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Evaluating Environmental Requirements for the Management of Brine Discharges in Spain

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Abstract:

Desalination activities may have a detrimental impact on the marine environment, caused mainly by hypersaline effluents. The aim of this paper is to assess the quality of Environmental Monitoring Plans (EMPs) of desalination plants in Spain, and the aspects which could be improved to correctly manage brine discharges. A total of 30 desalination projects submitted to Environmental Impact Assessment (EIA) between 1998 and 2009 have been reviewed. Requirements for the monitoring of brine discharges, and their sampling designs, in the EMPs have improved over time. However, this trend is similar for essential and irrelevant descriptors. Furthermore, the presence of protected species in the area of brine discharges showed a significant increase of requirements. Nevertheless, there was no increase of requirements with respect to a major brine discharge production plant. In conclusion, a review of the EIAs would be advisable to unify the monitoring requirements at the national level, and improving their sampling designs, including the essential descriptors when they are absent, and eliminating irrelevant descriptors when they are present. This standardization should be paid attention to desalination plants with higher brine production as they may have a greater influence on the marine environment.

Keywords

Environmental management plan; Environmental impact; Environmental requirements; Seawater desalination; Brine discharge

1. INTRODUCTION

Ever-increasing demands for freshwater resources in the face of ongoing water scarcity is expected for the foreseeable future, and at a global level [1]. There are different factors impacting upon these increasing water demands, but population and economic growth of the main contributing factors, although others such as climate change are highly likely to have a significant impact also [2,3]. This situation highlights the vitally important role of the desalination industry as an alternative supply method of freshwater in a global water stress context [1,4]. Thus, a substantial increase of desalinated water production is expected, mainly dominated by reverse osmosis (RO) technology [2]. RO technology is the most widely used method due to its lower energy consumption and greater efficiency compared to other technologies [5,6]. In Spain, RO plants provide a significant supply of freshwater due to the negative balance of water resources, specifically in certain Mediterranean coastal regions, such as in the southeast of Spain [7]. Moreover, this water scarcity is exacerbated by the demands of intensive agriculture and tourism [8].

RO desalination plants produce hypersaline discharges which usually are discharged into the sea given their coastal proximity and thus lower economic cost [5]. Brine discharges have a higher density than seawater, so they form a saline plume that tends to follow the bathymetry of the seabed [9]. Furthermore, they may also contain chemical elements due to the use of anti-scalants and coagulants used in the pre-treatment and membrane cleaning treatments, although most of them are effectively consumed by the process. Consequently, it may intensify the toxicity of the brine discharge, and it would thus induce a localized eutrophication and turbidity of the sea water [10–12]. These characteristics of brine discharges impact upon their dispersion mechanisms, which can in turn affect benthic communities such as seagrasses (*Posidonia oceanica* and *Cymodocea nodosa*), or benthic fauna [12–16]. Likewise, recent studies highlight both the short- and long-term impact upon the bacterial activity of benthic bottoms and also the possible impact upon fish larvae [12,17,18].

An Environmental Impact Assessment (EIA) is usually established within the scope of environmental laws as a tool to prevent or correct the environmental impact of a project development or infrastructure, including desalination facilities. EIA is a process includes a set of studies and administrative procedures to analyze the preventive, corrective and monitoring measures of the environmental impact [8].

As part of the EIA process, Environmental Monitoring Plans (EMPs) are established in order to mitigate the impacts of brine discharges upon the marine environment. EMPs are applied to ensure the effectiveness of preventive and corrective measures established in the EIAs [19]. EMPs can identify marine environmental impacts of brine discharges, and mitigate them when they are identified [14,16,20].

In the Spanish case, EIA process is regulated by European regulations outlined in Directive 85/337/EEC [21]. This law was supplemented and modified by various subsequent laws, and currently the process is regulated and complemented by Directive 2014/52/EU [22]. Moreover, the EIA process is regulated by Spanish laws that transposed the Directive 85/337/EEC [21] by the Royal Decree 1302/86 [23] and were developed by the Royal Decree 1131/88 [24]. Currently, the laws developed subsequently have been transposed into a single regulation, stipulated by the law 21/2013 [25]. Finally, Autonomous Communities are empowered to adopt their own procedures for the development of EIAs [8,19,26].

Projects subject to the EIA process are those activities that are in the list of Annex I, or Annex II and the environmental authority has decided submit the project to the EIA process [25]. In the case of desalination projects with new (or extension production capacities larger than 3000 m3/day), they are required to be submitted to the EIA (as specified in Annex II) given that they belong to Group 8, Section E: Water Engineering and Management Projects [8].

The aim of this paper is to assess the quality of EMPs of desalination plants in Spain, and the aspects to be improved to correctly manage brine discharges under defined scientific criteria. This study includes: i) an analysis of the number of projects and production capacity of EIAs evaluated; ii) evolution of environmental requirements over time; iii) analysis of environmental requirements in areas with the presence of protected species; v) influence of brine discharge production on EMPs; and, vi) identification of irrelevant parameters for the monitoring of brine discharges.

2. MATERIALS AND METHODS

An exhaustive analysis of the EMPs defined in the EIAs for the construction of desalination plants in Spain, between 1998 and 2018, has been carried out in this study. EIAs published in the Official State Gazette (*Boletin Oficial del Estado*), and one brine discharge authorization, were analyzed. A total of 30 desalination projects with specific EMPs for the marine environment were evaluated (see Table 1), all of them using RO technology. Desalination projects evaluated are distributed mainly along the Mediterranean coast and among the Canary Islands. Figure 1 shows the maximum freshwater production of projects evaluated and their associated distribution.

Table 1. Desalination projects submitted to the EIA and published in the Official State Gazette. *Discharge authorization obtained from *Dirección General de Calidad Ambiental de la Conserjería de Territorio y Vivienda de la Comunidad Valenciana*.

ID	Desalination projects submitted to EIA published in official Spanish Gazzete	Date	Production (m^3/day)
1	Seawater desalination plant at *Nuevo canal de Cartagena (Murcia)*	17/12/1999	65000
2	Seawater desalination plant at *Carboneras (Almería)*	17/12/1999	120000
3	Seawater desalination plant *2nd phase Telde (Las Palmas de Gran Canaria)*	16/01/2004	16000
4	Seawater desalination plant at *Campo Cartagena (Murcia)*	03/02/2004	160000
5	Seawater desalination plant *2nd phase Mar de Guía (Las Palmas de Gran Canaria)*	21/04/2004	5000
6	Seawater desalination plant at *Barcelona*	06/06/2005	200000
7	Seawater desalination plant at *Canal de Alicante*	07/06/2005	50000
8	Extension of seawater desalination plant at *Tordera (Girona)*	07/06/2005	28800
9	Seawater desalination plant at *Alcudia (Majorca)*	23/06/2005	14000
10	Seawater desalination plant at *Ciutadella (Minorca)*	23/06/2005	10000
11	Seawater desalination plant at *Santa Eulalia (Ibiza)*	23/06/2005	10000
12	Seawater desalination plant at *Andratx (Majorca)*	23/06/2005	14000
13	New seawater desalination plant at *Nuevo Canal de Cartagena (Murcia)*	17/10/2005	65000
14	Extension of seawater desalination plant at *Canal de Alicante*	18/10/2005	15000
15	Seawater desalination plant at *Tajo-Segura (Alicante)*	13/03/2006	180000
16	New seawater desalination plant at *Bajo Almanzora (Almería)*	24/03/2006	60000
17	New seawater desalination plant at *Águilas-Guadalentín.* Extension of Á*guilas (Murcia)*	21/04/2006	180000
18	Extension of brackish water desalination plant at *El Mojón (Murcia)*	08/05/2006	10000
19	Seawater desalination plant at *Campo de Dalías (Almería)*	22/06/2006	97200

