Sustainable desalination: long-term monitoring of brine discharge in the marine environment

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ABSTRACT

The environmental impact of desalination is the most important concern related to its sustainable development. We present the results of a long-term environmental plan to monitor brine discharge (BD) from a desalination plant located in a high environmental value area in Spain. Generalized additive models were used to analyze the biological parameters of biological communities. Results of 17 years of BD monitoring show how its environmental impact can be minimized through well-planned decision-making between scientists and industry. The brine dilution prior to its discharge into an artificial channel of low ecological value significantly reduced the brine

influence area. *P. oceanica* shoot production and echinoderms abundances were relatively stable across historical series and similar values in control and impacts locations were observed. Conversely, there was a higher abundance and species richness of fishes in the BD area. The important findings reported here should be considered for future applications in similar projects.

Keywords: sustainable desalination; environmental monitoring plan; brine discharge; environmental impact; seawater reverse osmosis

1. Introduction

Given the increased global demand for freshwater, desalination technology has become a feasible alternative to standard freshwater procurement methods and may help to address global water scarcity. Population growth and economic development are the key drivers of global water scarcity, but climate change is also likely to alter hydro-climatic conditions and thereby increase water scarcity (Hejazi et al., 2014; Hoekstra, 2014; Sun et al., 2019). In the last decade, the number of desalination projects has substantially increased in all major regions worldwide; however, the majority of freshwater production primarily takes place on the Mediterranean coast, Arabian Gulf, and around the Red Sea (Jones et al., 2019). In Spain, the Mediterranean peninsular coast and Balearic and Canary Islands are areas of high water stress mainly due to tourism, population growth, and intensive agriculture; in these areas, the desalination industry plays an important role in mitigating water scarcity (Hernández-Sánchez et al., 2017; Sadhwani Alonso and Melián-Martel, 2018).

Currently, reverse osmosis (RO) is the most commonly used technology in desalinated water production due to its efficiency and lower economic costs relative to those of other technologies (Jones et al., 2019; Mezher et al., 2011; Zarzo and Prats, 2018). The RO process produces a brine discharge (BD) that is commonly discharged into seawater (Missimer and Maliva, 2018). BDs are mainly characterized by a high salinity concentration that can double seawater salinity

depending on the intake water salinity and recovery rate of the RO process (Abessi, 2018; Fernández-Torquemada et al., 2019; Mezher et al., 2011). When released into seawater, BDs form a high-density plume that follows the bottom bathymetry. Saline plume dispersion varies significantly depending on effluent characteristics, such as desalination plant production, and BD disposal method (Fernández-torquemada et al., 2019; Fernández-Torquemada et al., 2009; Loya-Fernández et al., 2018; Petersen et al., 2019; Portillo et al., 2014a). In addition, BDs may contain the chemicals that are commonly used in desalination during pre-treatment and in the membrane and filter cleaning processes; these may include antiscalants, coagulants, antifouling agents, biocides, and antifoaming agents, which are all subsequently discharged with the BD (Lattemann and Höpner, 2008; Liu et al., 2013; Mezher et al., 2011; Portillo et al., 2014b). The characteristics of BDs may therefore have environmental impacts on the marine environment when they are improperly managed (Fernández-Torquemada et al., 2019; Kress, 2019; Petersen et al., 2018; Sharifinia et al., 2019).

BDs may produce on marine environment a reduction of abundance and diversity of benthic communities in which BDs become situated (De-la-Ossa-Carretero et al., 2016c; Del-Pilar-Ruso et al., 2009, 2008; Petersen et al., 2018). They may have a potential effect particularly on organisms most sensitive to salinity increases such as echinoderms (Fernández-Torquemada et al., 2013) or seagrasses (Cambridge et al., 2017; Garrote-Moreno et al., 2014; Marín-Guirao et al., 2013; Sánchez-Lizaso et al., 2008; Sola et al., 2020). They may also be used as bioindicators to prevent the environmental impacts from BDs (De-la-Ossa-Carretero et al., 2016b; Fernández-Torquemada et al., 2013). Recent studies show that BDs may also have negative effects on the bacterial activity of benthic bottoms, zooplankton and fish larvae (Frank et al., 2019, 2017; Petersen et al., 2018). When impacts on the marine environment are observed it is usually due to a low dilution of the BD and they may be reverted increasing the BD dilution with diffusers of with seawater by-passing (Belatoui et al., 2017; De-la-Ossa-Carretero et al., 2016c; Del-Pilar-Ruso et al., 2015; Fernández-Torquemada et al., 2013).

