GUADIANA RIVER ESTUARY

Investigating the past, present and future

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CENTRO DE INVESTIGAÇÃO MARINHA E AMBIENTAL

5. Salt harvesting

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5.1. Salt harvesting

Saltworks (other terms: salterns, saltponds, solar ponds) are man-made hypersaline systems where table salt or halite (NaCl, sodium chloride) is harvested. Salt production in the Guadiana River estuary is based on solar evaporation of sea water. In other areas, salt is obtained from solid state or brine mining.
Saltworks using sea water are usually located in low coastal areas, allowing gravitational filling of ponds during the high tides. Evaporative salt production is restricted to geographical areas where this process is favoured by combined action of wind, solar radiation, low rain rates, and high temperatures. Hence, the Mediterranean and part of the European Atlantic coastal areas fulfil these conditions, particularly during the summer months where the evaporation greatly exceeds precipitation.
Salt production is one of the few economic activities legally permitted in the estuary of the Guadiana River, which is under protection of several international, national and regional legal instruments that were implemented to preserve the ecosystems and promote a sustainable development in the áreas (Figures 5.1.A; 5.1.B).

Figure 5.1. A
Sea salt warehouse in Isla Cristina, Spanish Guadiana River estuary (photo by Noa Sainz, 2010)

Figure 5.1. B
Salinas landscape from Castro Marim Castle, Guadiana River estuary (photo by Noa Sainz, 2015)

5.2. History

In Europe the technology of progressive sea water evaporation to obtain salt goes back about 4000 BP. In the Guadiana River estuary, salt harvesting has been taking place since Phoenician times and was recorded in several manuscripts (Figure 5.2). This millennial activity experienced a severe decrease for the last century due to competition of mined, industrial salt and the ensuing loss of markets. In the first decade of the XXI century most of the solar ponds were abandoned with a negative impact on the landscape (Figure 5.3). Only 10 production units were active in 2010 in the Guadiana River estuary (Figure 5.4) with only marginal importance for the local economy (see Box 5.1.)

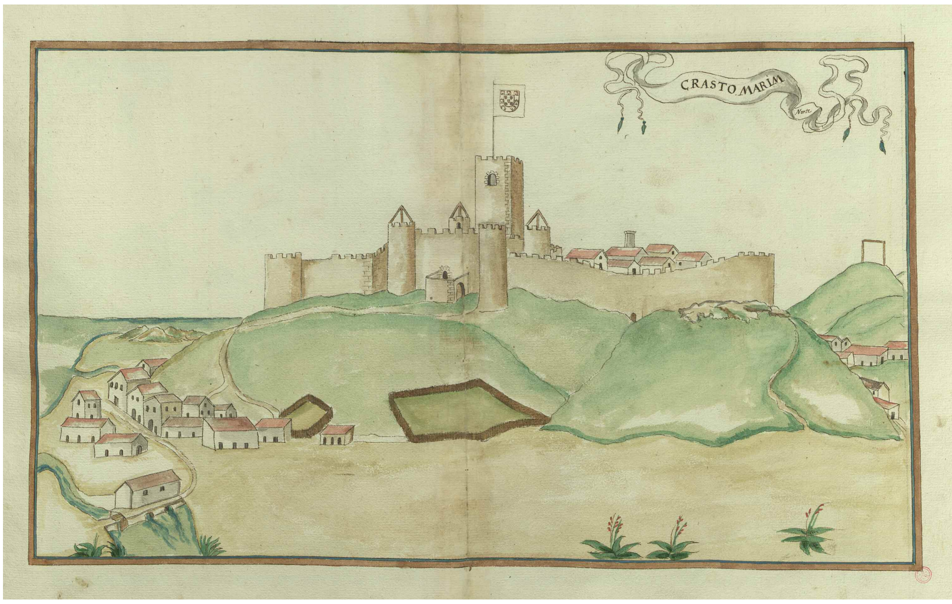

Figure 5.2.
Castro Marim, early XVI century, reproduction of a manuscript at *Fronteira de Portugal fortificada pellos reys deste Reyno* (Armas d´, 1642). On the back, next to the castle hill heaps of salt can be observed indicating the existence of active salt ponds.