20	Seawater desalination plant at *Sagunto (Valencia)*	05/09/2006	22900
21	Seawater desalination plant at *Marina Alta (Dénia, Alicante)*	12/09/2006	24000
22	Extension of seawater desalination plant at *Ceuta*	16/02/2007	8800
23	Seawater desalination plant at *Marina Baja (Alicante)*	05/03/2007	80000
24	Seawater desalination plant at *Jávea (Alicante)**	06/03/2007	28000
25	Seawater desalination plant at *Oropesa del Mar (Castellón)*	08/06/2007	65000
26	Seawater desalination plant at *Moncófar (Castellón).*	31/10/2007	65000
27	Seawater desalination plant at *Guía de Isora (Tenerife)*	27/12/2007	14000
28	Seawater desalination plant at *Costa del Sol (Málaga)*	25/01/2008	50000
29	Seawater desalination plant at *Granadilla (Tenerife)*	28/11/2008	14000
30	Modification of Seawater desalination plant at *Santa Eulalia (Ibiza)*	26/11/2009	5000

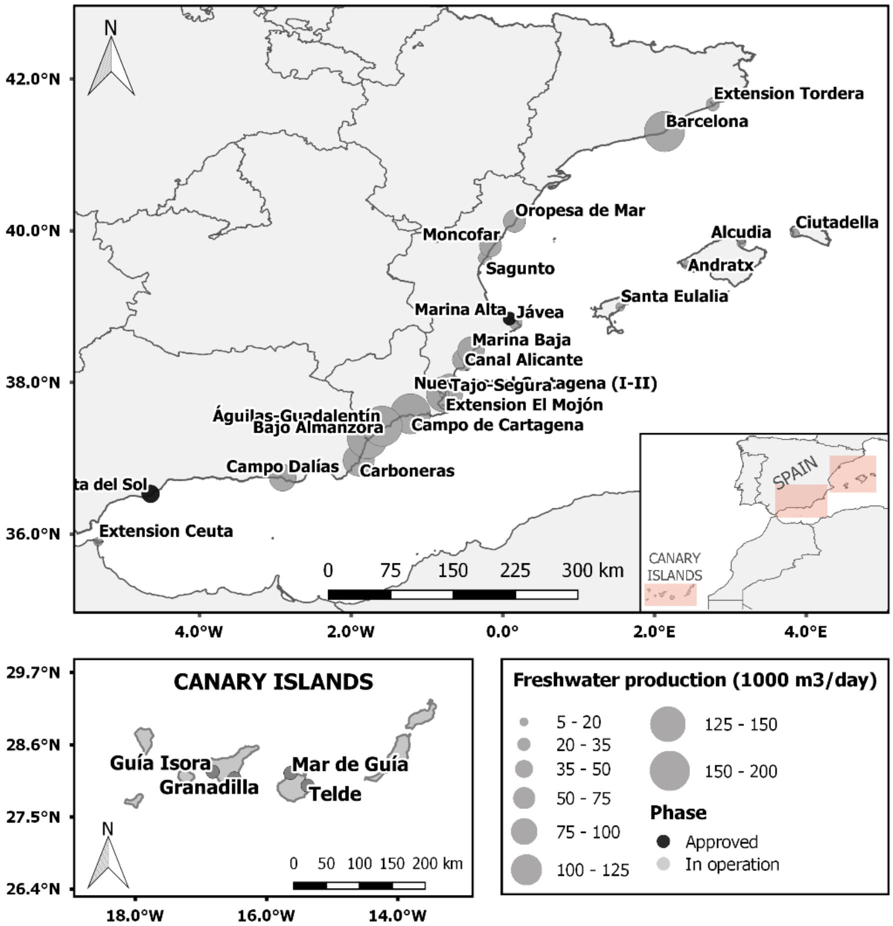

Figure 1. Location and production of desalination projects submitted to EIA in Spain between 1998 and 2018.

Maximum capacity of brine discharge production was evaluated using an average conversion rate of 45% for seawater [27], and 60 % for brackish water (defined in the EIA of *El Mojón* desalination plant; ID:18, Table 1).

The EMP of each EIA was analyzed, and the requirements established for monitoring the impact of the brine discharges on the marine environment were extracted. The requirements of each EMP were evaluated according to the characteristics of each desalination plant and the environment(s) in which they discharge. EMP requirements were assessed by considering the necessary parameters for a correct management of the brine discharge, as based on established scientific criteria [28].

Research carried which has been out to date on the different marine environmental impacts of brine discharges highlights the requirements that are important to consider when monitoring brine discharges. These include: i-ii) the analysis of the quantity and **quality** of the **effluent** and **marine environment** including, at least, salinity and nutrients but also substances that come from the pre-treatment and cleaning of membranes and filters, as coagulants and antifouling or organic matter [5,10,29,30]; iii) the control of the **saline plume** to determine the area potentially affected by the brine discharge [9]. For this, it is necessary that the implementation of salinity profiles which reach the bottom are used to determine salinity and temperature in a grid of points that cover the potential area of influence, and with seasonal replication to include different oceanographic conditions [9]; iv) to monitor **key** and **protected species** if they are present in the area to ensure they are not affected by the discharge [12,15]. In Spain, key species include the seagrasses *Posidonia oceanica* or *Cymodocea nodosa* and maërl beds [Directive 92/43/CEE; 31]; v) since discharges are usually on soft bottom sea beds, it is convenient to analyze **sediments** and associated infauna in the discharge area(s) [13,14,29,32]; vi) the use of salinity-sensitive species of benthic fauna as **bioindicators** has proven to be useful as sentinel species in order to prevent possible impacts on benthic habitats [20,33] and to discriminate between the effects of desalination and other impacts that may coincide in space [32,34]; vii) it is necessary to carry out a structural monitoring of the **submerged outfall** for the early detection of possible fractures [8]; viii) in the case of a possible rupture of the outfall (or if the discharge is close to key habitats), the existence of a **protocol of action** with mitigation measures is convenient, given that this may include the increase of dilution, or the reduction of production [15]. Table 2 summarizes the requirements considered in the analysis of the EMPs.

The requirements considered in this study were assessed using a semi-quantitative scale, defined in Table 3. Once requirements were assessed, the **quality** of **each EMP** was defined as

$$EMP\ quality_i = \frac{\sum_i \left(E_{i,e} + ME_{i,e} + SP_{i,e} + PK_{i,e,s} + S_{i,e,s} + B_{i,e,s} + O_{i,e,s} + P_{i,e}\right)}{\sum_i (E_i + ME_i + SP_i + PK_{i,s} + S_{i,s} + B_{i,s} + O_{i,s} + P_i)} \times 100 \quad (1)$$

where e is the evaluation of requirements that are important to consider in the monitoring of brine discharges of each EIA i, and s is the necessary or unnecessary control regarding characteristics of each desalination plant and the environment where are located the brine discharge. These characteristics were defined for the control of effluent (E_i) and marine environment (ME_i) quality, saline plume (SP_i), protected and key species (PK_i), the analysis of sediment (S_i), the use of a bioindicator (B_i), control of outfall (O_i) and the existence of protocol of action (P_i).

