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# Salinity tolerance of the Mediterranean seagrass *Posidonia oceanica*: recommendations to minimize the impact of brine discharges from desalination plants

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**Abstract**

Desalination of seawater has become an important and growing industry due to the present water shortage in some Mediterranean countries. This activity may result in some environmental impacts, mainly generated by the discharge into the sea of the brine produced, which can affect marine benthic communities. *Posidonia oceanica* (L.) Delile is an endemic seagrass of the Mediterranean Sea, where its meadows represent a relevant ecosystem susceptible to being affected by these desalination effluents. The present study was planned in order to investigate the effects of hypersaline discharges on *P. oceanica* and its main associated organisms, and to provide adequate knowledge to help managers in the taking of decisions related to hypersaline discharges potentially affecting *Posidonia* meadows, particularly in the Spanish Mediterranean.

The research included three different approaches conducted by distinct research teams whose results indicate that *P. oceanica* is very sensitive to salinity increases. Laboratory and field experiments showed significant effects on seagrass structure and vitality at salinities of 39.1 and 38.4, respectively. Due to this high sensitivity of *P. oceanica* to salinity increases, we recommend to avoid design and construction of brine discharges in areas

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where these ecosystems or others that are potentially sensitive occur. However, when this option is not possible, we suggest not to exceed neither 38.5 psu of salinity in any point of the meadow for more than 25% of the observations (on an annual basis) nor 40 psu of salinity in any point of the meadow for more than 5% of those observations.

*Keywords:* Desalination; Environmental impact; *Posidonia oceanica*; Salinity tolerance

## 1. Background

The present document summarizes the conclusions achieved in a first attempt to investigate the effects of hypersaline brine discharges of desalination plants on the Mediterranean seagrass *Posidonia oceanica*. This work was promoted by the State Company *Aguas de la Cuenca del Segura* (ACSEGURA) which was planning to build a large desalination plant (140,000 $m^3$ $day^{-1}$) in a locality on the Southeastern coast of Spain (Rambla de Matalentisco, Murcia, Spain). At this locality a continuous meadow of the seagrass *P. oceanica* is present between the coastline, and the 25 m depth line. *P. oceanica* is an endemic seagrass species of the Mediterranean and its meadows are protected by environmental regulations in accordance with their great ecological value and relevant services they provide [1–3]. In particular, Mediterranean seagrasses are included in the high priority conservation natural habitats catalogue of the European Council (Directive 92/43/EEC, 21 of May, 1992).

Salinity of brine discharges (60–90 psu) is considerably higher than ambient values to which seagrasses are adapted. Therefore, a possible conflict between habitat conservation and water production by desalination was perceived. Given that the seagrass habitat extends over a large part of the Mediterranean coast, and that it is foreseen a substantial increase in the installation of new desalination plants (in Spain and other Mediterranean countries), the capacity of *P. oceanica* to tolerate a salinity increase become an issue of general interest. Yet, to date, there is no information related to salinity tolerance thresholds of *P. oceanica* and its main associated organisms.

To cover this gap and with the aim of providing some directives to managers for brine water discharges, the State Society ACSEGURA and the Centre of Studies and Experimentation of Public Works (CEDEX) subscribed in May 2000 an agreement of collaboration to "Investigate sea discharges of reject waters from desalination plants". This work consists of two parts; the first one addresses the physical study of the discharge, including optimization of the device that maximizes the dilution of the brine, the second one, oriented to determine the biota tolerance thresholds to salinity increases. This document summarizes the conclusions arising from the second block of the work that was conducted under a collaborative agreement of CEDEX with the Centre of Advanced Studies of Blanes - CSIC, the Oceanography Centre of Murcia of the Spanish Institute of Oceanography (IEO), the Department of Ecology of the University of Barcelona and the Department of Marine Sciences of the University of Alicante.

## 2. Research program

Despite the call for this knowledge being requested for a single study case (Desalination Plant of Rambla de Matalentisco) the study was planned not only to prevent and foresee the possible impact of this desalination plant, but also to provide directives for the management of any hypersaline discharge that may affect *P. oceanica* meadows, particularly in the Spanish Mediterranean coast. Thus, the research includes three different approaches that correspond to different

subprojects, each one conducted by different teams:

(1) Experimental work in the laboratory: a number of *P. oceanica* shoots were maintained in 300 l tanks during 15 days under different controlled salinity treatments (salinity range: 23–57 psu). The work was conducted by the University of Alicante team using the facilities of MUNDOMAR Company at Benidorm (Alicante)
(2) Experimental work in the field: a series of plots, 1 $m^2$ surface and located in a natural stand of *P. oceanica* were treated *in situ* with two different concentrations of a hypersaline water discharge obtained from a pilot desalination plant constructed by ACSEGURA for experimental purposes. Research was conducted by the Centre of Oceanography of Murcia of the Spanish Institute of Oceanography.
(3) Field surveys: study of the long term impact of desalination plant discharge on a *P. oceanica* meadow in the Balearic Islands. Research was conducted together by the teams of the CEAB-CSIC and UB.

