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Minimizing environmental risks on constructing marine pipelines: Aguilas desalination plant

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ABSTRACT

In the building of marine brine discharge pipelines from desalination plants, there are some technical and environmental conditions that require previous numerous studies to guarantee their viability. In the project of Águilas desalination plant with a production capacity of 180.000 m^3/day, in Murcia, Spain, a marine emissary was designed. It was made up of various sections that entail different building complexities. The main difficulty was to build a tunnel in the rocky massif called "Peñon del Roncaor"; the tunnel was dug through a piling of 443 m of length and an exterior diameter of 2.400 mm that would have come up at a depth of 12 m to join the submarine section of 290 m of length. These more detailed geotechnical studies showed a great heterogeneity in the composition of the materials to be excavated from the Peñon. In order to avoid any risk of affecting to the castle right above considered of cultural interest, a new tracing of the tunnel was designed. The new tracing runs the Peñon's outer south borders right into the dumping area. This new tracing implies greater length of piping and greater seabed marine area occupation as well; it required carrying out additional bionomic studies to guarantee its environmental compatibility. We must bear in mind that the marine surroundings of Águilas are a protected area included in the Red Natura 2000 (LIC Submerged Costal Strip of the Murcia Region) whose predominant bionomic community is the *Posidonia oceanica* beds, limited to the Southwest by another less dense seagrass of *Cymodocea nodosa*. These seagrass meadows and rock communities suffer anthropic pressure for its proximity to the city of Águilas, as near-shore marine discharges, fishing activity, and others. And, there are other affections of natural condition: terrigenous sediments and nutrients that get to the dry riverbed name El Charco, having seriously affected the species of greater natural value and the implementation of those ubiquitous species, and thus impoverishing habitat in general. Due to the fact that *P. oceanica* seagrasses have very low tolerance to increased salinity in the western Mediterranean Sea; a hydrodynamic model was developed to estimate the likely dilution of the brine discharge for this new solution. Other works comprise a bathymetric survey to establish the profile of the ocean bottom—very important for pipeline construction—a sediment characterization, the study of the oceanographic conditions and a monitoring study of the marine water quality to settle the values of the water quality in the preoperation moment and the parameters needed for process designing. During the construction of the pipeline, an environmental surveillance program was developed. And at the end of the stage, a study was developed to know the impacts produced by the works carried out and to establish the "zero situation" before start

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of the operation phase. In addition to that, a very strict environmental legislation was applied along the process. These regulations included exhaustive and systematic controls of several environmental parameters when starting and during the plant operation.

Keywords: Desalination; Brine discharge; Environmental impact; Seagrass meadows

1. Introduction

1.1. The needs of desalination plants

Desalination plants of reverse osmosis are industrial facilities that filter salt from marine water to obtain low ionic water. The benefits of desalination plants are evident; they are clearly related to the socio-economic activity and comfort of the population fundamentally, in countries like Spain with a historical water deficit. However, we must bear in mind the environmental damage that desalination plants may bring about if they are not well designed and previous studies are carried out taking into account the location, dimensioning, design of brine discharge, noise pollution, and energy consumption.

Such benefits are implicit in the improvement of drinking water quality by eliminating: metal ions and carbonates that clog pipes and electrical appliances, organic matter excess, viruses, and improving flavor. Likewise irrigation avoids sanitary risks and maintains soil quality.

A proper, balanced environmental evaluation means: planning use and demand of the water and its socio-economic impact compared to other resources, estimating economic and environmental cost of energy composition, and estimating the degree of environmental sensitivity in the surroundings to allow the location of an industry of this type. The cost of minimizing the environmental impact must also be considered.

1.2. Environmental impacts of desalination plants industry

The magnitude of the environmental impacts of desalination industries are mainly related to: the site selection, presence or absence of a protected habitat, rare or endangered species in the marine surroundings, oceanographic, and physical conditions of the site.

Other environmental impacts are produced during the construction phase, and they depend on the construction techniques and the quality of the media: turbidity and suspended sediments produced during the excavation of ditches, the risk of suffering any accidental spills during the works (some construction activities involved an important amount of maritime traffic), esthetic, acoustic, and other social impacts (for instance, disturbances during seasonal holidays). A consequence among others is the temporary and permanent habitat loss and destruction of marine communities.

Commonly, project designers do not follow any basic environmental impact assessment methodology to study environmental base line and potential impacts, neither for analyzing and assessing those affections produced once the plant is built and operative. Fortunately, there are some recent technical reports that propose a guidance manual for desalination projects [1].

In relation to the brine discharge the main environmental constraints are the dilution at the edge of the mixing zone, toxicity of the brine, and its effect on the surrounding ecosystem. Since brine is denser than the seawater, it sinks deeper creating a hypoxic layer and diminishes oxygen levels at seabed floor level. This may lead to further changes in irradiance affecting the development and growth of some organisms, its population density, and its trophic resources [2]

There is an increasing amount of available information related to the environmental monitoring of brine discharges (dilution/dispersion and chemical quality). There are also several papers dealing with mitigation or management techniques to minimize potential environmental impacts from construction and functioning activities [3,4].

Nevertheless, there is still little information on the degree of dilution of spills in the environment of the nearby field [5] and the influence of environmental variables affecting saline spills. Many articles focus their attention on analyzing the potential impacts; for instance, the mixture of salinity of the plume of spilled or the changes in seagrass meadows. But there is little information on the effects that the marine hydrodynamics can have on spills, as well as other details on the design of the spills; for instance, the optimization design criteria of the diffusers section (no., type of ports, etc.).

Some works quantify the degree of dilution [6–8] showing brine total mixing values in the water column at a distance of 20 m from the dumping point; although, in this case local hydrodynamic conditions are at first unfavorable with calm situations. However, other articles are in favor of using dumping in high energy oceanic coasts [9].

Related to seagrass beds, the salinity variation can affect the growth and survival of several species [10,11]; moreover, its photosynthetic capacity is very sensitive to salinity increases [12]. *Posidonia oceanica* is very vulnerable to turbidity increase as a result of dumping and natural erosion of beaches that can root out rhizomes [13,14]. We must not forget that this species grow very slowly: around 5 cm horizontally and 1 cm vertically per year in the Mediterranean Sea [13].