Table 3. Semi-quantitative scale used for the evaluation of environmental requirements of EMPs.

-	Absence of control, without environmental impact for its necessary control
4	Control 100% of the parameters in the EMP
3	Sub-optimal identified environmental impact on the marine environment
2	Partially control, identified environmental impact on the marine environment
1	Insufficient control, identified environmental impact on the marine environment
0	Absence of control, identified environmental impact on the marine environment

Moreover, the use of an adequate **sampling design** was considered in this study that allows discernment of the effects of the discharge from the spatial and temporal variability, while avoiding pseudo-replication [35–37]. For that, the **sampling design** for requirements considered for monitoring brine discharges in each

EMP was evaluated using the semi-quantitative scale defined in Table 3. The assessment of the sampling design was carried out by considering the temporary design; an adequate design with control-impact, and before-after comparison for a correct assessment of the environmental impact; and also, a description of the material or procedure used for carrying out the analysis of the requirements.

Furthermore, **irrelevant parameters** were identified as those that do not result in better management of brine discharges to protect marine ecosystems when they are required in the EMPs. Thus, these descriptors are not supported by scientific criteria. Table 4 shows the irrelevant parameters identified in the EMPs evaluated.

Areas with **high** and **low** ecological value were established regarding the relevance of the ecosystem where the brine discharge was located. Criteria for defining areas of high ecological value were based on the distribution and presence of the protected species and relevant ecosystems, such as *Posidonia oceanica* or maërl beds [38]. Student's t-tests (unpaired, one-tailed) were performed to compare the means of EMPs requirements and requirements of sampling designs between both areas. Shapiro-Wilk and F-test were conducted to verify the normality distribution and homogeneity of variance for each group. Significant difference was considered when $p<0.05$. Moreover, linear regressions were conducted to evaluate the temporal evolution of EMPs requirements in both ecological areas and its relation to the production capacity of the desalination plants. Statistical analyses and graphs were performed with R software [39].

3. RESULTS

3.1. Desalination projects submitted to EIAs in Spain

A total of 30 desalination projects have been identified and submitted for an EIA, between 1998 and 2009, in Spanish Gazette. These are mainly distributed in the Southeast of the Mediterranean coast, and the Balearic and Canary Islands (Fig. 1). The majority of these projects were submitted between 2005 and 2007, and together represent 74% of total projects (Fig. 2).

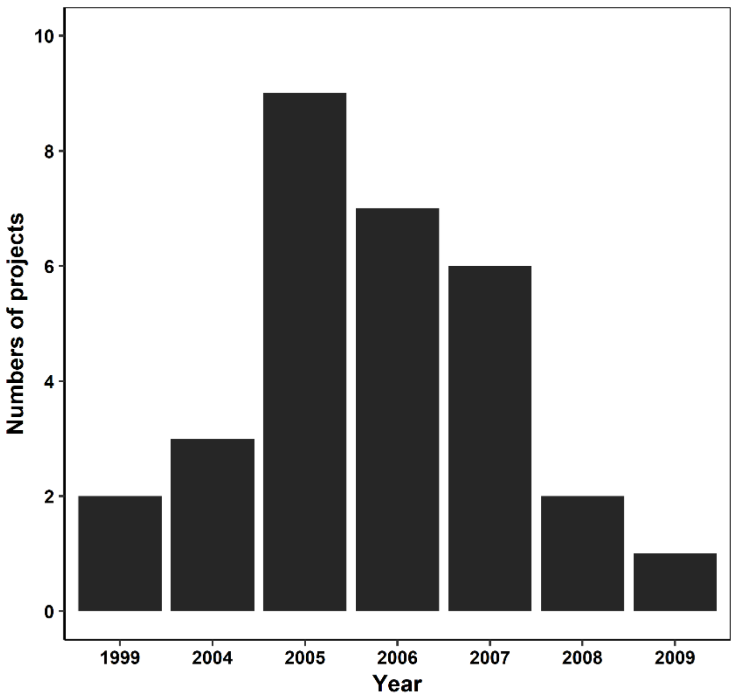

Figure 2. Number of desalination projects submitted to EIA each year in Spain.

On the other hand, the maximum freshwater production of the projects evaluated is 1.7 Mm^3/day, which approximately represents a maximum brine discharge production of 2.05 Mm^3/day (Fig. 3). Likewise, 74% of total freshwater and brine capacity production was installed between 2005 and 2007.

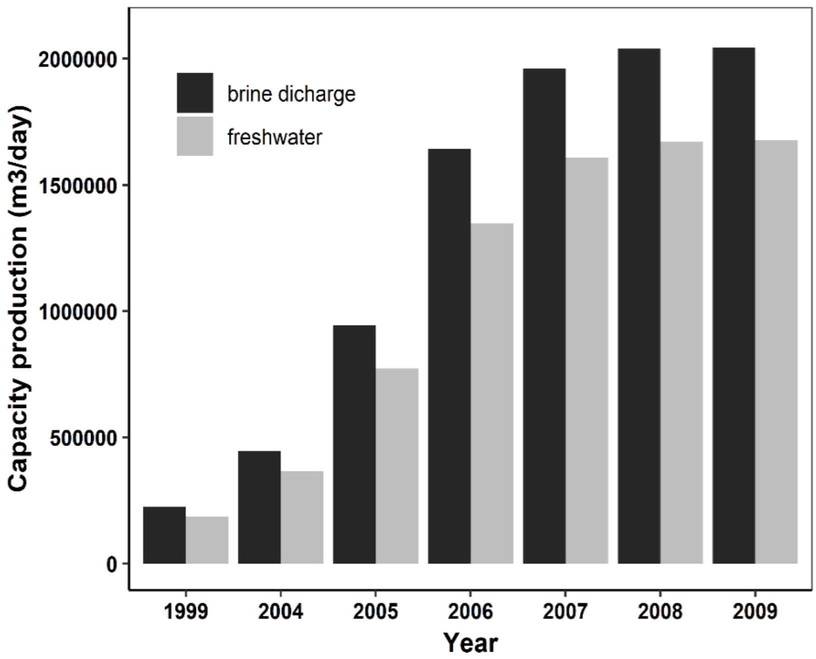

Figure 3. Evolution of production capacity and brine discharge volume for projects submitted to EIA.

Within the framework of different regions in Spain (Autonomous Communities), the majority of projects submitted for an EIA were carried out in Valencia (30%), followed by Murcia and the Balearic Islands (16.7%). Regions with the lowest number of projects submitted for an EIA were Catalonia and Ceuta at 6.7% and 3.3% respectively.

3.2. Analysis of requirements in EMPs

The results of the 30 EMPs evaluated are presented in Table 2. They showed a significant increase of environmental requirements in EMPs over time (Fig. 4; p=0.01).