In addition, the impingement and entrainment of seawater through submerged pipelines or open intakes on the shoreline potentially affects fish eggs and small marine organisms such as plankton and larvae, which are removed from the seawater during the desalination process due to their small size and lack of (or limited) swimming ability (Missimer and Maliva, 2018; Petersen et al., 2018; Sharifinia et al., 2019). Likewise, these seawater intake systems collect organic matter, nutrients, and microorganisms that require the use of aggressive pre-treatments as additional chemical additives, and higher filter and membrane cleaning frequencies, the products of which are subsequently discharged with the BD (Fernández-Torquemada et al., 2019).

Given that the collective characteristics of desalination effluents can produce negative effects on marine ecosystems if proper mitigation measures are not applied (De-la-Ossa-Carretero et al., 2016b; Del-Pilar-Ruso et al., 2015; Fernández-Torquemada et al., 2013), Environmental Monitoring Plans (EMPs) are typically established to monitor the effectiveness of mitigation measures and ensure the sustainable operation of desalination technology without environmental impacts from BDs (De-la-Ossa-Carretero et al., 2016b; Petersen et al., 2019; Sadhwani Alonso and Melián-Martel, 2018; Sola et al., 2019b). Indeed, environmental impact is the most important concern for the sustainable development of desalination (Ibrahim et al., 2018). The uncertainty in various countries surrounding the environmental impact of desalination may represent a barrier for desalinated water production (Sola et al., 2019a).

With the aim of allaying this uncertainty, our study presents 17 years of data from an EMP designed to monitor the brine effluent from Javea SWRO plant in Spain. Here, we evaluate the measures adopted during the development of a project in which industry and environmental science collaborated to effectively achieve a long-term sustainable operation with low impact on the surrounding marine environment.

2. Material and methods

2.1 Case study of Javea SWRO plant

The Javea SWRO plant, which began operations in June 2002, is located on the Spanish Mediterranean coast in an area of high environmental value due mainly to the presence of *Posidonia oceanica* seagrass meadows (Fig. 1); the area is protected by habitat Directive 92/43/CEE (EU, 1992) and national regulations (Spanish Government, 1986).

Fig. 1. The location of the Javea SWRO (Sea Water Reverse Osmosis) plant and sampling study areas for monitoring biological communities. Shown are the Gorgos river (the previous location of the brine discharge), Fontana Channel (current brine discharge location established through recommendations), and *Posidonia oceanica* seagrass meadow distribution.

The Javea SWRO plant has four lines that can produce 6720 m³ of freshwater per day; thus, its maximum freshwater production capacity is 26800 m³ per day with a recovery rate of 44.8%. However, its production varies seasonally, with more lines used in summer (2-4) than in winter (0-1).

During the construction phase of the plant, a preliminary study of possible initiatives to minimize the environmental effects from BD was carried out (Malfeito et al., 2005). In the initial plan, the Gorgos River, close to where the plant is located, was targeted as the BD disposal site (Fig. 1).

However, due to the presence of *P. oceanica* meadows close to the river (within 80 m), an alternative disposal location was recommended: an artificial channel called the “Fontana Channel,” which is 700 m long, 20 m wide, about 1 m deep, previously anoxic, and discharges close to a tourist beach (Fig. 1). Since conditions in the channel are not favorable for the dilution of the brine, it was proposed that the brine effluent was diluted 4:1 with seawater to achieve a salinity below 44 psu and that the discharge took place through 16 horizontal diffusers to increase dilution in the Fontana Channel (Malfeito et al., 2005; Sola et al., 2020).

At the Javea SWRO plant, seawater is taken in through 10 deep beach wells at a depth of 200 m; this eliminates the impingement and entrainment of marine organisms and reduces the levels of organic matter in the water, thereby negating the use of aggressive pre-treatments and further chemical additives (Fernández-torquemada et al., 2019; Mezher et al., 2011).

An EMP was established for monitoring the brine plume behavior in the marine environment and biological communities were used as bioindicators to identify potential environmental changes induced by the brine effluent (Sánchez Lizaso et al., 2004, Sola et al., 2020).