Different experiments have been carried out in labs to determine the salinity threshold of the main seagrass meadows on the Spanish east coast for various species, mainly in aquariums, *P. oceanica*, *Cymodocea nodosa* and *Zoostera noltii* [7,8,15–18] all of them show similar results indicating that *P. oceanica* shows reduction of seagrass vitality and higher mortality at 39.1 psu and above. In the case of *C. nodosa* y *Zoostera noltii*, damage is perceived at 41 psu and above.

In seagrass monitoring programs, the most widely used parameters are the cover and density of meadows to measure or establish their abundance to detect changes. Moreover, since there is an intimate relation between the health of these meadows and the quality of other marine environment, a set of parameters are analyzed simultaneously: water quality parameters, oceanographic conditions, and sediment characteristics. This information may help to understand trends detected on these communities.

Over the last decades, because of the coastal urbanization and industrialization, many *Posidonia* meadows have disappeared or have been altered. It is estimated that 46% of the underwater seagrass beds in the Mediterranean have experienced some reduction in range, density, and/or coverage, and 20% have severely regressed since the 1970s [19]. That is why this species is classified as a priority habitat type for conservation under the Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora. In Spain is protected by the Spanish Catalogue of Threatened Species, developed by the Order 139/2011. This species is often combined with other seagrasses, like *C. nodosa,* which is also protected by the mentioned legislation.

The meiofauna community can also be affected by brine disposal and by variation in particle size composition [20,21]. For this reason, studies of infaunal communities are regularly included in desalination projects.

Chemicals loads in the brine from the pre-treatment process and pipe corrosion might produce some kind of environmental damage, which have not been yet sufficiently studied. There are several studies about the effects of components as chlorine, copper, and antiscalants, their impact on organisms and concentration limits, and its way of degradation or accumulation in the environment [22].

1.3. Aguilas/Guadalentín desalination plant

The Águilas/Guadalentín desalination plant is settled in Murcia in the southeastern Mediterranean coast of Spain. This plant has an annual production of 60 h m^3/year that can be enlarged up to 70 h m^3/year [23] The plant provides water to the coastal region of the town of Águilas and to the agricultural region of Alto Guadalentín.

The plant is located at an industrial park of Majadas in the north of Agulias city center. Intake and brine discharge pipes are located in a costal stretch delimited by Cabeza del Caballo to the east and by the marina Juan Montiel to the west. The plant was built in a natural protected habitat (LIC submerged coastal Strip of the Murcia Region). The area is characterized by the presence of seagrass meadow *P. oceanica*.

The open intake is situated in the south of the emissary, in the mouth of the dry riverbed named Cañerete (Fig. 1). It was mainly built between April and September 2009. The complementary works to end the construction took place at the end of 2011.

The part of the open intake closest to land was carried out by a 320 m stake with an access shaft located in the riverbed on the left side simply following the alignment of the dry riverbed stretch. The building procedure involved drilling a tunnel which minimizes the surface occupation that, otherwise, would have required digging a trench of more than 9 m deep in an urban area. Due to space limitations at the mouth of the dry riverbed Cañarete, the pipes were directly placed over a launching ramp when they were being welded. (Fig. 2)

The last 420 m of the open intake already at sea was set in a ditch: the last 90 m lie on the seafloor. The conditioning of the seabed was previously carried out by using excavating machines mounted on a pontoon controlled by sand suction pumps. A 10 cm layer of gravel was put in place.

The design of the intake tower (Fig. 2) that sits on the seafloor at a depth of 18 m secures horizontal currents of low velocity and a laminar flow, so the dragging of marine organisms is minimized in it, as well as the suspension of solids in stormy weather and dragging of thick particles too.

Related to brine discharge outfall, the project was initially designed having the pipeline going through the "Peñón del Roncaor" rocky massif. Right on the top, an old fortress was built during the 15th and 16th

Fig. 1. Intake and outfall construction zones.

Fig. 2. Launching ramp and water tower intake.

centuries—San Juan Castle—and could be affected by the construction of the pipeline. This castle is considered of Cultural Interest by the Murcia Region regulations and, the Cultural Authorities warned about the high risk of affecting the stability and conservation of this antique construction.

Furthermore, geotechnical studies developed during the project described the regularity of landslides, and they warned about the risk of affecting the foundations of the structure as a consequence of the cross between the tunnel and any tectonic fault. These reports warned about the risk of the unpredictable alternation of materials with different mechanical behaviour along the tunnel and the presence of spoiled loams in the part under sea level. These circumstances could have made the drilling works more complicated and cause delay in the execution.

Following the prevention criteria, the project was changed and the course of the emissary pipeline was diverted around the rocky massif instead of going through.

The emissary was built between July 2010 and July 2011. The pipeline has a total length of 2.100 m, and in its final part has a diffuser section; it ends up at a depth of around 34 m. The submarine emissary starts from the extreme east of the jetty of the beach of West (Fig. 1). The first 70 m of the emissary were placed in a ditch. For such purpose, a provisional dike was built parallel to the ditch that was removed once the pipeline was already installed. On the following 70 m, the pipes rested on the ocean floor and were covered with a jetty. The rest of the emissary lies ballasted on the marine previously conditioned bed. When the emissary reaches the breakwater that closes the beach of West, at a height of the Roncaor massif, the pipe sinks in the water tangentially to the profile of the massif up to reaching 8 m deep. At this point, the alignment is modified by means of an elbow of 90˚, from which a stretch of 600 m connects with a 184 m long diffuser chain.

Diffusers were designed using CORMIX numerical model to optimize diameter and angle of discharge. This part is made of 24 ports of 240 mm in diameter and at an angle of 60˚. They are all separated by 8 m. The closest diffuser is located at a depth of 30 m and the farthest at a depth of 34 m.

The maximum discharge flow considered is 78 h m^3/year, which means an instant maximum flow of 3.47 m^3/s and a maximum salinity of 67.5 psu.

2. Objectives

The Águilas/Guadalentín desalination project included the design of a monitoring program adapted to the environmental characteristics of the marine surroundings whose general objectives are to determine the marine environmental conditions previous to its entry in operation; it also intends to evaluate the affection of the marine environment in the construction phase.