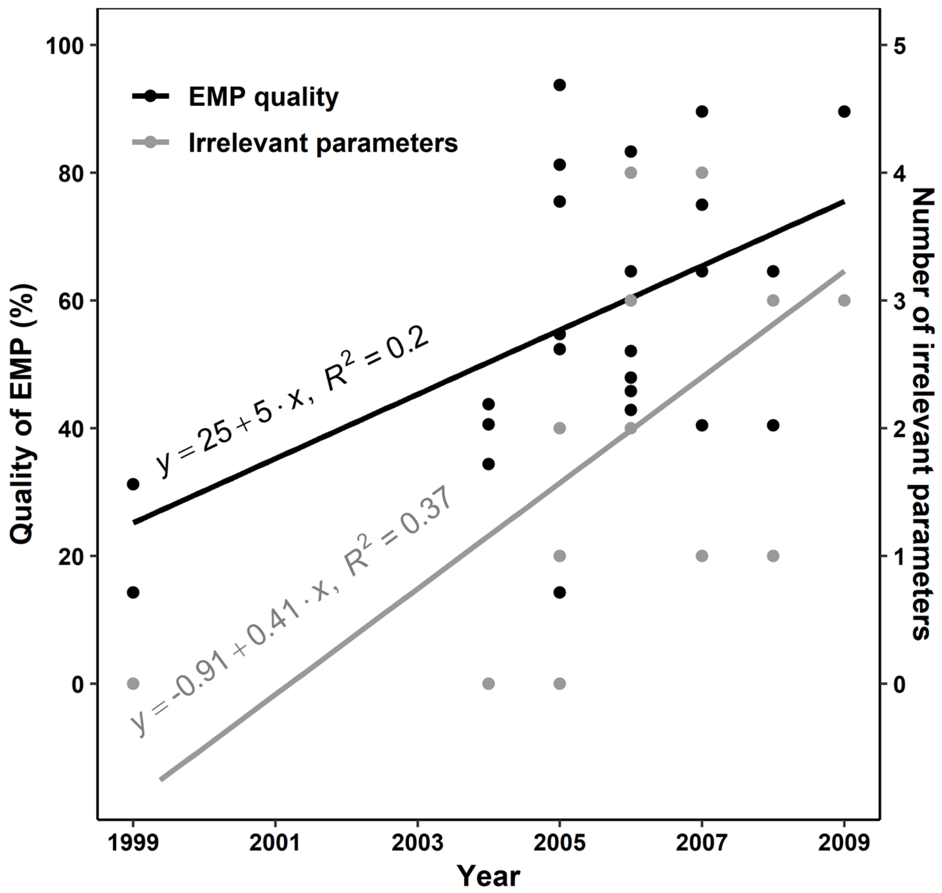

Figure 4. Linear regression showing the correlation between environmental requirements of EMPs and the published year of each EIA (black line) and linear regression showing the correlation between the number of irrelevant parameters required in the EMPs and their published year (gray line).

Likewise, EMPs with the lowest requirements were identified in 1999 and 2005 with 14.9% (IDs: 2, 6 and 8; Table 2), followed by 31.3% (ID: 1) and 34.4% (ID: 5) in 1999 and 2004 respectively. On the other hand, the EMPs with highest requirements were identified in 2005 with 93.8% (IDs: 9, 11 and 12; Table 2), followed by 89.6% in 2009 and 2007 (IDs: 30 and 23) and 83.3% in 2006 (ID:18). The average quality of EMPs analyzed was 57.8%, meaning that 50% of EMPs assessed are below the general average.

Table 2. Assessment of the 30 EMPs using the parameters defined for the correct management of brine discharges into the marine environment.

ID	Protocol of action	Key species	Saline plume	Control of outfall	Effluent quality	Bioindicator	Seawater quality	Sediment	EMP quality	Sampling design	Ecological area
1	0.0	0.5	0.0	0.0	0.0	0.8	0.9	0.3	**31.2**	**26.8**	High
2	0.0	-	0.3	0.0	0.0	0.0	0.7	0.0	**14.3**	**0.0**	Low
3	0.5	0.5	0.3	0.0	0.7	0.3	1.0	0.0	**40.6**	**0.0**	Low
4	0.5	0.5	0.3	0.0	0.7	0.5	1.0	0.0	**43.8**	**31.0**	High
5	0.5	0.0	0.3	0.0	0.7	0.3	1.0	0.0	**34.4**	**26.2**	Low
6	0.5	-	0.3	0.0	0.2	0.0	0.0	0.0	**14.3**	**7.5**	Low
7	1.0	1.0	0.7	-	0.2	1.0	0.0	0.0	**54.8**	**38.9**	High
8	0.5	-	0.3	0.0	0.2	0.0	0.0	0.0	**14.3**	**7.5**	Low
9	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	**93.8**	**66.7**	High
10	1.0	1.0	1.0	0.0	1.0	0.5	1.0	1.0	**81.3**	**64.3**	High
11	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	**93.8**	**85.7**	High
12	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	**93.8**	**71.4**	High
13	1.0	0.9	1.0	1.0	0.2	1.0	0.0	1.0	**75.5**	**52.4**	High
14	1.0	1.0	0.7	-	0.0	1.0	0.0	0.0	**52.4**	**33.3**	High
15	1.0	1.0	1.0	0.0	0.7	0.5	0.0	0.0	**52.1**	**40.5**	High
16	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**54.8**	High
17	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**54.8**	High
18	1.0	0.9	1.0	1.0	0.8	1.0	0.0	1.0	**83.3**	**73.8**	High
19	1.0	0.0	1.0	1.0	0.8	0.0	0.0	0.0	**47.9**	**39.3**	Low
20	1.0	0.0	1.0	1.0	0.7	0.0	0.0	0.0	**45.8**	**39.3**	Low
21	1.0	0.5	0.3	-	0.7	0.5	0.0	0.0	**42.9**	**34.7**	High
22	1.0	1.0	1.0	1.0	0.7	1.0	0.0	0.3	**75.0**	**82.1**	High
23	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**45.2**	High
24	1.0	0.5	1.0	1.0	1.0	1.0	0.7	1.0	**89.6**	**100.0**	High
25	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**45.2**	Low
26	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**45.2**	Low
27	0.0	-	0.3	1.0	0.5	0.0	1.0	0.0	**40.5**	**0.0**	Low
28	0.0	-	0.7	1.0	0.2	0.0	0.5	0.5	**40.5**	**27.5**	Low
29	1.0	1.0	1.0	1.0	0.7	0.5	0.0	0.0	**64.6**	**50.0**	Low
30	1.0	1.0	1.0	1.0	0.7	0.5	1.0	1.0	**89.6**	**71.4**	High
Frequency (%)	**78.3**	**77.0**	**75.6**	**66.7**	**57.6**	**47.5**	**39.2**	**30.6**	**57.8**	**43.9**	**60/40**

According to the environmental value of the area where the RO plant effluent was discharged, 18 EIAs were in areas with relevant ecosystems, and 12 were in areas with lower ecological value. The quality of EMPs for high-value areas showed a significant difference, with 69.2% of requirements compared to 40.5% in low-value areas (Fig. 5; $p<0.001$).