Figure 5.3.
Abandoned salt ponds in the Guadiana River estuary (photo by Noa Sainz, 2015).

Box 5.1. Did you know that…?

Salt production has traditionally played an important role in the livelihood of Mediterranean societies, as salting was a principal method of preserving food, and enhancing its taste. The word that illustrates best the importance of salt as a vital commodity is "salary", coming from Latin "*salarium*" or salt-money or monetary equivalent of salt portion, paid to the roman soldiers. Solar ponds are part of the cultural and industrial heritage showing a sustained increase in economic output over the last decades.

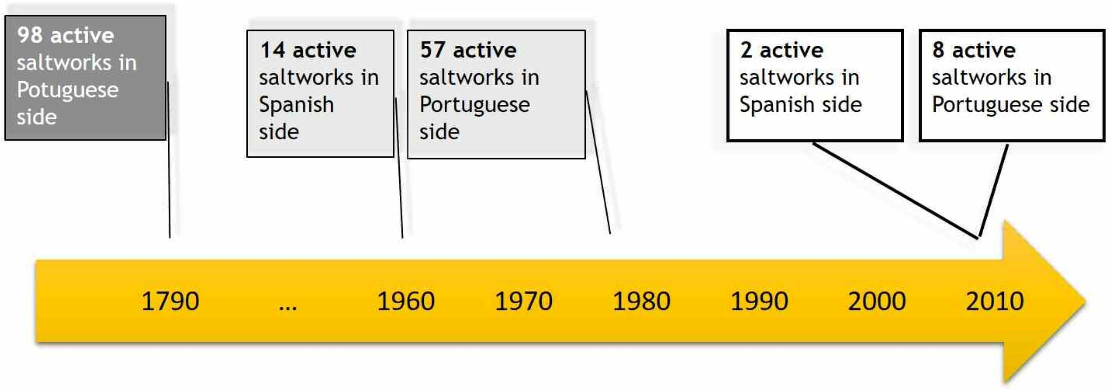

Figure 5.4.
Number of saltworks active in the Guadiana River estuary during the last 2 centuries (adapted from Menanteau et al., 2006).

The decreasing trend observed during the last century was recently reversed as a consequence of new environmental policies formulated in the Management Plan for the Nature Reserve of the Saltmarshes of *Castro Marim and Vila Real de Santo António* (http://www.icnf.pt/portal/ap/r-nat/rnscmvrsa), approved in 2008. The latter considers artisanal salt production as an important activity that should be promoted in the context of sustainable use of resources, and diversification of natural habitats for birds and other species of flora and fauna. In the past few years a slow recovery of several saltworks has been observed.

5.3. Saltworks configuration

Saltworks size can vary in the Guadiana estuary. The artisanal salt production units can occupy 1 hectare, while the industrial saltworks occupy 250 hectares. Nevertheless, all saltworks are organized by a successions of shallow (20-80 cm depth) evaporation ponds leading to the crystallization of sea salt at the end of the circuit. Water gets "saltier" and warmer as it goes through the circuit (see Figure 5.5). This water circuit can be differentiated into the main following compartments with different mean temperature and salinity:

- Marine water of salinity close to 35 PSU enters the sedimentation & storage ponds through the sluice which is opened during the spring high tide. Here, most of the suspended matter is deposited and temperature increases.
- The evaporation/pre-concentration area is divided into the evaporators, the heaters, and the reservoirs. Here the temperature further increases to 35-45ºC and salinity reaches, stepwise, 160-180 PSU. Less soluble salts like $CaCO_3$ and $CaSO_4$ are precipitated.
- In the crystallizers (*talhos* in Portuguese or *tajos*, in Spanish) the brine reaches the state of oversaturation, most commonly 220-250 PSU, and precipitates halite either as *fleur de sel* on the surface from which it is collected daily or as coarse salt collected usually every month, depending on the weather conditions.