3. Methodology

A monitoring area has been established to assess the condition of the environment throughout time, it is to say: before, during, and after the works. The conditions of the marine environment are studied in the future dumping area, and the environmental impact derived from the execution of the open intake and outfall is studied as well. During this phase a follow up activity was carried out on behalf of the specialized personnel to ensure the fulfillment of the corrective and preventive measures planned for the project such as: placement supervision and the correct state of anti turbidity barriers as well as the detection of any accident that could materialize.

With every taken data the following parameters were registered: date, depth, weather conditions, sea conditions, and direction of currents and winds. The statistical analysis is carried out by using an ANOVA. The replicas are taken independently and randomly to avoid pseudoreplication according to Hulbert [24]. The works on the marine environment have been developed by Taxon Estudios Ambientales, S.L.

The particular objectives are: (a) future validation of the dumping dilution study once the plant is operative and to state: (b) the quality of the water of the receptor media, (c) the quality of sediments, (d) the biodiversity and richness of organisms, and (e) the conservation state of the seagrass meadows, *P. oceanica* and *C. nodosa*.

(a) For the future validation and checking of the dilution study data, a hydrodynamic study and a characterization space-time of the water mass located in the dumping area has been carried out to measure salinity, temperature, and depth. For the validation data on intensity and current direction and salinity, a current meter (3D NORTEK model AquaPro 0.6 MHz and software Aquadopp) and a salinity meter (RBR model XR-420-CT) are installed next to the dumping area in the bottom of the ocean for two months: from 10th September to 10th November For the second, the data came from a net of sampling points (46–75) that covers the influence area of the dumping. It was carried out by using a multi parameter probe CTD (type SB-19plus SEACAT Profiler from Sea-Bird Electronics); salinity and temperature measures were taken along the water column. Several water quality campaigns were carried out in September 2006, February and August 2007, August and December 2008, and March and October 2009.

There is data available for each season of the year. The data are represented as vertical profiles of salinity, depth, temperature, and dot diagrams; they are also stated in a bidimensional representation of salinity and temperature of the bottom of the sea, where hyper saline dumping spread expands.

(b) Related to the water quality in the surrounding area of the dumping, there is information from August 2008. There are 15 sampling stations (Fig. 3) distributed as follows: three along the costal area, one in the dumping area of the effluent, three in a radius of 100 m around the dumping area, four in a radius of 300 m, and others in a radius of 500 m.

The parameters measured are: pH, suspended solids, DBO5, dissolved oxygen, microbiology, phosphates, nitrates, nitrites, iron (all of them collected with a Niskin bottle) and salinity, temperature, density, CTD. Data were obtained in the surface and at 20 cm from the bottom. In each station a vertical profile of temperature, salinity, and density is also provided. This methodology follows Spanish legislation (Orden MAM/3,207/2006 and Real Decreto 60/2011).

During the execution works (Fig. 4), four sampling stations were established around the dumping area (C1–C4), two of them close to the works—C1 (at 4 m deep and above *P. oceanica)* and C2 (at 32 m deep on a coastal detritic seabed). Two of them are sufficiently far away from the works acting as a control station. C3 (at 10 m deep on *P. oceanica)* and C4 (at 26 m deep on a coastal detritic seabed). The campaigns were carried out between November 2010 and August 2011 during which records related to turbidity and suspended solids were taken.

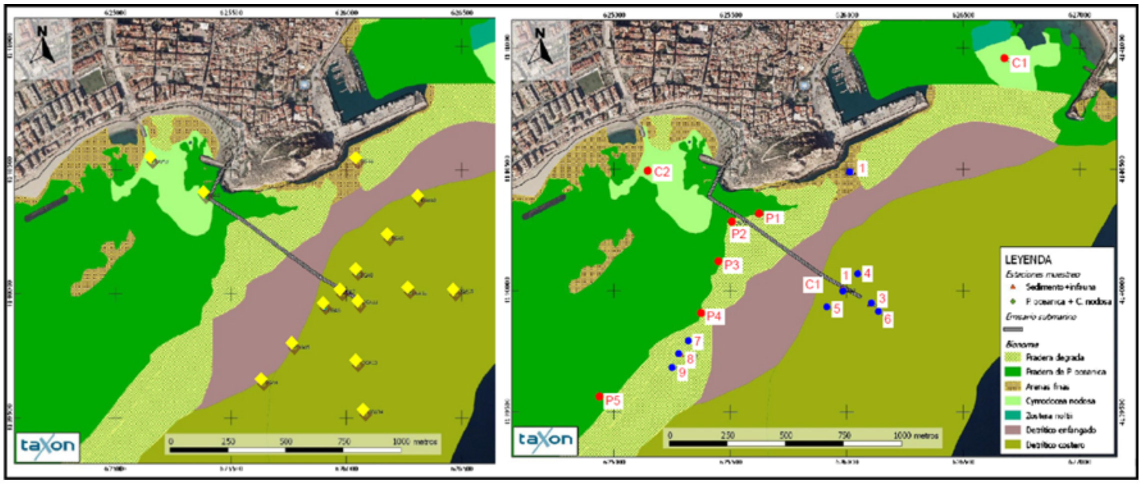

Fig. 3. Previous control point of the works for the water quality control (yellow), sediments and benthonic communities (blue) and *Posidonia oceanica* (P), and *Cymodocea nodosa* (C) meadows. P5 is a control station.

Fig. 4. Water quality control station, sediments, and benthonic communities (C) *P. oceanica* seabeds (P) left: outfall, during and after works; Right: open intake, before-during and after works (white spots for water quality; red spots for sediments and infauna; green spots for seagrass meadows).

In the case of the open intake, three sampling stations were set up where turbidity measures were registered chlorophyll A and turbidity (CTD) and suspended solids (Niskin bottle). Four campaigns were set in motion in the three phases, it is to say: previous, during, and afterwards (August 2008, July 2009, October 2009, and January 2012).

(c) For sediment control in the emissary works there is available data from August 2005 and 2008, April 2009, November 2010, and August 2011. Previous to the works, a network of nine sampling stations is established (Fig. 3). Those sampling stations are distributed in the influential area of the dumping and others farther away. Particle size, potential redox, nitrogen, carbonates, sulfides, iron, nickel, and microbiology are measured as well. A sampling campaign was carried out taking three replicas in each of the sampling stations by using a Van Veen Dredge 20×20 cm. After the sample taking, a direct measure was carried out of the potential redox with a EUTECH Instrument EcoScan pH6 probe. The rest of the parameters were measured in the lab transported in cold and darkness. This methodology follows the same analytical methods previously mentioned. During the works of the intake (Fig. 4) the very four stations are shown in which water quality is studied. In the case of the intake in two stations one of them established as reference control, sampling is carried out before and after the works (August 2008 and January 2012).