## 3. Results

Laboratory experiments [4] showed that the increase in seawater salinity results in a reduction of seagrass vitality (leaf growth, necrotic spots in leaf tissue and premature senescence of the leaves) and higher plant mortality. These effects were statistically significant at salinities of 39.1 psu and above. In some cases, affected plants that had been exposed to short hypersaline episodes were able to recover their normal growth once returned to normal salinities. Plant mortality increased with salinity, being the differences significant at 40 psu and above. At 45 psu, approximately 50% of the plants died within 15 days. The results obtained were the same if the whole plant was exposed to the treatment salinity or if the aquarium was stratified with only the basal portions of leaves being under the hypersaline water. Experiments in similar aquaria were also performed to test the tolerance to hypersalinity of some important and frequent animals in the meadows; the mysid *Leptomysis posidoniae* and the sea urchin *Paracentrotus lividus*. In both cases, mortality increases were detected at salinities over 40.5–41 psu, although always depending on temperature. In general, at the same salinity the survival decreased as temperature increased.

The field experiment was of notable technical difficulty but also showed significant effects of brine treatments on seagrass meadow structure and vitality associated with salinity increase. During the experimental 3-month period, salinity values were of $39.2 \pm 0.8$ psu (standard deviation) in the parcels with "very high salinity" (VS) and of $38.4 \pm 0.3$ in the "high salinity" ones (HS). This represents an average increase of 1.52 and 0.71 psu, respectively, over the ambient seawater salinity measured in control plots ($37.7 \pm 0.12$). Spatial variability within the plots was higher in the experimental plots than in the controls (note increase in standard deviation) and was not constant throughout the experimental period. In the HS plots, the frequency of salinity values equal to or higher than the mean treatment was only of 26.9 and 44.4% for the VS plots. At the end of the experiment, plant mortality was higher in plots with brine treatment than in control plots, being higher in the VS treatment (20%) than in the HS treatment (14%). In addition, other indicators (i.e. number of leaves, maximum leaf length, presence of necrotic marks, leaf growth rate and biomass) showed lower seagrass vitality in the plots with the brine than in control ones. Differences were found from null to moderate in plots of "HS", and from moderate to very important in parcels of "VS". Furthermore, both in HS and VS treatments total non-structural carbohydrates decreased in rhizomes up to 27.2% of mean values measured in control plots. This result may

be explained by the decrease in the total and available photosynthetic surface caused by brine as was reported by the reduced leaf vitality descriptors.

The study of the long-term effects of brine produced by an active desalination plant in a natural meadow was conducted in Formentera, and has to cope with the complexity and heterogeneity of the natural meadow studied. Nonetheless, we detected a very important impact on *P. oceanica* plants in the nearest area to the emissary (salinities between 38.4 and 39.8 psu) with very low shoot abundance, a significant reduction in leaf size, an overload of epiphytes and some alterations in the physiology of plants compared to unaffected homologous areas. The analysis of the emissary waters revealed elevated nutrient contents (particularly nitrates but also phosphates), higher than detected on receiving waters. The high nutrient concentrations of the brine may be the result of organic pollution not related to the desalination plant. This fact, together with other plant symptoms, such as the extremely high epiphyte abundance, the higher nitrogen and phosphorous concentration in tissues and the higher herbivore activity, leads us to think that, even without discarding a possible salinity stress, the main cause of the degradation of the meadow in the near field of the emissary is eutrophication. However, in the far field of impact of the saline plume, with salinity fluctuating from 37.8 to 39.3 psu, the plants were no longer having eutrophication symptoms. The meadow did not show differences in shoot densities compared to reference sites, however changes in the structural pattern of the shoot distribution, increase in the frequency of necrosis marks in the leaves, and a significant lower abundance of the accompanying macro fauna, compared to homologous meadows not affected by the discharge. We can thus attribute the alterations in the far field of the meadow to salinity stress.

## 4. Evaluation of the results

The results obtained here indicate that *P. oceanica* is very sensitive to salinity increases. Laboratory and field experiments showed significant effects on seagrass structure and vitality at salinities of 39.1 and 38.4, respectively. This means that the threshold of salinity tolerance of this seagrass species is very low, only 1–2 psu higher than the mean ambient salinity (37–38). This also means that both independent experiments produce similar results and that they are consistent with those obtained in field surveys. The experimental results therefore support the hypothesis that variability of seagrass descriptors measured in the field surveys (desalination plant in Formentera) can be attributed to the observed salinity increase both in the far fields and, at least partly, in the near field of the brine discharge.