Figure 5.5.
Water circuit in an artisanal saltworks (area: 1 hectare) in the Guadiana River estuary. Arrows indicate the direction of the water flow and are placed where water flow can be controlled with sluice gates (photo adapted from Google Earth).

Before harvesting season, the evaporation area and the crystallizers undergo a cleaning process in order to remove the excess of accumulated sediments, organic matter and algae.

5.4. Types of salt

Industrial saltworks and artisanal saltworks can be found at the Portuguese side of the estuary. On the contrary, at the Spanish side it can only be found artisanal saltworks.
University of Algarve-CIMA's research is focused on the formation of *fleur de sel* (or *flor de sal* in Portuguese/ Spanish) which is a kind of sea salt harvested by hand. *Fleur de sel* is formed (Figure 5.6.A) and collected from the surface of the crystallizers brine. Its collection is done with a skimmer (Figure 5.6.B), and immediately after its collection it is placed in perforated plastic boxes for draining of residual brine (Figure 5.6.C) and in the last stage it is sun dried on plastic nets (Figure 5.6.D).

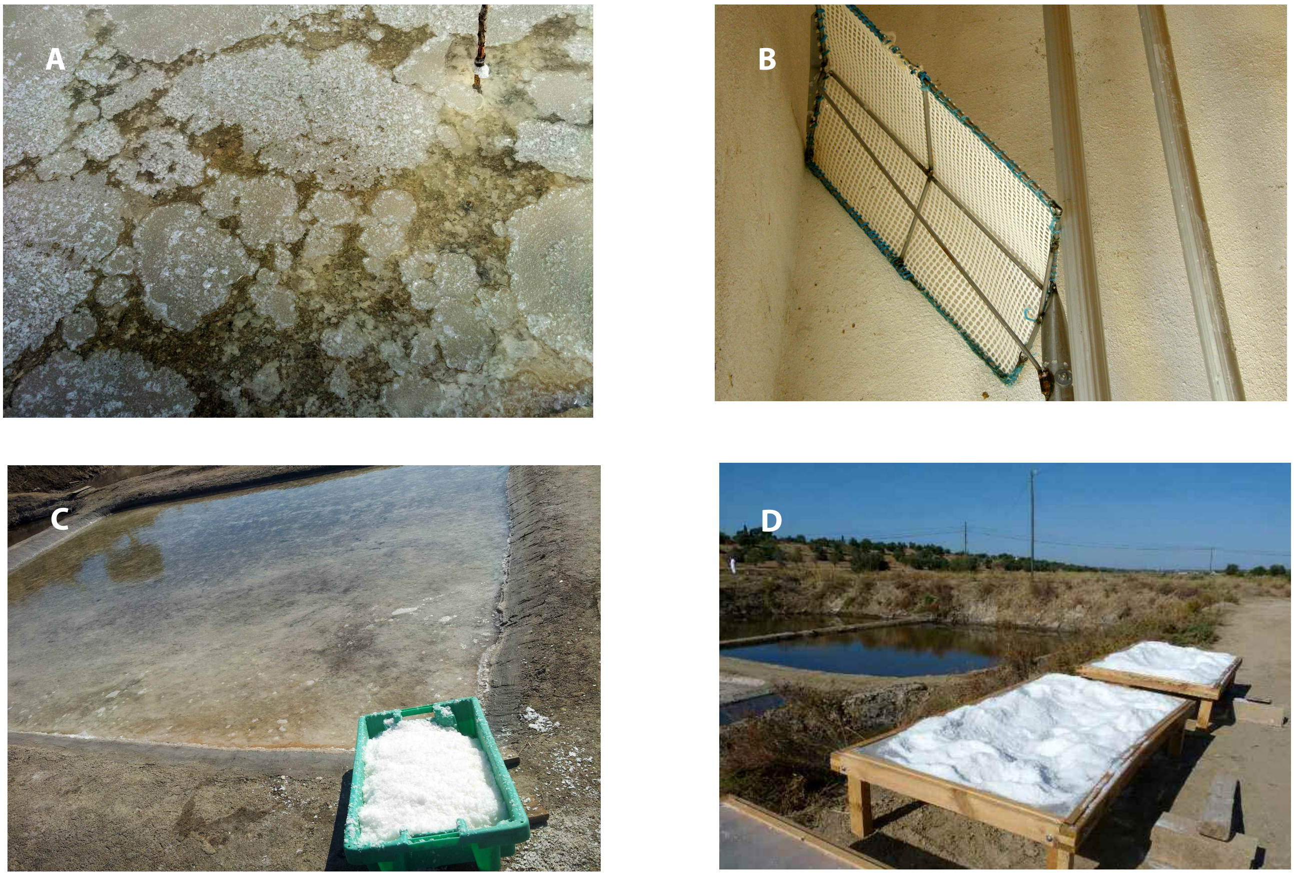

Figure 5.6.
Figure 5.6: (A) Fleur de sel formed at the surface of the brine; (B) tool for collection of fleur de sel; (C) fleur de sel draining box; and, (D) fleur de sel drying nets (photos by Noa Sainz and Tomasz Boski, 2014/2015).

Coarse salt, which accumulates in the bottom of the crystallizers is harvested when its crust is too thick to admit enough new liquid or in the other words when the brine lamina is too thin for collecting *fleur de sel*. This happen after 1-2 months depending on prevailing weather conditions and quantity of *fleur de sel* collected. Before removal of coarse salt, the brine left in the crystallizer is evacuated, and the salt is pushed onto the dikes separating the crystallizers (Figure 5.7.A), forming small heaps of salt for its final natural drying before packaging (Figure 5.7.B).

Figure 5.7.
(A) Raking coarse sea salt; and, (B) coarse sea salt heaps drying up in a traditional solar saltworks at the Spanish side of the Guadiana River estuary (photos by Noa Sainz, 2015/2010).

Variables that affect artisanal salt formation are: strength of solar radiation, air humidity, wind speed and direction, atmospheric temperature, and salinity and temperature of the brine (Figure 5.8), which jointly determine the rate of evaporation. Salt formation can also be influenced by the microorganisms found in the brine. For instance, red halophilic bacteria aid solar energy absorption and, hence, brine evaporation. While atmospheric conditions are beyond human influence the physical-chemical variables of the solutions may be partially controlled by managing the circulation of brine in the evaporations - crystallizations circuit.