(d) For the characterization of the benthic communities in the works of the outfall system there is available data of August 2005 and 2008, April 2009, November 2010 and August 2011 from the same stations where the sampling of the characterization of the sediment was taken (Fig. 3) and those defined during the execution of the works (Fig. 4). The importance of this group lies that allows checking the possible fluctuations or perturbations of the media through the estimation of its structural parameters and the determination of the species indicators of the environmental stress.

Sediment samples were taken from 4.000 cm^3 by using a metallic quadrat of 20×20 cm frame inside, with sediment extraction of 10 superficial centimeters with a small shovel and posterior deposition in netted bags with 500 μm light, therefore, favoring the filtering of the sampling during the ascent. In every sampling station three replicas are taken for each sample. Those samples were transported to the lab where individuals found are separated alive, tagged, and fixed in alcohol 70% for later taxonomical identification. From these samples a systematic and quantitative study of the found polychaeta is carried out.

The main parameters used for the study of structure of this community are: diversity (diversity α Shannon-Weaver index and diversity β, coefficient of similarity of Sorenson CN modified by Curtis [25] equitability, richness and abundance.

In the case of the intake, sampling campaigns are carried out in the previous phase and after the works (August 2008 and January 2012)

(e) For the study of seagrass communities, a first inspection was carried out in 2005 by using side scan sonar. Afterwards, direct observation of the distribution of the meadows along transect was used. The direct observation quickly indentifies relevant declines in seagrass beds distribution or features. It is important to establish upper and lower depth limits of these meadows because they can change whenever they are suffering any environmental impact. There are available data on prairie quality before and after the works; such data were gathered in August 2005 and 2008, November 2008, April 2009, November 2010 and August 2011 for the emissary area. In the case on the intake, the data is from August 2005, November 2008, and January 2012.

In the surrounding of the emissary there is a total of seven sampling stations located at the lower part of the seagrass meadows (Fig. 3), five located in the nearby area of the dumping, and two far from the potentially affected area of the dumping. In these seagrass beds there are studies on their spatial structure: shoot density, coverage, and global density [26], leaf surface, leaf biomass, number of leaves per shoot, epiphyte biomass, and frequency of herbivorous attacks.

During the work of the intake, the control stations are set around the influence area Fig. 4. The control of the seagrass *P. oceanica* community is done by direct observation of the area that surrounds the pipeline. The surface of the prairie affected by excavation, burial sediment process, and lack of light is studied. The same previous parameters are measured.

(f) In the sampling stations located at seagrass meadows there are additional studies on echinoderms

Fig. 5. Turbidity barriers installed at dry riverbed Cañarete (intake works) and El Charco (outfall works).

density and aboundance/m^2 through direct visual inspection. Six ten meter long transects are carried out using a 1×1 m grid in each one of them.

In order to avoid dispersion of suspended solids during the excavation and creation of a dike needed for the execution of the outfall system, turbidity screens are put in place (Fig. 5) to enclose the work perimeter. 200 m of turbidity barrier type Markleen Series A in an L shape is put in place between the preexisting jetty and the Roncaor massif totally closing all the area of the work platform of jetty, dragging, and excavation of the emissary ditch. Afterwards, 50 m screens type Silmat-I-DOT designed to contain slimes was set parallel to the jetty platform and during its dismantling.

In the case of the intake, the barriers were used between the dike of the marina and the jetty, therefore, closing the entire area of the works. Likewise, during the excavation works in open sea, screen barriers around the ships were set in place to keep turbidity from reaching bathing areas.

3. Results and discussion

In terms of hydrodynamic study (intensity and current direction) for the analysis of currents data is gathered on the most superficial layer, 16 m as a presentation of an average depth and maximum at 30–32 m. There has been an average registration of intensity on the surface of 0.44 m/s (maximum and minimum of 1.58 m/s and 0.01 m/s respectively) and main dominant direction W-SW (41.87%) and secondary N-NE (27.52%). In the inferior layers current intensity diminishes down to an average of 0.08 m/s (maximum and minimum of 0.54 m/s and 0.00 m/s respectively) but maintaining the same direction.

The salinity meter anchored next to the current meter in the dumping area of the outfall has taken 8,230 data in a continuous manner (every 10´). The data are consistent with available water records. Because of its arid and dry climate and scarce contribution of continental waters show high salinity values: most of them between 36 and 38 psu (average value 36.68 psu).

The rest of records obtained after the analysis in a screen in the surroundings of the dumping throughout the four periods of the year show seasonal changes. In summer and due to a thermocline, there are extreme measurement values between the surface and bottom. During the rest of the year the values are more or less homogeneous in its vertical and horizontal distribution because of lost of sun radiation. The average salinity value and temperature in August is 37.38 psu and 23℃; in December 36.86 psu and 17.3° C, in March 37.83 psu and 14.8℃, and 37.67 psu and 21.9℃ in October.

Related to the parameters that define the water quality of the sea in the surroundings of the dumping, there are measures in 15 different points (surface and bottom) in the summer of 2008:

- The DBO5 or biological demand of oxygen presents general lower levels under 5 mg/l. It is an indicator of the good water quality. It only obtains three higher values on surface and another disparate at the bottom perhaps as a result of pollution during the manipulation of the sample.
- In terms of suspended solids, all the records show inferior values of 2 mg/l. It is about a parameter conditioned by environmental factors: hydrodynamism, wind, rain, and so forth. Likewise, turbidity average values obtained from deep and superficial waters are 0.67 NTU and 0.27 NTU, respectively.
- In terms of nitrates, nitrites, and phosphates values present some very low rates either on the surface and deep, characteristic of clean well-oxygenated waters. Only a high value has been detected at a sampling station located right on the coast and next to a sewage spillage, which must be taken into account in the future.
- Iron, biological parameters indicators of fecal pollution, and dissolved oxygen show normal values either on the surface or in depth in all control points, therefore, fulfilling all the objectives of bathing waters.
- Chlorophyll A allows estimating the productive capacity of the waters. It is influenced by factors such as sampling period or availability of nutrients in the media. Average surface value is 0.36 μg/l and 0.84 μg/l at the bottom. These can be considered as normal values if we take into account that in open sea areas concentration fluctuate around 2 μg/l [27].