2.2 Sampling

The dispersion of saline plumes was monitored 2-4 times per year. Vertical profiles of salinities were completed in a grid of approximately 30 equidistant stations, ranged between 1 m and 7 m depth, distributed in the area of the BD with a CTD. From 2008, the brine effluent composition was monitored monthly after the RO process in the SWRO plant and after dilution with seawater in the diffuser discharge.

Monitoring of *P. oceanica* meadows was carried out annually at three sampling locations: two control locations and one location near the discharge area (Fig. 1) (Underwood, 1994). As shown in Fig. 1, the control locations are separated but both are approximately 2 km from the BD area, ensuring that the seagrass in these locations is sufficiently similar and unaffected by impacts other than the operation of the SWRO plant. Within each location, three stations were established at 3, 7, and 15 m depths with four permanent parcels. At each permanent parcel, four 40 x 40 cm

squares were established within which all the shoots of *P. oceanica* were marked to evaluate population dynamics. Marked shoots were monitored annually to estimate shoot recruitment and mortality rates.

Echinoderms are extremely sensitive to changes in seawater salinity and consequently have previously been used as bioindicators for the impacts of desalination (De-la-Ossa-Carretero et al., 2016b; Fernández-Torquemada et al., 2013). In the present study, echinoderms were monitored using the same procedure applied for *P. oceanica*, i.e., establishing two control locations and one impact location but at a 3 m depth (Fig. 1). Within each location, two stations were established: one on the rocky bottom and the other in the *P. oceanica* meadow, where 10 quadrats of 1 m² were sampled and the echinoderms within the quadrats were identified and counted.

Fish communities were monitored using underwater visual census method. This technique is ideally suited to monitoring the abundance of fish as it allows for the collection of community level data without the disturbance inherent in other more destructive sampling techniques (Harmelin-Vivien et al., 1985; Sale and Douglas, 1981). For fish monitoring, a control location and an impact location were established, and two stations were established within each location (Fig. 1). At each station, the abundance and size (total length in classes of 2 cm) of each fish species was recorded by a SCUBA diver within four random replications of areas 25 m long and 5 m wide were sampled; thus, 16 samples/replicates of 125 m² were obtained per year. The surveys were done always in the same season (summer) to reduce the natural variance between replicates thus providing better evidence of spatial patterns of distribution. The warm season is the most suitable period for visual counts in the Mediterranean, as fish communities are more diverse and stable during this period (Harmelin, 1987).

2.3 Statistical analysis and spatial representation

The salinity data obtained from each sampling survey were analyzed using the kriging spatial interpolation technique to obtain a real representation of the saline plume in the space. In the

kriging method, the sampled data points are used to estimate salinity values over a continuous spatial area. The applied model is based on the work of Fernández-Torquemada et al. (2009). The spatial representation and model cross-validation were conducted using the Geostatistical Analyst extension in ArcGIS© v.9.0 software (Johnston et al., 2001)

In addition, generalized additive models (GAMs) were used to analyze the trends in biological parameters (e.g., the abundance or density of individuals) as smooth splines of time between the control and impact locations. GAMs can estimate non-linear trends in many ecological processes (e.g. the annual natural fluctuations of populations themselves) and are used to identify whether significant temporal changes, such as the effects of an impact during a particular period, have occurred (Fisher et al., 2018; Simpson, 2018). GAM analysis was conducted using the “mgcv” package in R (R Core Team, 2017). The degrees of freedom and the amount of smoothness for each spline regression were determined internally during the model fitting for each variable analyzed (Wood and Scheipl, 2016). However, smoothing regression was not applied to functions for which linear patterns were detected with the variable analyzed.

3. Results

3.1 Plant production and brine characteristics

The total freshwater produced at the Javea SWRO plant between 2002 and 2019 was 57.3 Hm³, which represented a total volume of approximately 70 Hm³ BD discharged into the marine environment (Fig. 2). The maximum freshwater production, produced between 2014 and 2016, was 26.5% of the total freshwater and brine produced. These results suggest that the demand for desalinated water slightly increased in the last decade.

Fig. 2. Annual production of freshwater and brine discharge by the Javea SWRO (Sea Water Reverse Osmosis) plant between 2002 and 2019.

The average energy consumption of the SWRO plant was 4.6 Kw/m³ and the energy consumed by the brine dilution process represented approximately 2.2% of the total energy consumed by the SWRO plant.

