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Environmental impact of brine disposal on *Posidonia* seagrasses

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Abstract

The location of big SWRO plants is usually limited by environmental restrictions such as the presence of the Posidonia habitat in the Mediterranean coast. The unknown impacts of brine on the flora and fauna associated at sea grasses has caused environmental damages either high cost disposal solutions of doubtful viability. Previous to the construction of 160.000 m^3/day SWRO Plant in the southeast coast of Spain, an unique research study was carried out in the Mediterranean coast by some of the most advanced Spanish Research Centres in cooperation with two Spanish universities. The knowledge of the *Posidonia* limits can help not only to locate Desalination plants but to design disposal devices. This paper reports the results of two years study testing the salinity impact on Posidonia habitat lab and field with brine produced with a SWRO pilot plant. Additionally a brine disposal model has been developed to support the design of a full scale disposal system.

Keywords: brine, Posidonia, desalination impact, high salinity discharge

1. Introduction

In December 1999, the public company Acsegura received the order from the Spanish Government to build and operate a Sea Water Desalination Plant of 140,000 m^3/day located in the southeast of Spain in Murcia Region. The Mediterranean coast of Spain is covered by the sea grasses of *Posidonia oceanica*, included in the list of protected habitats of the EC.

The "Habitats" Directive 92/43/EEC [1] is a Community legislative instrument in the field of nature conservation that establishes a common framework for the conservation of wild animal and plant species and natural habitats of community importance; it provides for the creation of a network of special areas of conservation, called Natura 2000, to "maintain and restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest". Habitat 1120 * Posidonia beds *(Posidonion oceanicae)* include:

1. Beds of *P. oceanica* (Linnaeus) Delile characteristic of the infralittoral zone of the

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Mediterranean (depth: ranging from a few dozen centimetres to 30–40 m). On hard or soft substrate, these beds constitute one of the main climax communities. They can withstand relatively large variations in temperature and water movement, but are sensitive to desalination, generally requiring a salinity of between 36 and 39%.

2. Plants: *P. oceanica*.

Animals: Molluscs, *Pinna nobilis*; Echinoderms, *Asterina pancerii*, *Paracentrotus lividus*; Fish, *Epinephelus guaza*, *Hippocampus ramulosus*.

P. oceanica is widely extended around the Mediterranean sea ranging from a few dozen centimetres to 30–40 m. *P. oceanica* is an endemic plant in the Mediterranean with roots, stalk, leaves and fruits that lives under water between the surface and a maximum depth of 40 m. The plant forms beds of Posidonia that are the most important ecosystem of the Mediterranean, equivalent to the forests of the land ecosystems. Posidonia situated on the sandy seabed and rarely on rocky beds that supply great quantities of oxygen and organic material contributing, also, to the balance of sediment on forming barrier reefs that maintain the coastal stability and protect the beaches from erosion.

The fields of *Posidonia* are also a great source of biodiversity as they are the habitat of numerous vegetable and animal species, some of which are in danger of extinction. The *P. oceanica* has an annual growth cycle and the dead leaves, sometimes in the form of balls, are deposited on the beaches, protecting them from the erosion caused by the waves.

In spite the *P. oceanica* great importance, the regression is becoming usual due to human activities, such as fishery, aquiculture, effluents discharges, beaches regeneration, marinas, etc. producing a direct or indirect impact on the Posidonia or the environment.

Posidonia oceanica L. Del., a Mediterranean endemic species, is one of the best-known as well as the most endangered plants in the Mediterranean Sea [4]. It is not an alga but a flowering plant, i.e. a vascular plant with all the characteristic woody parts—rhizome and roots, leaves, flowers and fruits. At first sight it reminds us of grasses; this is the reason why we usually refer to it as to a grass, which can be also said of other flowering plants living in our sea—*Cymodocea nodosa*, *Zostera marina* and *Zostera nana*.