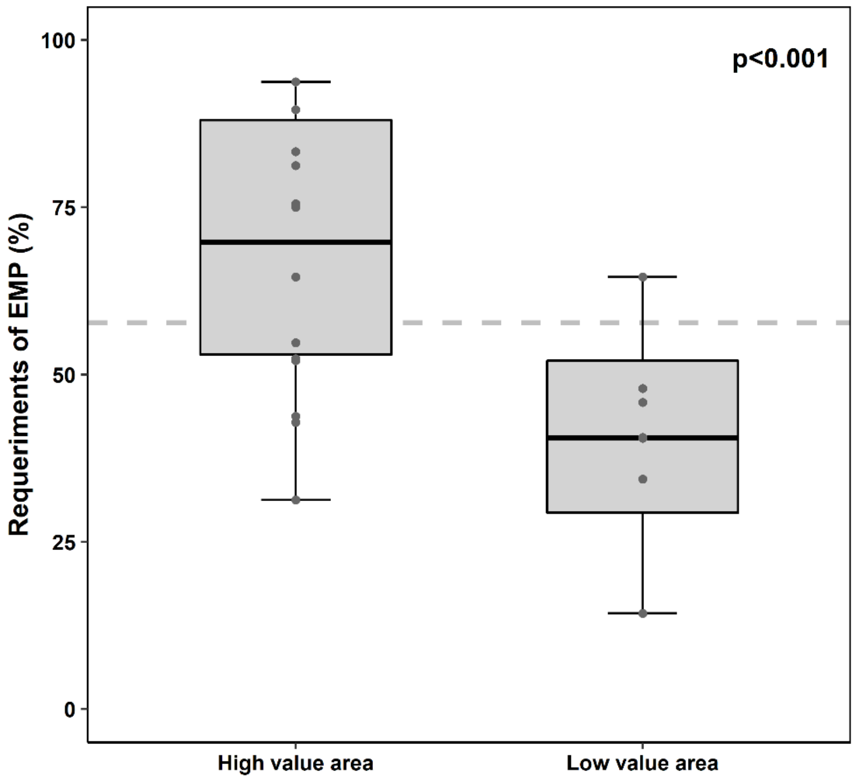

Figure 5. Comparison of requirements of EMPs in areas of high ecological value respect to lower ecological value. Solid black line in the boxplots represents mean requirements of EMPs in each environmental area. Dashed gray line represents the general mean of EMPs requirements. The box limits in the boxplots represents the interquartile range. P-value is indicated. Means were considered significantly different when $P < 0.05$ according to t-test statistical analysis.

Nevertheless, a significant trend to improve the requirements of EMPs over time was observed in both areas (Fig. 6; $p<0.05$). Finally, the quality of EMPs evaluated showed higher requirements when brine discharges were located in the regions where protected species are distributed (Fig. 7).

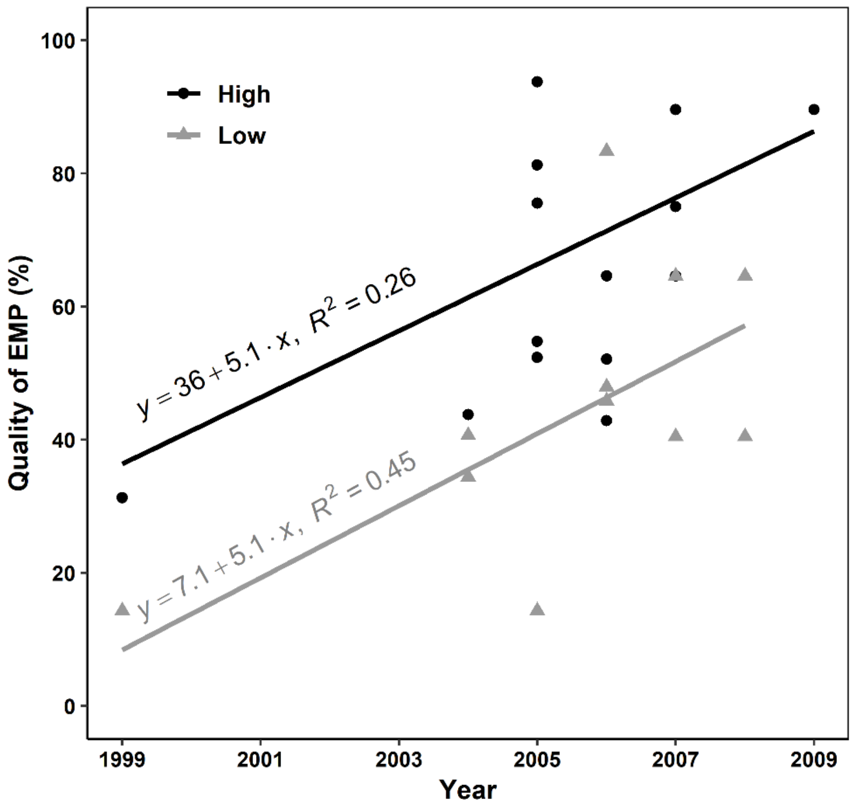

Figure 6. Linear regression between the environmental requirements of EMPs evaluated and the published year of each EIA for the two ecological areas defined.

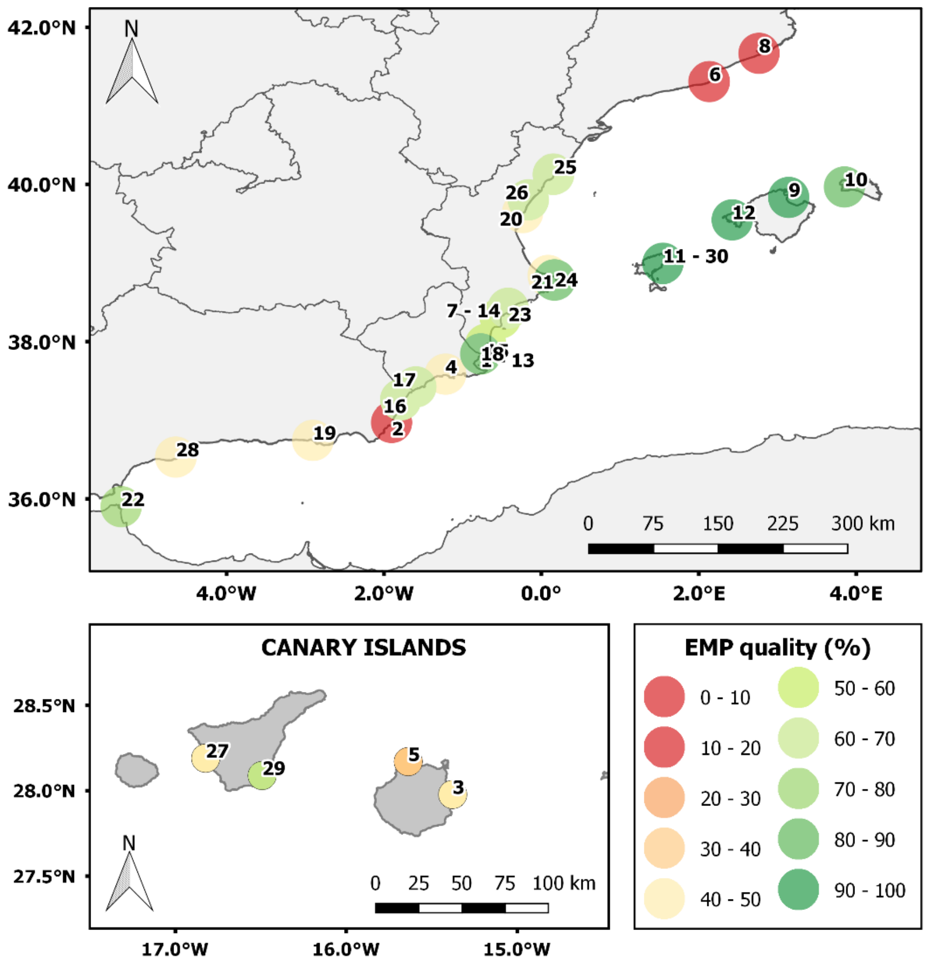

Figure 7. Environmental requirements of EMPs evaluated regarding the distribution of desalination projects submitted to EIA. Green regions show the regions with relevant ecosystems according to protected species [38].