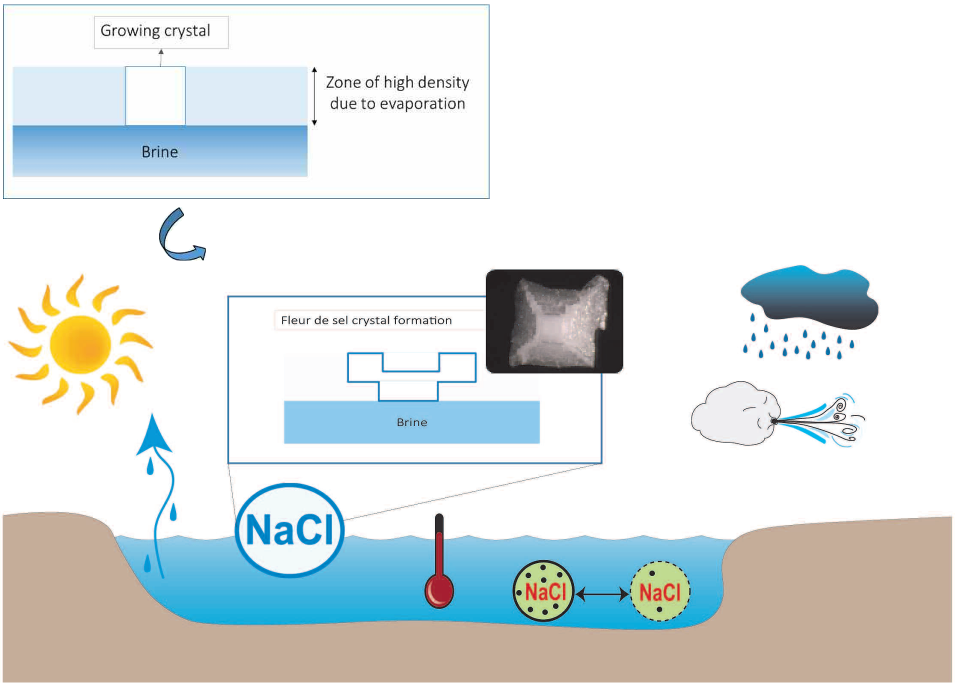

Figure 5.8.
Cross section of a crystallizer showing how fleur de sel crystals are formed. Microscopic picture of a crystal of *fleur de sel* (from top of the pyramid).

Fleur de sel, which is formed on surface of oversaturated brine, appears initially as quasi-two-dimensional floating, centimetric size flakes which through an in-depth growth assume the geometric form of hopper pyramids (see Figure 5.9).

Figure 5.9.
Lateral macro picture of a crystal of *fleur de sel* (photo by Noa Sainz, 2014).

Fleur de sel is composed in ca. 96% of sodium chloride, the remaining being calcium, potassium and magnesium (see Table 5.1) which together with the adsorbed organic matter are responsible for its appreciated specific flavour. The origin of organic matter is attributed to the algae which can support the high salinity. (see Box 5.2.)

Components		Fleur de sel	Coarse sea salt
Sodium chloride	g/kg	966	968
Humidity	g/kg	45.7	37.1
Insoluble matter	g/kg	0.1	0.2
Sulphates	g/kg	14	10.9
Calcium	g/kg	2.4	0.6
Potassium	g/kg	0.9	1.8
Magnesium	g/kg	6.1	7
Iodine	mg/Kg	0.51	0.552
Copper	mg/Kg	<0.05	<0.05
Iron	mg/Kg	0.06	0.12
Lead	mg/Kg	<0.05	<0.05
Mercury	mg/Kg	<0.01	<0.01
Arsenic	mg/Kg	<0.02	<0.02
Cadmium	mg/Kg	<0.02	<0.02

Table 5.1.
Composition of artisanal sea salt collected in Castro Marim saltponds in 2015 harvest season.

Box 5.2. There is still life in there

High salinity can be the perfect environment for some organisms. Some algae, like *Dunaliella*, are rich in β-Carotene responsible for the roe/reddish tint of salt and of the pond shrimps.

Box 5.2 Figure
Dunaliella bloom in a sea salt crystallizer (photo by Noa Sainz, 2015).

Industrial sea salt after collection by heavy machinery must be transported to the specialized industrial units for the purpose of re-dissolving, drying and grinding prior to human consumption. It differs substantially from artisanal sea salt (see Table 5.2) as it is an almost pure sodium chloride containing only small amounts of Al_2O_3 added as anti-agglutinating agent . The Portuguese company Salexpor occupies around 250 hectares of industrial saltworks in the Guadiana River estuary. They can produce 30,000 tonnes of coarse salt in one harvest season.

Purified salt composition	
Sodium chloride	Min. 98%
Humidity	Max. 1%
Insoluble matter	Max. 0.2%

Table 5.2.
Physicochemical characteristics of purified crystal sea salt composition after washing, drying and grinding for human consumption (1 Kg) from the company that utilises the industrial saltworks in the Guadiana River estuary.