Its name—named after Poseidon, the chief god of the sea—seems very appropriate indeed, for its extensive underwater meadows that spread from the shore to the depth of 40 m representing one of the key ecosystems of the Mediterranean Sea. Most often they are found on sandy floors, less often on hard ground. Its rhizomes, which can grow horizontally or vertically, are densely intertwined and constitute a kind of a secondary Bottom. They may be several decimetres thick and can create actual reefs at some places. At the tip of each rhizome there is a shoot of a centimetre wide and even more than a metre long leaves. Their numbers vary during the year, ranging between 5 and 8. The older leaves situated on the outer side of the shoot fall off but are soon replaced by new ones growing in the shoot's interior.

The meadows of *P. oceanica* are of great importance for the marine ecosystem, not only in view of producing oxygen and organic substances (approximately 20 tons/ha/year) but also as a biotope for an infinite number of marine organisms dependent on such meadows in terms of their diet, habitat, shelter, etc. There are also many sessile organisms, which live attached to the surface of the leaves and rhizomes. There is of course more than enough places for them, considering that the actual surface area of all leaves in a single square metre of a meadow ranges from 20 to 50 m^2. Posidonia meadows are at the same time a very important factor in the diminishing of erosion. In spite of

these entire positive characteristics, less and less natural habitats of this plant have been observed in the Mediterranean particularly due to various construction works, pollution, drag netting, anchoring, etc.

P. oceanica has been declared endangered in many areas of Mediterranean. In this meadow numerous marine organisms have been noted, most perceivable amongst them being *Pina nobiliss*, various sponges, crabs (*Maia verrucosa, Pagurus* sp.), gastropods (*Murex* sp.) and bivalve molluscs (*Chlamis varius, Aca noe*). The habitat represents an ecosystem that plays an important part in the exchange of substances in the sea and, which is of particular significance, provides a biotope, hiding place and a refuge for numerous marine organisms and thus contributes towards the diversity of the underwater world aswell as the conservation of ecological process [2].

Biological cycle is similar to a land plant. Flowers appear between September and October and fruits around spring time. Plant growing is continuous through the year highly affected by the lighting and temperature of the water. Mayor growing occurs during spring and summer, being minimized at winter season.

2. Impacts on Posidonia meadows

Posidonia beds are not rare (France alone has 1,15,000 ha) they have suffered a progressive and irreversible regression throughout the Mediterranean due to:

- Sand extraction and development of infrastructure, harbours and artificial beaches, enhancing turbidity and covering the beds with sand.
- Damming of rivers. Changes in sedimentation in the littoral zone have led to either exposing or burying of habitat.
- Trawling and anchoring are especially destructive to exposed rhizomes [7].
- Eutrophyication, augmenting algal blooming. Sewage and industrial waste discharge cause a complete loss of the habitat locally.

Caulerpa taxifolia (an tropical alga introduced in the French Mediterranean in 1984) is progressively overwhelming *Posidonia* beds.

According Marbá, N (1996) 78% of the Posidonia sea grass along Mediterranean coast of Spain is affected by density decreasing. The situation in the Westersn Mediterranean is most serious. Shoot density is rapidly decreasing, up to 50% over a few decades. Besides, increased turbidity and pollution have resulted into a squeeze of the beds; in various places living beds have withdrawn between 10 and 20 m depth. Dead beds occur abundantly, even in waters which have already been protected for 35 years. For the French mainland coast habitat loss is estimated 10–15%; but taking into account the decrease of shoot density the overall decline of the resource will be between 30 and 40%. This is probably a good estimate for most western Mediterranean coastlines, although the situation around the islands and in the eastern Mediterranean is better.

The main ecological requirement of Posidonia, as plant consists of a good illumination, what determines it doesn't exists below a certain depth, at which the light necessary does not arrive to maintain its requirements. A good part of the negative effects originated by the human activities takes place, indeed, increasing the turbidity of waters preventing or making difficult the penetration of the light.