Regarding the environmental requirements evaluated in EMPs, the requirements most frequently included (see Table 2) were the inclusion of a protocol of action (78.3%); the monitoring of key and protected species when they were present in the area of brine discharge (77%); the control of saline plume extension (75.6%); and, the inspection of the submerged outfall when this method of brine discharge was used (66.7%). The least implemented requirements were the control of effluent quality (57.6%); the inclusion of a bioindicator species (47.5%); the control of seawater quality in the area of brine discharge (39.2%); and, the analysis of the sediment (30.6%).

The histogram in Figure 8 indicates a general trend in both areas to improve the sampling design defined in EMPs. The overall average of sampling design requirements was 43.9% ± 26.1. However, the mean requirements for sampling designs in high ecological areas was significantly higher with 57.1% ± 21.1 compared to 24% ± 19.8 in low ecological areas ($p<0.05$).

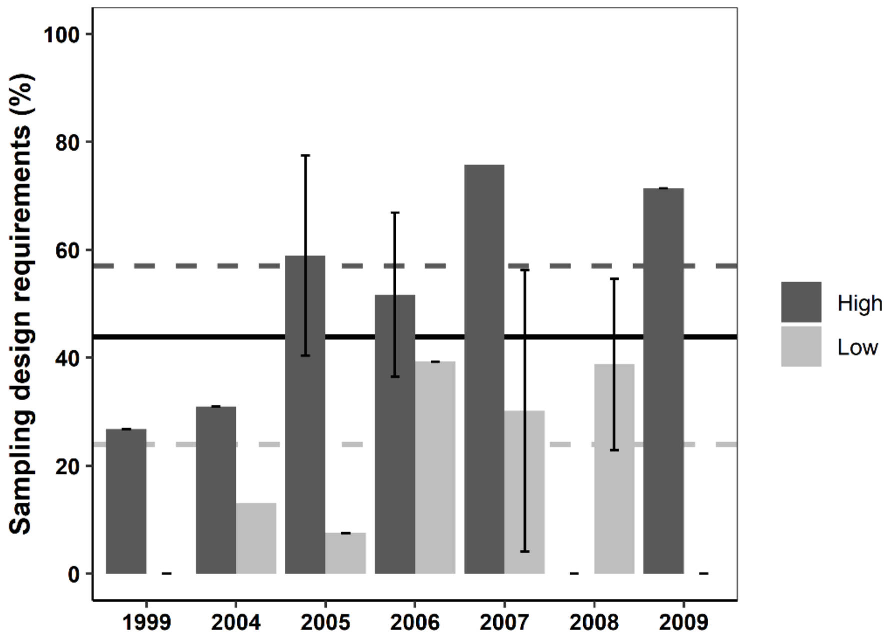

Figure 8. Percentage of sampling design requirements of EMPs (bars represent standard deviation). Solid black line indicates the general average of EMPs; dashed dark-gray line indicates the average for high ecological value areas; dashed light-gray line indicates the average for low ecological value areas.

Finally, a higher production rate does not imply higher environmental requirements of EMPs. In fact, linear regression showed a significant negative trend between the requirements of EMPs and the brine discharge production rates (Fig. 9; $P<0.05$).

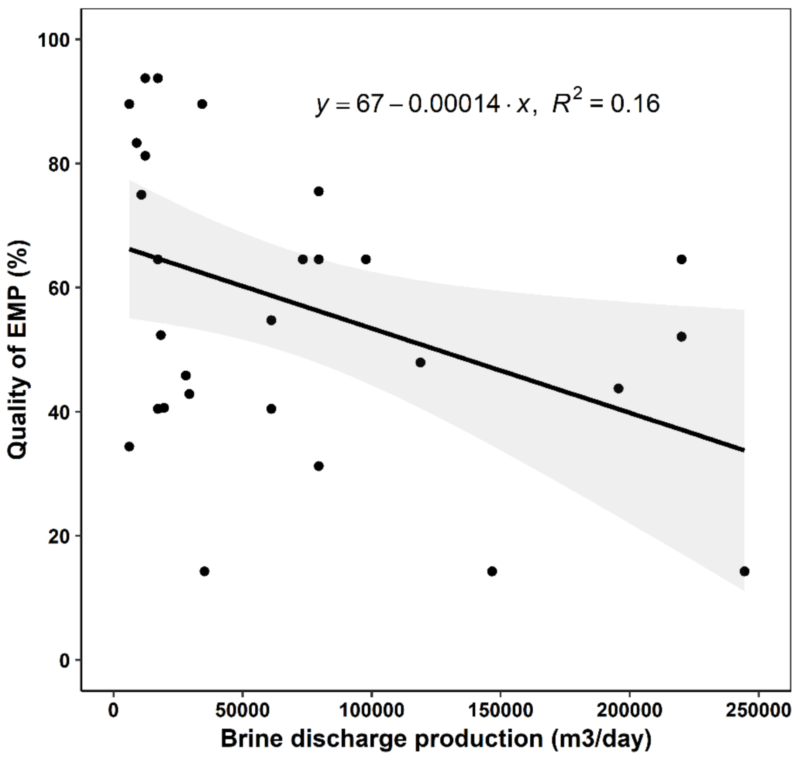

Figure 9. Linear regression between the requirements of EMPs and brine discharge production of projects evaluated.

3.3. I**rrelevant parameters in EMPs**

Irrelevant descriptors identified in the EMP analysis, and these are described in Table 4. Seven descriptors were identified in the analysis which do not contribute to a better environmental protection of marine environment(s) from discharge effluents. Moreover, a significant tendency to include irrelevant parameters over time has been observed, specifically between 2006–2009, where 84.9% of the total irrelevant parameters were identified (Fig. 4). Within the parameters identified, the requirement of sea state reports was the most frequently included parameter in EMPs (53.3%), followed by the monitoring of currents with 43.3%.

Table 2. Irrelevant descriptors identified in the EMPs. Requirement of the parameter in the EMP (1); No need of control of irrelevant descriptors (-); Salinity thresholds identified for *P. oceanica* not accorded for scientific criteria [15]

ID	Sea state	Currents monitoring	Flow variables	Salinity thresholds (ppt)	Sensors calibration	Heavy metals	Coastal dynamics
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	1	-	-	38.3/39.5	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	38.3/39.5	-	1	-
10	-	-	-	38.3/39.5	-	1	-
11	-	-	-	38.3/39.5	-	1	-
12	-	1	-	38.3/39.5	-	1	-
13	1	-	-	38.3/39.5	-	-	-
14	1	-	-	38.3/39.5	-	-	-
15	1	1	1	38.5/40.5	-	-	-
16	1	-	1	-	-	-	-
17	1	1	1	-	-	-	-
18	1	1	-	-	-	-	-
19	1	1	1	-	-	-	-
20	1	1	1	-	-	-	-
21	1	1	1	38.5/40.5	1	-	-
22	1	1	1	-	1	-	-
23	1	1	1	-	1	-	-
24	-	-	-	-	-	-	1
25	1	1	1	-	1	-	-
26	1	1	1	-	1	-	-
27	-	-	-	-	-	1	-
28	-	1	-	-	-	-	-
29	1	1	-	-	1	-	-
30	1	-	1	-	1	-	-
Frequency (%)	**53.3**	**43.3**	**36.7**	**36.0**	**23.3**	**16.7**	**3.3**

On the other hand, salinity thresholds in EMPs for *P. oceanica* which differ to those recommended by scientific advice [15] were also identified. These improper thresholds were present in 36% of the EMPs with established salinity thresholds for *P. oceanica*. Finally, the requirement of calibration and replacement of conductivity sensors not linked with manufacturer's information, or international standards, was observed. It was present in 23% of EMPs.