Thus, despite the differences in the type and scale of the research approach used by each group, the results obtained are highly coherent among them and can provide answers to basic questions raised by coastal managers (i.e. recommendations on critical salinity thresholds). Nonetheless, there are still many issues that need to be addressed in future research. Both laboratory and field experiments demonstrated the sensitivity of *P. oceanica* at the short-term (15 days and 3 months, respectively), so their results cannot be extrapolated to field conditions where many environmental parameters (i.e. light, temperature, hydrodynamics) interact. We do not know what would happen if the situation persisted, such as if the identified effects would be cumulative or synergistic, causing higher mortality or degradation than those detected until now, or, on the other hand, a certain change and acclimation of *P. oceanica* to osmotic stress would occur diminishing the range of impact. Doubts also exist about response variability, depending upon seasonality, depth or other natural environment components that could modulate the plant response. Other preliminary results (not reported

here) also suggest that plants at deeper depths may be much more sensitive to the brine that those living near the surface.

Field studies of seagrass meadows under chronic osmotic stress are also subject to many uncertainties, mainly because environmental heterogeneity (substrate, topography, etc.) can mask the effect of the brine effluent. The nature and composition of the brine is also important. In the case studied here, the significant impact of the eutrophication in the very shallow meadow hid the effect of the salinity increase. Also, it is difficult to characterize the salinity regime over time in the different points of the meadow affected, as well as its associated heterogeneity. Moreover, these results can certainly not be extended to other discharge situations, particularly if the volume of the effluent, the depth ranges of the meadows and hydrodynamics of the system are different from those in our study site.

Finally, the experimentation with accompanying animals has not been as extensive as it has been with the plant and, although it has evidenced great sensitivity to increases in salinity, it was not able to determine precise salinity thresholds. Moreover, it should be stated that fauna and flora together are one of the most outstanding patrimonial values of the *P. oceanica* ecosystem.

In summary, when producing recommendations about critical values, one should act with caution, taking into consideration:

(1) the sense of "environmental caution" which means leaving some margins of security that guarantee the persistence of the affected meadows, and
(2) not giving as definitive results that (though they are very important because they are the only ones) should be open to later verifications. Further studies are needed in order to corroborate or modify and improve the critical thresholds that provisionally are provided in this paper.

## 5. Recommendations on critical salinity thresholds

As a general recommendation and given the high sensitivity of *P. oceanica* and its associated fauna to even moderate to salinity increases, it is recommended to avoid the design and construction of brine discharges in areas containing these ecosystems (or others that are potentially sensitive), with sandy bottoms without vegetation being preferable.

In the event of impossibility to fulfill of this recommendation due to constructive, economic or of any other type of restrictions, and keeping in mind the results presented here and, in particular, the principle of environmental vigilance formulated in Rio de Janeiro Summit, the following alternative recommendations are made to be applied to any hypersaline discharge that could impinge on meadows of *P. oceanica* in the Western Mediterranean:

– It should not be allowed to exceed 38.5 psu of salinity in any point of the meadow for more than 25% of the observations on an annual basis.
– It should not be allowed to exceed 40 psu of salinity in any point of the meadow for more than 5% of the observations on an annual basis.

Any observational study should be performed with a frequency period in accordance with the general regime of variability of the parameter in question. Therefore, when referring to the meadow salinity, it is important to refer to salinities measured inside the leaf stratum, within a height embedded between the surface of the sediment and 5 cm above the foliar meristem of the plant.

The proposed values seem in the present state of knowledge, to be compatible with the meadows' maintenance and its associated fauna. It also seems more adequate, regarding the receiving environment and the performance of the desalination plant, not to give it in the form

of a reference value but as a certain frequency distribution. It is important to notice that these proposed values are only applicable to Western Mediterranean. Other *P. oceanica* populations may have different tolerance thresholds that must be estimated, mainly in the Eastern Mediterranean where populations are naturally submitted to higher salinities.

The suggestions mentioned above are the most realistic that can be provided with the acquired and available knowledge; they can, and they should, be revised as soon as new information on this topic is available.

## 6. Other suggestions

In the context of design and implementation of hypersaline discharges on *P. oceanica* meadows, it is fundamental to emphasise two following aspects:

– Critical values pointed out above, probably represent an adequate dilution as to minimize or suppress the effects of other pollutants that could be contained in the discharge (in a continuous or sporadic way). However, when executing impact studies it is necessary to know which substances, as a result of the desalination plant managing (i.e. cleaners, anti-scalants and other products) or even as result of natural composition of the treated water (i.e. phosphates, nitrates and ammonium) are present in the reject water. It will be also necessary to determine the possible impact on the biota of these other substances, either by the available literature or experimentally.

– Although the execution of environmental monitoring programs is a usual practice in almost any significant intervention in the marine environment, we want to emphasize the importance of these practices in the context of saline management discharges. The monitoring programs should be designed and performed with maximum rigor and scientific quality. This strictness must be reflected in selecting an appropriate sampling design (detailed space characterization of the meadow, sampling in several control stations, etc.), with statistically acceptable replication degree. The accompanying biota also requires special attention. Environmental monitoring programs are an important source of information, allowing verification of the proposed ideas and, if it is the case, adjust and improve the recommendations.

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