It is known, in addition, that in estuarial atmospheres or mouths of rivers they are habitats on which these communities are not based, what means that a low salinity is not tolerated by the *Posidonia*.

Considering the ecological characteristics of *P. oceanica*, very demanding in the environmental conditions, and analyzing its areas

of distribution can be reached the conclusion, that it does not support an ample rank of variation in the salinity of waters.

However, before approaching the works object of the present paper, it was not known nor existed documentary references on the tolerance(not even approximated) that can have the plant to the increases of salinity reason why the accomplishment was indispensable from the different studies that, through different approaches, they could approach us the knowledge of the effects that the increase of salinity presents on Posidonia, in the way to try to define certain ranks of salinity for which the effects are critical, serious, moderate or slight and, based on which to be able to determine the proportions of suitable way out the spills to the water sea from desalination plants.

Is evident that a solution, considered up today consists of locating the spill in a zone no colonized by meadows, but this is not always possible in certain zones of our geography and, more in particular, within the Region of Murcia in which in a high percentage, its coast is fortunately occupied by these important vegetal colonies [3].

One second solution would consist of locating the device of spill to a greater depth than the occupied one by the meadows, being based on the criterion of which the hypersalty water, as being denser than the one of the sea, it will tend to move at any moment towards deeper zones. This alternative presents, in our opinion, three disadvantages:

- Its high economic cost, when needing a conduction of great length, equal like minimum to the width of the prairie (several kilometres in certain zones of the Mediterranean coast).
- The necessity to excavate a ditch or to install an important number of anchorages for such emissary throughout the wide one of the prairie, what will have a doubtless physical effect that, in the case of a ditch it can extend on a quite greater surface to both sides of the same one.
- Spill can not affect to prairie of Posidonia but if it would have negative effects on other communities that colonize the bottoms of greater depths, as it could be, for example, maërl.

The knowledge of the tolerance of *P. oceanica* to the increases of salinity can, combined with measures that increase the dilution of the effluents, cause that the accomplishment can be environmentally permissible from a brine spill on or in the environs of a zone colonized by these prairies.

3. Investigation approach

In order to minimize the impact of the brine discharge of the SWRO plant on the *Posidonia* beds, ACSEGURA asked CEDEX to study the effect of the high salinity on the plants, as there was no knowledge at all about it. Therefore the investigation further presented is the first time in the world is carried out linking desalination with impact on *Posidonia* seagrass.

This investigation focused on the design of the discharge method of the SWRO Plant to minimize the environmental impact of the high salinity brine discharge on the marine habitats and design the disposal method to achieve that goal.

The first stage of any investigation is the research of any bibliography related with the goal or subjects included in. In this case references related with the investigation were very limited and there were no previous investigations about the effect of high salinity discharge on *Posidonia* beds. Existing documents are related to the effects of low salinity, coming from sewage disposal instead of high salinity effects.

Therefore, the path of the investigation was entirely new and the analysis proposals had to be set from the origin. The lack of knowledge in this field set the opportunity to face up a great challenge.

An additional difficulty to set the research was to know if it was possible to adapt Posidonia bundles into laboratory conditions in aquariums, as this was the first level initially planned for the research. Laboratory research is always the first approximation to any investigation involving flora and fauna, previous to study field conditions. Any laboratory research has the advantage the possibility to keep under control the test conditions as temperature, light and salinity. Additionally tests can be replicated and set reference parameters limiting the uncertainty of the results.

Field tests have as main advantage that natural conditions are not affected; however, the replica possibilities and conditions of the tests are not always possible. In any case the combination of both, laboratory and field gave as the possibility to contrast the preliminary results obtained at laboratory in the final tests carried out on the field.