In the case of the intake, the previous data of suspended solids on the surface and in depth before and after the works are low (<2 mg/l). Turbidity also shows low values previous and after construction (0.43 NTU and 0.28 NTU, respectively).

The studies carried out for the characterization of sediments in the surroundings of the dumping area mostly show medium and fine sand, with a presence of organic matter somehow superior than expected in coastal areas favoring the appearance of anoxic processes in the sediment of some of the control stations. The values of carbonates and sulfides are low, and in terms of heavy metals (Ni, Fe, and Zn) quite inferior to the objective quality in the sediments that establishes the "Recommendations for the management of dredged material in Spanish Ports" [28]. And in last place, the microbiology study shows very low values for *E. coli* and enterococci. On the contrary, we came across a slightly high average coliform value in the farthest sample stations.

In the case of the sediments in the surroundings of the open intake it has do with sandy seabed (>60%) with around 35% of fine sand in the proximities of the works.

In the benthic communities in the dumping area there is predominance of mollusks, polychaeta, crustaceans, and in a lesser extent echinoderms and cnidarians (Fig. 6). Polychaeta is the main organisms of these communities, either in species or number of individuals, followed by mollusks and crustaceans 188 species have been studied in the soft substratum in the study area. The highest average values of abundance are identified at the farthest stations and to the south of the outfall (at 26 and 27 m deep) with around 129 individuals, followed by the located at the foot the rock (12 m deep), and the one located at the end of the outfall (−34 m). The lowest values are measured at the station next to the emissary (−32.7 m) with 63, 67 individuals. Polychaeta are the most abundant taxonomic group with the exception of the station located at the foot of the rock where crustaceans are predominant.

The average highest values of richness are located in the same stations previously mentioned (around 50 species) and the lowest located at the foot of the rock (24 species). Polychaeta are the richest taxonomic group with around 124 species compared to crustaceans with 32 and mollusks with 26.

In terms of diversity, the obtained values in all stations are high between 5.21 bits/ind and 3.36 bits/ind. Likewise, in the majority of stations there is no predominance of one species over another and equitability values are at around one.

The most representative Polychaeta families present are those with carnivorous feeding habits like Onuphidae, Syllidae (it accounts for 18% of the total), Lumbriconeridae, Phyllodocidae, and Dorvilleidae; followed by other sedimentivorous polychaetes families such as Cirratulidae, Capitellidae, Maldanidae, Paraonidae, Oweniidae, Spionidae, Terebellidae and Flabelligeridae; and also the filtering type such as Sabellidae.

The highest indexes of biodiversity and also the abundance of the Syllidae family are located at the sampling stations in the *P. oceanica* meadows. This, along with the Capitellidae, seem to present a good initial resistance against dumping [29] while Paranoidae shows high tolerance against dumping.

In the studies of the Polychaeta community in the surroundings of the open intake we appreciate no significant differences among families. Both stations are located at sand patches within a prairie of *P. oceanica*. At the station located at around 100 m of the final stretch of the outfall, the filtering Sabellidae family predominate indicating clear waters. At this station, we can observe a qualitative change in the composition of the species at the end of the construction period and species better adapted to sedimentation or burial processes appear.

So, opportunist species coexist with more structured habitat species, therefore, showing a slight increase in diversity parameters, richness, and abundance. The most representative families are those of trophic habitats sedimentivorous and detritivorous, such as Spionidae, Maldanidae and Chaetopteridae; although, the Sabellidae family still predominates. At the farthest sampling station, the Syllidae family predominates.

Related to seagrass meadows, the studied area in the surroundings of the dumping area is made of a vast community of *P. oceanica* that expands from Punta Parda (to the south) to Águilas marina, next to the study area to the north.

During the drafting of the project, previous information was available about the distribution and quality of the prairie, [30,31]. It was stated that the

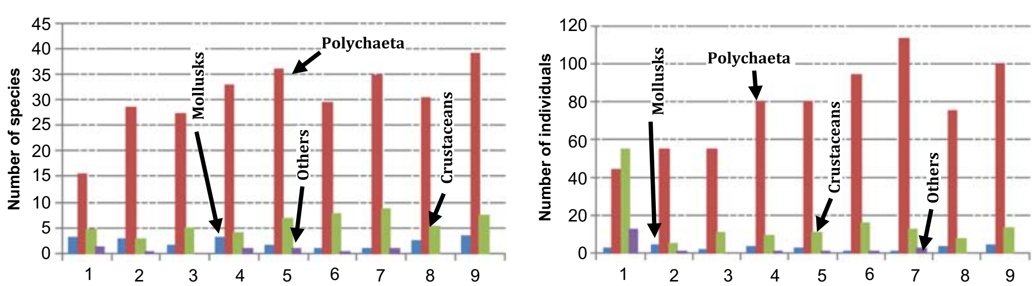

Fig. 6. Distribution of the different taxonomic groups at the sampling stations in the surrounding of the outfall. Species level (left) and abundance (right).

community located opposite Águilas port was suffering and important regression apparently due to dragging fishing prior to the location of an antitrawling artificial reef. This was confirmed with the bionomic studies carried out during the project for the design of the dumping (year 2005). Afterwards (2008 and 2009) studies show the disappearance of the prairie of Águilas marine port entrance and opposite of its breakwater protection. The degradation state of this meadow was also observed opposite San Juan castle. Therefore, its inferior limit went from around 23 m deep in 2001 to 21.5 m deep in 2008–2009.

In the surroundings of the outfall the prairie has an inferior limit of 25 m deep and a superior of 9 m deep. It is a well-kept meadow.

These prairies show different morphological forms, a typical case of the coast of Murcia and Alicante. The inferior limit of these prairies is made of small patches as a result of sedimentary stress of these zones. As the prairie gets deeper, it becomes continuous and, in certain occasions, they form intermatte channels covered by sediments.

In 2010 and as previous reconnaissance of the works, a new bathymetric study was carried out; it was verified that the NE extreme of the seagrass bed was more degraded than in the SW. Its limit had gone back again to 19 m deep, which confirmed a regressive trend (Fig. 7). In 2011, the follow up works of the affections derived from the outfall work confirm its inferior limit between 18 and 19 m deep.