From 2008 to 2019, the salinity of the brine was on average 68.2 ± 4.4 psu, with slight annual variability shown during certain years (Fig. 3). Seawater by-passing produced a significant reduction in the salinity of the brine before its discharge (an average of 42.4 ± 2.9 psu after the dilution process).

Fig. 3. Average annual salinity values of brine discharge after the SWRO (Sea Water Reverse Osmosis) process and after dilution with seawater from 2008 to 2019. Error bars indicate standard deviation (SD).

The average salinity values of BD were constant throughout the year with a monthly average of 68 psu (Fig. 4). However, the salinity of diluted BD slightly increased during the summer due to lower rainfall in this season.

Fig. 4. Average monthly salinity values of brine discharge after SWRO (Sea Water Reverse Osmosis) process and after dilution with seawater from 2008 to 2019. Error bars indicate standard deviation (SD).

The temperature of the BD was relatively constant throughout the year (average monthly temperature: 20.1 ± 1.1 °C) because the seawater was taken in through beach wells. After its dilution with superficial seawater, the temperature of BD approached the natural conditions in the area, with maximum values in the summer and minimum values in the winter (Fig. 5).

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219 **Fig. 5.** Monthly temperature values of brine discharge after SWRO (Sea Water Reverse Osmosis)
 220 process and after dilution with seawater from 2008 to 2019. Error bars indicate standard deviation
 221 (SD).

222 The BD in the Fontana Channel increased the water renewal and oxygen content of the channel,
 223 which was previously anoxic (Fig. 6).

Fig. 6. Average dissolved oxygen values at the bottom and surface of the Fontana Channel and open sea in 2004. Error bars indicate standard deviation (SD).

3.2 Salinity plume

Fig. 7 shows the dispersion of the plume in a selection of surveys in contrasting environmental conditions. Results show that the behavior of the plume salinity from the Javea brine effluent was similar across the 17 years of monitoring. In addition, the salinity in the Fontana Channel was <44 psu, indicating that the BD has been effectively diluted by seawater by-passing. The salinity on the surface water was rapidly diluted. The bottom salinity had a spatial distribution related to the bathymetry within the discharge area.

The saline plume also showed strong seasonal behavior. For example, during summer, the saline plume area could extend to a distance of about 300 m from the channel outfall (Fig. 7: A.2 to D.2). The highest salinity values on the bottom, 38-43 psu, were observed around the channel outfall. During winter, when there was lower freshwater production, the saline plume's area of influence was substantially reduced (Fig. 7: A.1 to D.1).

Fig. 7. Spatial representation of the saline plume on the water bottom around the Fontana Channel outfall area. Data were obtained during winter in 2003 (A.1), 2008 (B.1), 2013 (C.1), and 2018 (D.1), and during summer in 2003 (A.2), 2008 (B.2), 2013 (C.2), and 2018 (D.2).

3.3 Monitoring of biological communities

Results showed similar temporal trends of *P. oceanica* meadows in the control and impact locations, with annual oscillations but a stable pattern from 2003 to 2019. From 2003 to 2007, in the locations closest to the coast (3 m), there was a temporal trend for higher shoot production rates in the meadows located in the impact area relative to those in the control area (Fig. 8). However, from 2008 onwards, shoot production values were similar in the control and impact areas, with a balance between recruitment and mortality that was close to zero over the historical series.

At the deeper stations (7 and 15 m), there were no major differences in shoot production rates between the control and impact locations. In general, annual fluctuations in shoot production were observed at both the control and impact stations; however, the locations within the 7 m station showed slightly higher rates in the impact area than in the control stations, which had values close to zero. At the 15 m depth, from 2003 to 2005, lower shoot production rates were observed in the meadows located in the impact area; however, from 2006 onwards, the shoot production in this area was very similar to that at the control stations.

Fig. 8. Temporal trends in *P. oceanica* shoot production at the three stations analyzed (3, 7, and 15 m depth). Fitted lines from generalized additive models are presented with 95% confidence intervals. The total percentage of deviance explained by the models is presented in the legend with its significance level (*p-value <0.05; ** p-value <0.01; *** p-value <0.001).

BD apparently had no effect on echinoderms from 2003 to 2019 (Fig. 9); indeed, echinoderm abundance was relatively stable across the historical series. In the *P. oceanica* meadows, there was a higher abundance of echinoderms at the impact location than at the control locations, but all *P. oceanica* locations showed high fluctuations in echinoderm abundance during the historical series. In contrast, there was a higher average abundance of echinoderms in one of the control areas at the rocky bottoms, but all rocky bottom locations showed relatively stable abundances over the historical series.