Methodology used in the investigation was planned according different levels of approximation in order to evaluate the response of Posidonia to the experimental conditions similar to a high salinity discharge. So three different levels were analyzed:

1. Mesocosmos experiments (lab)
2. Macrocosms level (field)
3. Validation of obtained results comparing with the effects of brine coming from working desalination plants.(field)

As it was mentioned previously, the lack of knowledge and preliminary investigations in this field, mean a great challenge requiring scientific contributions from the most qualified national experts. Some institutions and universities gather the information on national and regional particularities, as well as types of associated habitats. The final report was compiled by the CEDEX, based on the contributions of the following groups of experts:

- Instituto Español de Oceanografía. Centro Oceanográfico de Murcia (IEO).
- Consejo Superior de Investigaciones Científicas. Centro de Estudios Avanzados de Blanes (CEAB).
- Universidad de Barcelona. Departamento de Ecología (UB).
- Universidad de Alicante. Departamento de Ciencias Ambientales y Recursos Naturales (UA).

University of Alicante was in charge of lab research and the field investigations were carried out by the IEO, CEAB and UB.

The final report and conclusions was approved by agreement of all the participants in March 2003.

4. Experimental proceedings

Each one of the approach levels that finish being mentioned integrate a series of tests and analyses that are the following ones:

4.1. Answer to the salinity in mesocosmos

Experiments with *P oceanica* were made in tanks of medium volume, in the short term (15 days) and the main descriptors studied were the survival and the growth in plants. In each test the environmental factors in each one of the aquariums were controlled (light, salinity and temperature) that stayed most constant than it was possible.

Likewise some tests were made with two species of fauna associated to the Posidonia sea grass: misidaceum and sea urchims.

4.2. Study of the effects of spills from existing desalination plants on P. oceanica *(studies in the field)*

A good approach to the knowledge of the environmental effects of a certain human activity is the observation of previous performances the most seemed possible to which is

tried to evaluate. In the case that occupies to us, desalination plants in the coast have being in operation for several years, reason why in principle the accomplishment of recognitions of field around some of the selected spills seemed possible.

The main disadvantage of this level of approach resides in the interpretation of the results since the well observed effects also can be originated by the increase of salinity originated by the brine spill but also by other factors, such as the increase of turbidity generated in sweeps, the chemical agent addition, etc.; or it even could be that the meadows already presented a certain state of degradation originated by causes having nothing in common to the spill. Therefore, for the suitable interpretation of the results of this part of the investigation it will be needed, necessarily, of the support of the other two integrated levels of approach in the investigation.

After a search between the Spanish plants in operation and after diverse works of recognition in the desalination plant of Camp de Mar, in Andraitx (Mallorca), finally this part of the study was focus on the desalination plant of Formentera, where it was made an intense recognition and an important number of salinity measures.

4.3. Simulation of the saline spill on beds of P. oceanica *(macrocosmos)*

This third level of approach was designed initially along with the previous ones, nevertheless its greater complexity caused that it began when the other two were in an advanced state of accomplishment, with which the accumulated experience was used for the suitable design of these experiences.

The work considered by means of the pursuit of the effects of small hypersaline spills on the micro scale distribution of Posidonia. From the spill of a plant pilot, constructed by ACSEGURA in San Pedro del Pinatar, after the dilution adapted to the salinities to try, one canalized small spills towards experimental parcels, previously characterized.

Considering that, due to the experimental complexity, two salinities could solely be tried, at sight of the results of the other levels of the investigation, it was decided on a high salinity, that it turned out to be of 38.4 psu and other salinity that we will denominate very high, of 39.2 psu.

5. Results

The different made experimental approaches offer a vision, also different from the effects that the increase of salinity originates on Posidonia. Thus, whereas the laboratory tests offer a valuable information of the short term effects, the tests of mesocosmos and, mainly, the recognitions of field, they approach to us much more the chronic effects at medium and long term. So, it is no rare that some effects observed in the laboratory experiments to be increased in the remaining levels of approach.

Preliminary results pointed out by CEDEX were as follows [8]:

1. Has been verified, without doubt, that fanerogamme marine *P. oceanica* is little tolerant to the increase of salinity, originating different negative effects when the salinity is increased above its habitual values (increase of mortality, appearance of necrosis in weaves and greater fall of leaves).