In terms of density (no. leaves/m^2 prairie), coverage (% of seabed occupied by leaves), and global density [(density/surface of sampling) × (coverage/100)] of the prairie surrounding the emissary, the average values of higher density (Fig. 3) were obtained at station P1 (Table 1) and the lowest at P2 and P3. In terms of coverage, the highest values are at control station P5 and the lowest at P2 next to the laid out of the outfall.

The two previous parameters are related to the global density parameter. The highest records were given at P5, which is the area of *P. oceanica* farthest from the spillage point. The lowest once again is close to the emissary P2.

Low values of leaf surface and biomass and epiphyte biomass are registered at station P1 in the area of most degraded prairie. The analyzed parameters indicate that the farther we get of the future spillage the better conditions of the prairie.

Related to the prairie in the surroundings of the intake the superficial sampling station (−9 m) has been eliminated as planned in the project for the excavation works executed in the first stage. In the second station located next to the tower of the open intake, shoot density and coverage values previous and afterwards show no significant differences. Density global values foreseen and afterwards are 17.88 and 19.88 respectively.

Echinoderms species found in the five stations located in the prairie are: *Esphaerechinus granularis*

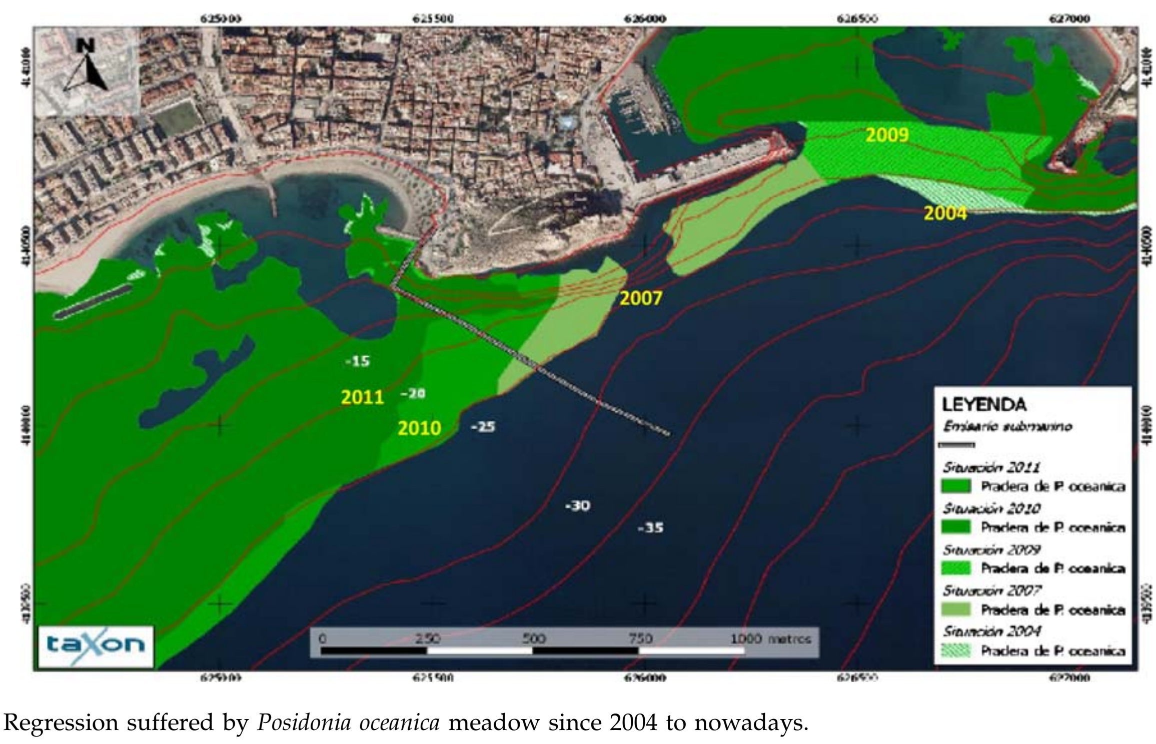

Fig. 7. Regression suffered by *Posidonia oceanica* meadow since 2004 to nowadays.

Table 1
Average values of structural parameters of *Posidonia oceanica*. FAH (frequency of herbivorous attacks%)

Station	Shoot density	Coverage	Global density	Leaf surface	Leaf biomass	Epiphyte biomass	No. of leaves	FAH
P1	216.67	2.88	6.23	268.6	0.8	0.8	7.7	25.8
P2	120.83	0.88	1.06	382	1.1	1	7	16.4
P3	120.83	2.00	2.42	372.2	1	0.7	7.5	2.8
P4	154.17	1.70	2.62	331.2	0.7	1.1	6.5	2.2
P5	175.00	5.60	9.80	424.1	1	1.2	7.2	11.9

Fig. 8. Turbidity curtain surrounding the dike and barrier construction (left) and the marine excavation works (right).

(Echinoidea), *Echinaster sepositus* (Asteroidea), *Holothuria tubulosa* and *Holothuria forskali* (Holothuroidea). From them, *H.tubulosa* is the most abundant and it is present in every sampling station.

3.2. *Environmental marine monitoring during and after the construction phase*

The foreseen control program is initially focused on correct control of the management of excavation mud and once the pipeline reaches the marine seabed, we monitored the environmental impact derived from the opening of the ditch and support of the pipeline over the seabed.

The turbidity barriers have successfully remained on site throughout the entire time of the excavation works (Fig. 8) when enclosures were created. However, when these barriers were placed in open sea their effectiveness was reduced as proven in the execution of the intake. Likewise, bad marine weather conditions have displaced barriers or ground them breaking floating devices and curtains; it was necessary to replace them.

For suspended solids (Figs. 4 and 9), the levels observed on the surface and bottom before and after the works of the outfall show very stable values with records of 8.1 mg/l and 0.6 mg/l respectively. In terms of turbidity stable values were appreciated corresponding to transparent waters. Previous records show higher values as a result of weather conditions.

In the case of the open intake, during the works higher values of suspended solids were registered with maximum values of 26.6 mg/l deep and lowest at 13 mg/l (Fig. 10). In the case of turbidity, during the works, maximum values were registered at the station located at less depth and closer to the works with a maximum and minimum of 2.38 and 1.45 NTU, respectively.