4. DISCUSSION

Currently, Spain has more than 700 desalination plants. Nevertheless, the majority of these represent plants with a low production capacity [8,40]. EIAs evaluated in this study represent approximately 33.5% of total production capacity in Spain, and the approximately 28% of desalinations plants exceeding 10.000 m^3/day [8,40]. It would be desirable to know environmental requirements for the discharge of all desalination plants, including smaller ones, and those that were developed before the application of environmental regulations and which are consequently without an environmental assessment [24].

EMPs should be designed correctly, and of course based on the best scientific knowledge available [28]. Given advances in scientific knowledge, it is possible to highlight what environmental impacts may occur in the areas where the brine discharges are located [12] and, therefore, what requirements are important to consider in EMPs [28].

High heterogeneity in the environmental requirements of the EMPs evaluated has also been observed. EMPs requirements have increased significantly over time in Spain, and are higher in areas with the presence of protected species in comparison with areas of low ecological value. But no relationship was observed between these requirements and brine discharge production. It would be desirable to pay more attention to plants with higher production during the environmental assessment since they may produce a higher impact upon the marine environment. Moreover, the increase of environmental requirements is not necessarily related to a better knowledge of potential impacts that may be produced by desalination plans since it has been observed that a similar increase in irrelevant parameters- or incorrectly defined descriptors- occurs in EMPs over time. It is not justified to require monitoring for parameters that are not related to the discharge, or that do not improve environmental protection given that these parameters for the management of brine discharges leads to an unnecessary increase in the economic costs of EMPs without increasing the protection of marine ecosystems.

On the other hand, the majority of EMPs evaluated require an improvement in their sampling designs. It is important to consider an adequate sampling design to detect the potential impacts from brine discharges on marine ecosystems. They should include multiple reference locations and replicated sampling before, and after, the brine discharge starts [41]. The use of an inadequate sampling design complicates the statistical assessment and furthermore hinders knowledge of the potential effects on marine ecosystems [37,41]. Thus, EMPs with correctly sampling design defined allow to detect the impacts on marine environment of desalination plants and they can be mitigated [14]. We analyzed the requirements established in EMPs, but we have no data to examine whether, in practice, they are implemented correctly, or if they include additional descriptors over the minimum established by EMPs.

EMPs correctly defined allow to sustainable management of RO effluents. Thus, it is possible to identify and mitigate environmental impacts on the marine environment when EMPs are being correctly implemented [14,20]. Likewise, EMPs should be flexible in order to adapt to unpredictable scenarios or the best current scientific knowledge.

In this research we analyzed the EMPs as defined in the EIAs. Further research in this field will be necessary to study: i) the environmental licenses approved by the different regions (Autonomous Communities), given that they could include additional or irrelevant requirements; ii) assess the economic costs of monitoring irrelevant parameters in EMPs, and the economic cost of adding relevant requirements when they are absent in EMPs; and, iii) evaluate the implementation EMPs.

5. CONCLUSIONS

Requirements for the monitoring of brine discharges and their sampling designs in the EIAs have improved over time, but this trend is similar for both essential and irrelevant descriptors. Additionally, the presence of protected species in the area(s) of RO effluents showed a significant correlative effect with greater requirements in the EMPs. Nevertheless, there was no increase of environmental requirements with respect to a major brine discharge production rate.

In conclusion, a review of the EIAs would be advisable in water to unify the monitoring requirements at the national level. We would also recommend a simultaneous improving of their sampling designs, including the essential descriptors of when they are absent, as well as eliminating irrelevant parameters when they are present. This standardization should be based on the most up-to-date scientific advice, and pay particular attention to desalination plants with higher production rates, as they have a demonstrably greater influence upon the marine environment.

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7. REFERENCES

[1] M.W. Shahzad, M. Burhan, L. Ang, K.C. Ng, Energy-water-environment nexus underpinning future desalination sustainability, Desalination. 413 (2017) 52–64. doi:10.1016/j.desal.2017.03.009.

[2] E. Jones, M. Qadir, M.T.H. van Vliet, V. Smakhtin, S. Kang, The state of desalination and brine production: A global outlook, Sci. Total Environ. 657 (2019) 1343–1356. doi:10.1016/j.scitotenv.2018.12.076.

[3] M. Qasim, M. Badrelzaman, N.N. Darwish, N.A. Darwish, N. Hilal, Reverse osmosis desalination: A state-of-the-art review, Desalination. 459 (2019) 59–104. doi:10.1016/J.DESAL.2019.02.008.

[4] V.G. Gude, Desalination and sustainability – An appraisal and current perspective, Water Res. 89 (2016) 87–106. doi:10.1016/J.WATRES.2015.11.012.

[5] T. Mezher, H. Fath, Z. Abbas, A. Khaled, Techno-economic assessment and environmental impacts of desalination technologies, Desalination. 266 (2011) 263–273. doi:10.1016/j.desal.2010.08.035.

[6] D. Zarzo, D. Prats, Desalination and energy consumption. What can we expect in the near future?, Desalination. 427 (2018) 1–9. doi:10.1016/j.desal.2017.10.046.

[7] J.C. Hernández-Sánchez, N. Boluda-Botella, J.L. Sánchez-Lizaso, The role of desalination in water management in southeast Spain, Desalin. Water Treat. 76 (2017) 71–76. doi:10.5004/dwt.2017.20657.

[8] J.J. Sadhwani Alonso, N. Melián-Martel, Environmental Regulations—Inland and Coastal Desalination Case Studies, Sustain. Desalin. Handb. (2018) 403–435. doi:10.1016/B978-0-12-809240-8.00010-1.

[9] Y. Fernández-Torquemada, J.M. Gónzalez-Correa, A. Loya, L.M. Ferrero, M. Díaz-Valdés, J.L. Sánchez-Lizaso, Dispersion of brine discharge from seawater reverse osmosis desalination plants, Desalin. Water Treat. 5 (2009) 137–145. doi:10.5004/dwt.2009.576.

[10] E. Portillo, M. Ruiz de la Rosa, G. Louzara, J.M. Ruiz, L. Marín-Guirao, J. Quesada, J.C. González, F. Roque, N. González, H. Mendoza, Assessment of the abiotic and biotic effects of sodium metabisulphite pulses discharged from desalination plant chemical treatments on seagrass (Cymodocea nodosa) habitats in the Canary Islands, Mar. Pollut. Bull. 80 (2014) 222–233. doi:10.1016/j.marpolbul.2013.12.048.

[11] J.S. Chang, Understanding the role of ecological indicator use in assessing the effects of desalination plants, Desalination. 365 (2015) 416–433. doi:10.1016/j.desal.2015.03.013.

[12] K.L. Petersen, H. Frank, A. Paytan, E. Bar-Zeev, Impacts of Seawater Desalination on Coastal Environments, Sustain. Desalin. Handb. (2018) 437–463. doi:10.1016/B978-0-12-809240-8.00011-3.

[13] Y. Del-Pilar-Ruso, J.A. De la Ossa Carretero, F.G. Casalduero, J.L.S. Lizaso, Spatial and temporal changes in infaunal communities inhabiting soft-bottoms affected by brine discharge, Mar. Environ. Res. 64 (2007) 492–503. doi:10.1016/j.marenvres.2007.04.003.