2. In agreement with the experiments made in laboratory, salinities in the surroundings of 50 psu originate the death of the 100% of the plants in 15 days.

3. Mortalities of the order of 50% of the plants are reached with salinities around 45 psu.

4. A salinity of 40 psu originates a mortality of 27% of the plants, although experiments made with superior salinities gave discordant results (20% of mortality for 43 psu as opposed to 55% of mortality for 42.9 psu).

5. In the laboratory experiments it was frequent to observe a mortality of a certain percentage of plants in the treatments with water at salinity of the sea, that as average it turned out to be from 8.5% (varying between 0 and 15%).

6. Regarding the growth of the plants, the experiments showed that over 48–50 psu the plants let grow completely.

7. The rates of growth are reduced on the growth to salinity of 38 psu in the following average rates:

- With salinity around 43 psu *Posidonia* growth is the half of the growth at natural sea salinity.
- With salinity around 40–41 psu the plants growth is an average a 14% less than with natural salinity of the sea.

8. If the increase of salinity has not been excessive, returning into the conditions of normal salinity, the rate of growth returns to its normal values in high percentage, being reached a total recovery of the beams given a treatment of 43 psu.

9. The data which it has come to indicate that to cause the effects of mortality and diminution of the rate of growth it is not necessary that the totality of the plant this submerged in the hypersalty water but that is enough whereupon the basal part of the same one is it.

10. Of the recognitions of field it is possible to emphasize that it has been verified that, independently of the effects that could originate on the prairie the increase of salinity, the effluent of the plant of Formentera at least originates an increase in nutrients in the water which can be origin of some of the effects of degradation of the meadows which they have been possible to observe.

11. The prairie next to the emissary, in an advanced state of degradation one was bathed by waters of salinity between 39 and 43.4 psu, although the evidence does not exist, according to the equipment of CEAB and UB, of which the degradation has been originated by the increase of salinity.

12. The discontinuous meadows, with affection of the density and cover, one was bathed by waters between 38.6 and 40 psu.

13. Finally, the continuous meadows, in that the affection due to the increase of salinity is let notice at behaviour level and characteristics of the plants but that it does not seem to affect the density and cover of the prairie was, at the moment of the measures, affected by salinities between 38 and 39.5 psu.

6. Conclusions

Once known the results corresponding to the tests made by the experimental IEO with water spills on experimental parcels, like complementary works that have come developing on the part of the rest from the participant groups, the final conclusions of the study of the CEDEX, in which to tolerance to the increase of salinity of *Posidonia*, they were the following ones:

1. A criterion of sizing relative to the tolerance of *Posidonia* has settled down based on the obtained results of the different experimental approaches made and having in account the principle of precaution, what means all the values, adopted as a consequence of the present research must not been definitive results and can be modified in the future according investigations advances.

2. Based on the previous assumption, the recommendations of the investigation were:

- Brine discharge from desalination SWRO plants must be avoided on *P. oceanica*

meadows, being preferred to discharge on sandy bottoms without flora.
- If previous recommendation is not possible, the discharge must be such that never happen 25% of the time above 38.5 psu neither 5% of the time above 40 psu.

3. The previous values correspond to a dilution of the water so that, in agreement with the obtained results, the Posidonia would not undergo significant deterioration some due to the increase of salinity. However, it corresponds to the competent Environmental Authority in each case to authorize the spill to adopt the value that considers more advisable at sight of the results of the different studies.

4. Some results indicate that salinity tolerance of Posidonia locate at low depth and therefore with high level of lighting, is higher than the plants locate at deeper position, what suggest than depth is also a factor to be considered at disposal authorization time.

5. In the case of the SWRO Plant located at Mazarrón Bay the discharge of the brine is discharged through a 1600 mm HDPE pipe equipped with 20 fittings of diameter between 120 and 180 mm 1 m above the pipe. The discharge angle is 60° above the horizontal.

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