The marine sediments in the surroundings of the outfall are fundamentally made of sands of less than 2 mm with average values that fluctuate between 89.92% at C1 and 48.75% at C4. With the exception of C1 that at the end of the works exceeded 79% of fine sands, the rest showed predominance over sands of greater size per grain (>0.4 mm). The fraction of gravel shows the lowest values at C1 (0.32%) and the highest at C3 (26.21%). In the case of slimes and clays the farthest station of the works (C3 and C4) has registered fluctuations before and after the works. C3 has experienced a drop from around 20 to 9.7% and C4 has

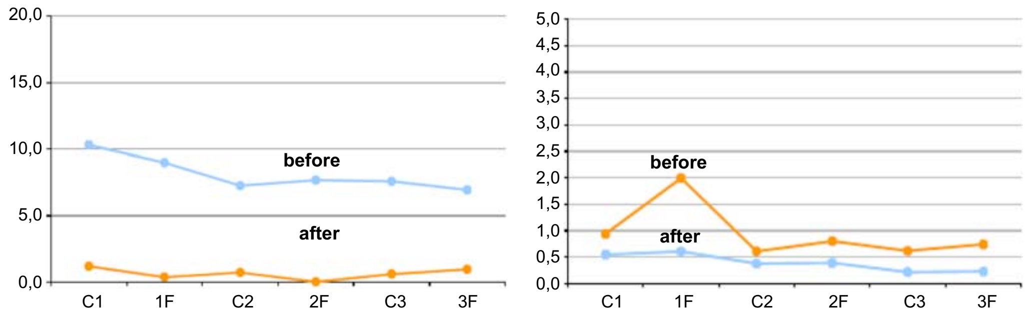

Fig. 9. Graphic representation of SS and turbidity values in the previous phase (blue) and the completion of the emissary works (orange).

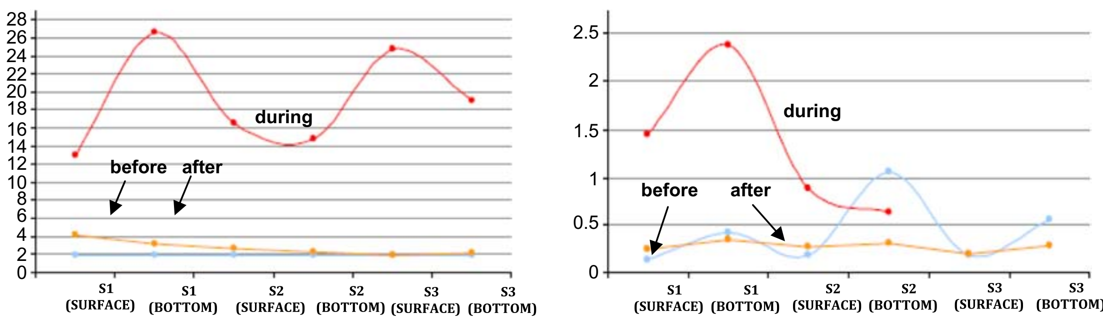

Fig. 10. Graphic representation of SS and turbidity values in the previous phase (blue), during (red) and the completion of the intake works (orange).

Fig. 11. Surface affected by the outfall works. Left: ditch excavation area (purple), Jetty (blue). Right: surface of *Posidonia oceanica* directly affected by the works (red) and semi buried prairie (green stretch parallel to the jetty).

gone from an initial 6.21 to 46% at the end of the works.

Therefore, only station C4 (control) has registered important variations from the beginning of the works affecting in a greater extent the distribution of coarse, medium, and fine sand materials. This variation may be the result of hydrodynamic characteristics of the area, but under no circumstance has anything to do with the works given the distance to this control point.

In the case of the intake, no important variation has been detected in the distribution of the different size of sand grain before the beginning or ending of the works in any study station.

Fig. 12. Left: semi buried prairie by the seabed sand movement and dismantling of the jetty. Right: squashed prairie by the ballast of the emissary where it lays on the seabed.

At the works of the outfall, the greatest harm on the *P. oceanica* meadow has been produced by the construction and dismantling of the jetty used as a work platform for the excavation of the ditch, where the emissary is placed and also because of the burial of the prairie in the construction of the jetty that sets the piping to the bottom (Fig. 11). So, the harmed area of the prairie has been around 2.357 m^2; we must add the surface occupied by the ballasts of the emissary to the first flange union that practically coincides with the ending of *P. oceanica*. Out this surface, 65.66 m^2 corresponds to the excavated area and the rest, 2.291 m^2 to the jetty area.

In a stretch of 2–3 m wide parallel to the work jetty, the prairie has been semi buried (Figs. 11 and 12). This stretch occupies an area of 134 m^2.

In relation to its spatial structural parameters and considering the global density, it is observed that the values of this parameter before and after the works (Fig. 13) are similar except at P5 (Fig. 4) where a significant descent is registered. This is an expected value because the station is next to the works where most of the ground movement took place (excavation, and the creation of a jetty).

P2 station shows very low values. In this area the prairie is very degraded and in clear regression. In fact, in 2008 its inferior limit was around 23.6 m deep and nowadays there is a landscape of dead matte with isolated leaves and an inferior limit situated at approximately 18 m deep.

At the P1 station located in the inferior limit of the prairie to the northeast of the outfall, the records are also very low. In this area, an important regression of the inferior limit of the prairie has been detected; it has gone from 21.5 m deep in 2008 to 18 m deep nowadays. The same prior biocenosis takes place; it is to say dead matte with isolated rhizomes of *P. oceanica*. Stations P3 and P4 to the west and east of the outfall are superficial stations (10 and 11 m deep) and show higher values compared to the previous stations.

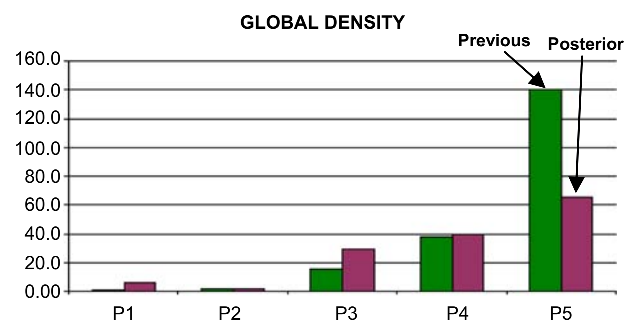

Fig. 13. Graphic representation of global density obtained in each of the sampling stations before and after the works of the emissary.

