipeline area (Transect B) and two control transects 2 km to the north and to the south (Transects A and C). Four stations were sampled at each transect (1, 2, 3 and 4) (Fig. 2). Based on brine plume dispersion (Loya-Fernandez et al., 2012; Del-Pilar-Ruso et al., 2015), these benthos stations were classified into three exposure levels: i) exposed: station B2 close to the outfall, ii) influenced: stations B1 and B3 sited < 250 m from outfall, and iii) not exposed: stations sited > 1 km away.

Samples were collected during 18 sampling campaigns from 2005 to 2014. The first campaign consisted of a previous study before desalination plant activity, campaigns 2 to 10 were before installing the diffuser, and 11 to 18 afterwards after installing the diffuser. Four Van Veen grab samples (400 cm^2) were taken at each station. Three samples were sieved through a 0.5 mm screen, and preserved in 10% formalin to study the benthic community, counting total abundance and differentiating total abundance of echinoderms, abundance of amphipods and abundance of opportunistic polychaetes. Based on previously studies, families Capitellidae, Eunicidae, Magelonidae, Nephtydae and Paraonidae were considered as opportunistic Polychaeta in the case of brine discharges (Del-Pilar-Ruso et al., 2009, 2015). Another sample was used to characterise the sediment. Grain size was assessed by standard sieve fractionation (Holme and McIntyre, 1984). Redox potential and pH were measured using a CRISON 507 pH device. Organic content of dry sediment was estimated as the weight loss after ashing. Bottom salinity of each station was obtained by means of a RBR XR-420-CTD logger.

BOPA index was calculated for each sample according to the guidelines of Dauvin and Ruellet (2007): $\text{BOPA} = \log[(fp_{op} / (f_a + 1) + 1]$, where fp_{op} is the opportunistic polychaete proportion of all fauna (0 to 1) and fa is the amphipod proportion of all fauna (0 to 1). The BOPA index ranges from 0, when there are no opportunistic polychaetes, to 0.30103, when there are only opportunistic polychaetes reflecting the most disturbed situation.

Data of echinoderm abundance and BOPA index were analysed using the software package PRIMER 6 (Clarke and Gorley, 2006) with the PERMANOVA add-on (Anderson et al., 2008). Formal tests were done using permutational analysis of variance with 9999 permutations of residuals under a reduced model using the Euclidean distance resemblance matrix of BOPA and echinoderm abundance. Analysis used a design with two fixed factors: exposure level (exposed, influenced, and not exposed) and period (previous, before diffuser installation and after installation).

In order to assess the relationship between physicochemical parameters (granulometry, pH, redox potential, organic matter content and salinity) with echinoderm abundance and BOPA, a multiple linear

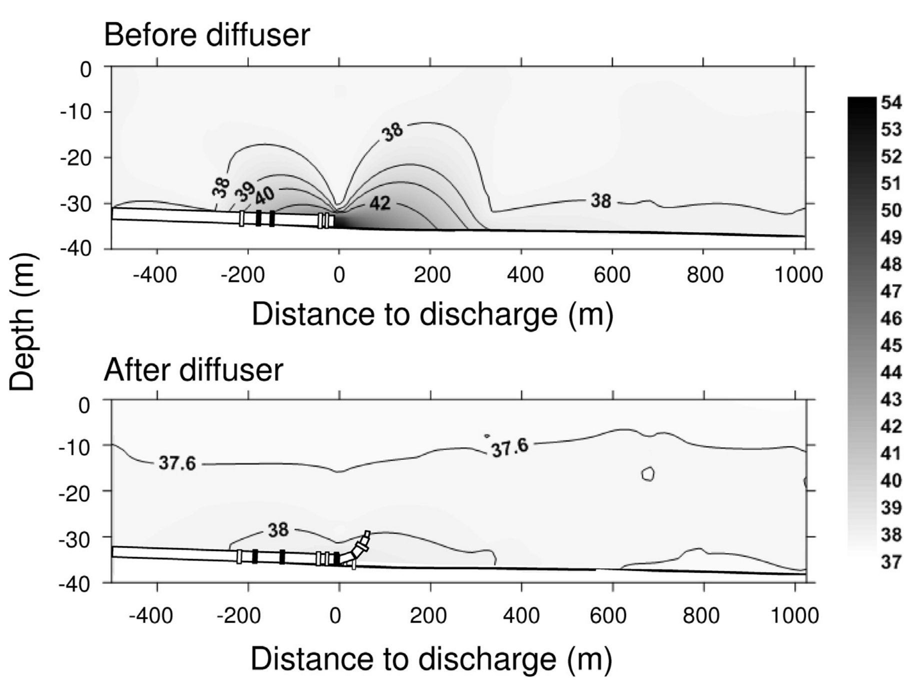

Fig. 1. Salinity profiles before and after diffuser installation including a schematic diagram of the discharge design.