[14] Y. Del-Pilar-Ruso, E. Martinez-Garcia, F. Giménez-Casalduero, A. Loya-Fernández, L.M. Ferrero-Vicente, C. Marco-Méndez, J.A. de-la-Ossa-Carretero, J.L. Sánchez-Lizaso, Benthic community

recovery from brine impact after the implementation of mitigation measures, Water Res. 70 (2015) 325–336. doi:10.1016/j.watres.2014.11.036.

[15] J.L. Sánchez-Lizaso, J. Romero, J. Ruiz, E. Gacia, J.L. Buceta, O. Invers, Y. Fernández Torquemada, J. Mas, A. Ruiz-Mateo, M. Manzanera, Salinity tolerance of the Mediterranean seagrass Posidonia oceanica: recommendations to minimize the impact of brine discharges from desalination plants, Desalination. 221 (2008) 602–607. doi:10.1016/j.desal.2007.01.119.

[16] J.A. De-la-Ossa-Carretero, Y. Del-Pilar-Ruso, A. Loya-Fernández, L.M. Ferrero-Vicente, C. Marco-Méndez, E. Martinez-Garcia, J.L. Sánchez-Lizaso, Response of amphipod assemblages to desalination brine discharge: Impact and recovery, Estuar. Coast. Shelf Sci. 172 (2016) 13–23. doi:10.1016/j.ecss.2016.01.035.

[17] T. Röthig, M.A. Ochsenkühn, A. Roik, R. Van Der Merwe, C.R. Voolstra, Long-term salinity tolerance is accompanied by major restructuring of the coral bacterial microbiome, Mol. Ecol. 25 (2016) 1308–1323. doi:10.1111/mec.13567.

[18] N. Belkin, E. Rahav, H. Elifantz, N. Kress, I. Berman-frank, The effect of coagulants and antiscalants discharged with seawater desalination brines on coastal microbial communities : A laboratory and in situ study from the southeastern Mediterranean, Water Res. 110 (2017) 321–331. doi:10.1016/j.watres.2016.12.013.

[19] J.L. Fuentes-Bargues, Analysis of the process of environmental impact assessment for seawater desalination plants in Spain, Desalination. 347 (2014) 166–174. doi:10.1016/j.desal.2014.05.032.

[20] Y. Fernández-Torquemada, J.M. González-Correa, J.L. Sánchez-Lizaso, Echinoderms as indicators of brine discharge impacts, Desalin. Water Treat. 51 (2013) 567–573. doi:10.1080/19443994.2012.716609.

[21] European Union, Directive 85/337/EEC of the Council of June 27th 1985, on the assessment of the effects of certain public and private projects on the environment, Off. J. Eur. Union L175 (1985) 40–48.

[22] European Union, Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014, on the assessment of the effects of certain public and private projects on the environment, Off. J. Eur. Union, L124 (2014) 1-18.

[23] Spanish Government, Royal Decree 1302/1986, of the 28th of June, on Environmental Impact Assessment, Bol. Oficial Estado 155 (1986) 23733–23736.

[24] Spanish Government, Royal Decree 1131/1988, on the 30th of September, that develops the EIA regulation on RD 1302/1986, Bol. Oficial Estado 239 (1988) 28911–28915.

[25] Spanish Government, Act 21/2013, of the 9th of December, on Environmental Impact Assessment, Bol. Oficial Estado 296 (2013) 98151–98227.

[26] J.J. Sadhwani, J.M. Veza, C. Santana, Case studies on environmental impact of seawater desalination, Desalination. 185 (2005) 1–8. doi:10.1016/J.DESAL.2005.02.072.

[27] P. Palomar, I.J. Losada, Desalination in Spain: Recent developments and recommendations, Desalination. 255 (2010) 97–106. doi:10.1016/j.desal.2010.01.008.

[28] Y. Fernández-Torquemada, J.L. Sánchez-Lizaso, Monitoring of brine discharges from seawater desalination plants in the Mediterranean, Int. J. Health. (2007) 449–461. doi:10.1504/IJENVH.2007.017870.

[29] Y.C. Lin, G.P. Chang-Chien, P.C. Chiang, W.H. Chen, Y.C. Lin, Potential impacts of discharges from seawater reverse osmosis on Taiwan marine environment, Desalination. 322 (2013) 84–93. doi:10.1016/j.desal.2013.05.009.

[30] T.K. Liu, T.H. Weng, H.Y. Sheu, Exploring the environmental impact assessment commissioners' perspectives on the development of the seawater desalination project, Desalination. 428 (2018) 108–115. doi:10.1016/j.desal.2017.11.031.

[31] European Union, Directive 92/43/CEE of 21th May on the conservation of natural habitats and of wild fauna and flora, Off. J. Eur. Union, L26 (1992) 7-50

[32] Y. Del-Pilar-Ruso, D. la O.C. Jose Antonio, L.F. Angel, F.V. Luis Miguel, G.C. Francisca, S.L. Jose Luis, Assessment of soft-bottom Polychaeta assemblage affected by a spatial confluence of impacts: Sewage and brine discharges, Mar. Pollut. Bull. 58 (2009) 776–782. doi:10.1016/j.marpolbul.2009.03.002.

[33] J.A. De-la-Ossa-Carretero, Y. Del-Pilar-Ruso, A. Loya-Fernández, L.M. Ferrero-Vicente, C. Marco-Méndez, E. Martinez-Garcia, F. Giménez-Casalduero, J.L. Sánchez-Lizaso, Bioindicators as metrics for environmental monitoring of desalination plant discharges, Mar. Pollut. Bull. 103 (2016) 313–318. doi:10.1016/j.marpolbul.2015.12.023.

[34] J.A. De-la-Ossa-Carretero, Y. Del-Pilar-Ruso, F. Giménez-Casalduero, J.L. Sánchez-Lizaso, Amphipoda assemblages in a disturbed area (Alicante, Spain, Western Mediterranean), Mar. Ecol. 37 (2016) 503–517. doi:10.1111/maec.12264.

[35] S.H. Hurlbert, Pseudoreplication and the Design of Ecological Field Experiments, Ecol. Monogr. 54 (1984) 187–211. doi:10.2307/1942661.

[36] A. Stewart-Oaten, W.W. Murdoch, K.R. Parker, Environmental Impact Assessment: 'Pseudoreplication' in Time?, Ecology. 67 (1986) 929–940. doi:10.2307/1939815.

[37] A.J. Underwood, On Beyond BACI: Sampling Designs that Might Reliably Detect Environmental Disturbances, Ecol. Appl. 4 (1994) 3–15. doi:10.2307/1942110.

[38] J.M. Ruiz, J.E. Guillén, A. Ramos Segura, M.M. Otero, Atlas de las praderas marinas de España, IEO/IEL/UICN, Murcia-Alicante-Málaga (2015). doi:10.1109/INFCOMW.2009.5072203.

[39] R Core Team, A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria (2013). URL http://www.R-project.org/

[40] AEDyR (Spanish Desalination and Reuse Association), Desalación en España en primera persona: de hitos pioneros, a referente internacional (in Spanish), (2018). URL https://historiadesalacion.es.

[41] D.A. Roberts, E.L. Johnston, N.A. Knott, Impacts of desalination plant discharges on the marine environment: A critical review of published studies, Water Res. 44 (2010) 5117–5128. doi:10.1016/j.watres.2010.04.036.