Table 2
Limit values for the water quality parameters in the brine discharge

Parameters	Limit values for brine outfall
DBO5	25 mg/l
DQO	125 mg/l
SS	35 mg/l
pH	6–9 u. pH
Detergents	3 mg/l
*T*ª	3°C
Phosphorous	2 mg/l
Nitrogen	15 mg/l
Iron	1.5 mg/l
Total chlorine residual	1.5 mg/l

Related to the rest of communities present, the ones occupied by the light rocky seabed affected by the works correspond to a previously altered biocenosis with species of scarce ecological value that quick recover. The density of echinoderms observed is very low.

3.3. Legal requirements on brine discharge and other environmental parameters

In order to protect, *P. oceanica and C. nodosa* meadows and not to change the marine environment around the brine discharge, Águilas desalination plant requires controls and surveillance of several parameters during its operation phase according to Spanish regulations. The discharge legislation requires plant owners to acquire an Environmental Operating License that obliges operators to assure permanent controls ensuring the analyzed parameters are below the authorized limits. These authorizations cover physicochemical and biological analysis.

The effluents from the whole desalination process are the discharges from the RO process (brine flow) and the flow from the sand filters and membrane cleaning. These effluents are permanently controlled by, among others, a salinity meter and flow-meter equipment set in a manhole located before the discharge to sea takes place.

The limits of the water quality parameters stated in the Environmental Operating License (Table 2) were established taking into account that the disposal is discharged in a "high ecological sensitivity area" which is protected and demands more restrictive values on discharges parameters. These values are required to be under the limits before the discharge is done; assuring them in that process point means they are going to fulfill the mandatory standards in the marine environment.

Since there is a lack of an specific legislation for desalination plants, the marine dumping authorization used is the one of urban sewage waters; however, the dumping of desalination plants has nothing to do with wastewater treatment plant outfalls. The brine discharge of a desalination plant does not contain microbiological components or derived elements from nitrogen or phosphorous that could bring about the eutrophication of the marine environment.

Likewise, residual chlorine content is not significant in the case of RO desalination plants, which is not the case of thermal multi-stage flash plants [22]. Chlorine compounds (such as sodium hypochlorite) are used in the pretreatment as a disinfectant and because of the low concentrations it is always under the set threshold.

Consequently, among all these parameters, the most important parameter to be fulfilled was suspended solids. The concentration of suspended solids in the cleaning water can reach values up to 1.500 mg/l. However, with 70% supposed output of the equipment, the values of suspended solids after the decanter can be minimized to 450 mg/l. This concentration can be reduced by mixing this flow with the brine effluent (which has no suspended solids in this water) and getting values under 35 mg/l in the total mixed effluent that is discharged into the sea, ensuring the values upheld in the Environmental Operating License.

Related to seagrass meadows, although there is no regulation which establishes salinity limit to protected them, environmental administrations demand not to exceed the value of 38.5 psu in more than 25% of the continuous analysis carried out in the established sampling points (or 40 psu in more than 5%) for *P. oceanica*, and the value of 39.5 psu for *C. nodosa* (or 41 psu in more than 5% of the analysis).

In terms of instrumentation to carry real-time continuous monitoring of the salinity in sea environment during plant operation, three CT type SeaBird SBE 37-IMP salinity meters have been installed. We are dealing with high precision conductivity (0.001 mS/cm) and temperature (0.0,001 °C) equipment. This equipment communicates through an inductive cable that connects every single CTD, and it reaches the catch basin on the ground where the data server and communication modems are located. For the protection of the electronic components, the system uses a SAI that guarantees stability and prevents any interruption in the supply of power.

This equipment is, therefore, connected in real time to the data server. Conductivity and temperature records are integrated in a made to measure software able to automatically calculate the basic descriptive statistic.

4. Conclusions

The detailed studies carried out previous to the works on marine conditions in the surroundings of Águilas show that the quality of the water and sediments registered normal values for the physicochemical studied parameters. However, degradation signs are present in the closest areas to Águilas marina, in the proximity of the outfall of the desalination plant.

As expected, during the works high values of suspended solids and turbidity were registered that rapidly recovers their normal values and, therefore, does not pose reduction of light intensity and a threat to the prairies of nearby seagrasses.

The sediment study at the stations next to the works does not show significant differences between the previous and afterwards conditions. The granulometric differences observed are caused by the hydrodynamic characteristics of the area. Benthic communities do not show significant affections as a result of the construction works. The observed changes in the surroundings of the intake are considered isolated and hardly relevant.

Related the *P. oceanica* meadows, we have been witnesses of the changes suffered on Águilas coastal area community. The emissary goes by an area where the seabed showed evident degradation and regression signs before the works, probably because of man-induced disturbances; it is a result of location and the activities that characterize this area. Station P1 where the prairie is most degraded is located next to the influence area of the marine pipeline of sewage waters right under the rock. The studies carried out show its degradation in the surrounding of the future brine spillage (Águilas marina and at the foot of the Roncaor rocky massif); its inferior limit has been backing down in the last years nowadays reaching 19 m deep. The seagrass meadow degradation is more notorious in the north east extreme of the study area, and it improves as we move south west.

The macrobenthic community is also affected at the foot of the rock.

The excavation works have been precisely carried out, therefore, reducing the affected surface area of the prairie. The environmental impacts on biological communities produced during the works of the emissary are restricted to the occupied surface of the pipeline and a minor and nearby area of the works. The construction of the marine pipeline has not affected the quality of the existing prairie as shown in the study of structural parameters.

In the study area, there are numerous activities that may damage the marine environment; (a) near-shore trawling and other fishing techniques. Through a side-scan sonar marks of 20 m to 50 m deep have been highlighted; (b) marine spillage of sewage waters; (c) beach regeneration activities; (d) marine crops; (e) port activities.

All the gathered information previously obtained to the operation of the desalination plant allows defining the conditions of the ZERO STATE of the marine environment. During the works, an exhaustive control has been carried out and a series of preventive and corrective measures were implemented; they have minimized environmental impacts.

Having an operational diagnosis allows a follow up on the marine environment in the functioning phase. As a result, it is possible to detect if changes in the marine environment can be attributed to natural variations or to the brine spillage itself.

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