Fig. 9. Temporal trends in echinoderm abundance at three locations analyzed at both the *P. oceanica* meadows and rocky bottoms. Fitted lines from generalized additive models are presented with 95% confidence intervals. The total percentage of deviance explained by the models is presented in the legend with its significance level (*p-value <0.05; ** p-value <0.01; *** p-value <0.001).

From 2003 to 2019, there was a higher abundance of fish at the impact location than at the control location (Fig. 10). However, results showed a substantial decrease in average fish abundance within the impact area from 2012. A similar negative trend was also observed within the control location, although both locations showed a slight increase in fish abundance from 2017.

Fig. 10. Temporal trends in fish abundance at the two locations. Fitted lines from generalized additive models are presented with 95% confidence intervals. The total percentage of deviance explained by the models is presented in the legend with its significance level (** p-value <0.01).

In addition, from 2003 to 2019, there was a higher number of fish species present in the impact area relative to the control area (Fig. 11). Although the number of fish species within the impact area fluctuated annually, the values remained around the initial monitoring value recorded in 2003.

Fig. 11. Temporal trends in fish species in the two locations. Fitted lines from generalized additive models are presented with 95% confidence intervals. The total percentage of deviance explained by the models is presented in the legend with its significance level.

4. Discussion

Data from long-term monitoring shows that the collaboration between industry and environmental science has ensured the sustainable operation of the Javea SWRO desalination plant (Sola et al., 2020). This study confirms that desalination could be a “win-win solution” to combating water scarcity with no apparent long-term impact on the marine environment, as has been previously been proposed by Pistocchi et al. (2020).

Seawater intake through beach wells prevents the impingement and entrainment of small marine organisms with limited swimming abilities that typically occurs in open seawater intakes (Missimer and Maliva, 2018; Petersen et al., 2018; Sharifinia et al., 2019). Moreover, beach wells provide feed water with more consistent and homogeneous physical and chemical characteristics

and smaller amounts of organic matter and nutrients, i.e., seawater of better quality, than open intakes, which reduces the need for chemical additives and aggressive pre-treatments (Fernández-Torquemada et al., 2019). In the present study, the homogenous characteristics of feed water are reflected in the low annual temperature oscillation of BD prior to its dilution with sea water.

In the present study, changing the discharge location to the previously anoxic Fontana Channel using seawater by-passing to dilute the brine and applying diffusers, all combined, ensured rapid effluent dilution and conservation of protected habitats (Fernández-Torquemada et al., 2004). The diluted BD from the Javea SWRO plant was shown to have an average salinity of <44 psu and the rapid dilution of effluent reduced the area affected by the salinity plume to ≤ 300 m from the mouth channel. This dilution is much faster than that observed in other desalinations plants where the salinity plumes have reached several kilometers from the discharge point (Fernández-Torquemada et al., 2009; De-la-Ossa-Carretero et al., 2016c) thereby impacting benthic communities (De-la-Ossa-Carretero et al., 2016c; Del-Pilar-Ruso et al., 2015; Kress, 2019; Petersen et al., 2018). However, fast dilution of brine has also been observed in other plants with higher production capacities than Javea SWRO plant that use seawater by-passing (Fernández-Torquemada et al., 2009; 2013; Zarzo et al., 2009), mix the effluent with cooling water from a power plant (Petersen et al., 2019), or use different types of diffusers (Portillo et al., 2013; Loya et al., 2018; Belatoui et al., 2017). Furthermore, the BD from the Javea SWRO plant improved the environmental conditions in the previously anoxic artificial channel; it increased water circulation and promoted the recovery of faunal communities within the channel (Malfeito et al., 2005). The dilution system of the Javea SWRO plant also has a low energy consumption (<3% of the plant's total energy consumption). These energy costs can be assumed by the plant and they address the environmental issues related to BD. However, this energy consumption could be reduced with the development of SWRO plants that utilize renewable energies (Shahzad et al., 2017).

Long-term monitoring showed no apparent effect of BD on biological communities, which was likely due to the rapid dilution of the effluent. Several studies have reported the widespread

regression of *P. oceanica* meadows over recent decades due to the cumulative effects of various natural and anthropogenic disturbances (Guillen et al., 2012; de los Santos et al., 2020). However, *P. oceanica* meadows are stable at the Javea SWRO plant, both in the area close to the discharge and in control meadows. Moreover, higher abundances of echinoderms observed close to the discharge also indicate the positive effects of rapid effluent dilution: echinoderms are sensitive to salinity changes and have previously been used as sentinel species for desalination impacts on benthic communities (De-la-Ossa-Carretero et al., 2016b; Fernández-Torquemada et al., 2013).

A higher abundance fish and more species were observed in the impact area relative to the control area. We cannot determine whether the effluent attracts some fish species or whether there is higher habitat diversity in the discharge area because we have no similar data from before the plant began operating. However, Kelaher et al. (2020) recently reported an increase in local fish abundance and species richness related with the BD of a SWRO plant in Australia. In the present study, we also identified a decrease in fish abundance in both study areas from 2012 that could not be attributed to the discharge. Instead, this decrease may be due to other factors such as local fishing activity since the area has become popular for recreational and artisanal fishing of target species since the oxygen levels in the channel improved.

Taken together, the results of this study highlight the benefits of a well-defined, long-term EMP for monitoring the effects of BD on the marine environment and for discriminating the effects of other local impacts that may overlap in the BD area (Sola et al., 2019b). Other studies have demonstrated how science-based EMPs enable discrimination between the effects of BD and other impacts such as sewage discharges and aquaculture (De-la-Ossa-Carretero et al., 2016a; Del-Pilar-Ruso et al., 2009).

The long-term monitoring reported here shows that it is possible to achieve the sustainable management of a SWRO plant through an adequate environmental assessment process (Sola et al., 2020). Indeed, long-term EMPs are essential for understanding the behavior and potential negative impacts of BD in marine environment and ecosystems (Petersen et al., 2018). Our results, which represent the longest historical series of BD monitoring published to date, provide robust

evidence to support future desalination projects and reduce their impact on the environment. However, the current lack of long-term studies highlights the need for more comprehensive research in this field (Clark et al., 2018; De-la-Ossa-Carretero et al., 2016b; Del-Pilar-Ruso et al., 2015; Fernández-Torquemada et al., 2013; Kress et al., 2020). Nevertheless, the present research provides a model example of a sustainable SWRO plant that can act as a reference as the use of RO technology to produce freshwater increases globally (Jones et al., 2019; Shahzad et al., 2017). Finally, based on the findings of this long-term monitoring project, we make the following recommendations for addressing the environmental effects of BD: (1) a rigorous environmental assessment process must determine the best location to discharge the effluent and the best possible mitigation measures; (2) both engineers and environmental scientists must collaborate during the environmental assessment processes in order to adapt the project to the local characteristics and mitigate the impact of effluents; (3) wherever possible, the brine should be diluted prior to its discharge into the sea (although seawater by-passing may slightly increase the plant's energy consumption, the use of diffusers or mixing with cooling water is also effective (Loya-Fernández et al., 2018; Portillo et al., 2013)); and (4) a long-term EMP should be designed and implemented to ensure that the measures adopted during the environmental assessment process are carried out correctly, that the sustainable operation of the SWRO plant is guaranteed, that the environmental impacts caused by BD are either eliminated or that mitigation measures are adopted if negative impacts on the marine environment are detected, and finally that it is possible to discriminate between the effects of BD and those other impacts that may overlap in the discharge area (Underwood, 1994).

5. Conclusions

According to this research, it is possible to achieve the long-term sustainable operation of a SWRO plant through well-planned and executed collaborative decision-making between scientist and industry. With an adequate environmental assessment process that includes analysis of

feasible alternatives for seawater intake and brine effluent disposal, the environmental impacts of desalination activities on marine ecosystems can be minimized. Moreover, with a science-based monitoring system, negative impacts on the environment can be eliminated or detected and dealt with swiftly. The Javea SWRO plant can act as an example for future SWRO plants, which will produce freshwater without substantially impacting the marine environment.

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7. Author statement

IS and JS contributed conception and design of the study; YF, AF, CV and IS processed the field data; IS presented and analyzed the field data; YF, AF, CV, YP, JG and IS contributed to the field sampling surveys of environmental management plans; IS wrote the first draft of the manuscript; IS and JS wrote sections of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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