5.5. Economy

Portuguese Official National Statistics showed that in 2010 the production of coarse sea salt on mainland Portugal declined by 38.4 % compared to 2009. The main reason for this sharp decrease is that many producers have re-oriented their production because of higher revenues that may be obtained from commercializing *fleur de sel*, when compared to coarse sea salt (see Box 5.3.)
Fleur de sel in some of the traditional saltworks in the Guadiana River estuary has a certified quality by the international associations *Nature et Progrès* (http://www.natureetprogres.org) and the Portuguese *Sativa* (http://www.sativa.pt/default.asp), both specialised in organic farming. The European certificate of "Protected Geographical Indication" has been awarded to a *fleur de sel* produced as well in other locals of the Algarve region, but the Guadiana *fleur de sel* has not been registered under this designation. Obtaining this certification and matching international standards of labelling, would contribute to an increased competitiveness of *fleur de sel* from the Guadiana River estuary. Moreover, the Guadiana *fleur de*

Box 5.3. Coarse sea salt vs *fleur de sel*

Artisanal *fleur de sel* (also known as flower of salt) from Algarve, whose price may be two order of magnitude higher than traditional coarse salt found its way to several markets, and greatly improved the financial output of local producers. Technological improvements like more precise control of the brine's flux, weather forecasting and evaporation enhancing may play a role in further improvements of the process and its profitability.

Box 5.3 Figure
Fleur de sel for sale in Portugal (photo by Noa Sainz, 2014).

sel could be promoted and could protect its name by registering under other quality schemes, such as the "Protected Designation of Origin" (PDO) and/or "Traditional Speciality Guaranteed" (TSG) (https://ec.europa.eu/agriculture/quality_en): PDO covers agricultural products and foodstuffs which are produced, processed and prepared in a given geographical area using recognised know-how; and, TSG highlights traditional character, either in the composition or means of production of the product.
In 2006, in the area of the Nature Reserve of the Saltmarshes of *Castro Marim and Vila Real de Santo António* ca. 30 ha were occupied by active saltworks, while 200 ha were still abandoned but considered as recoverable. The abandonment trend is now reversing and for example, in 2016, 1 ha of saltworks was recovered an started to produce *fleur de sel* and coarse salt. Lately, there has been a product diversification from saltworks, and for instance, in 2015 an approximately 1 ha of saltworks focused its activity on tourism and offered floating baths in one pond and beauty treatments with mud as an outdoor spa for skin exfoliation. This has been observed in other saltworks in Europe, for instance salina mud from Secovlje salina (Slovenia) composed of quartz, carbonates and clay minerals and containing variable amounts of sulphides, is used in health resorts of that area.
Recently, some tourism-oriented activities have been developed in active saltworks at the Guadiana River estuary, such as offering the possibility to tourists of experience the profession of *marnoto* (salt harvesting worker, in the local jargon) for some hours, encouraging traditional knowledge dissemination. Moreover, another activity focusing on visitors directly link to the saltworks is bird watching, attracting every year more tourists. Other activities promoted in European salinas relying on the exploitation of the Mediterranean's salt heritage are guided tours and school visits, although they should be accompanied with other activities to be economically profitable. In the case of the Guadiana saltworks, the University of Algarve - CIMA has been working in the area for the last two decades and it has produced materials for education and management.
Although experiences on farming *Artemia spp* in saltworks in Asian countries have reported increased incomes for families, no similar practices are taking place in the Guadiana River estuary. The former is probably due to the fact that large quantities of *Artemia spp* are required to make this a profitable business and mainly because there is no industry already established on this product in the area. Nevertheless, it should be mentioned that research on this issue is currently being carried out in abandoned saltworks in another part of the Algarve. So, this activity could be considered as well for the Guadiana River estuary, after an appropriate research and development period.
There is only one industrial sea salt producer company in the Guadiana River estuary and it is at the Portuguese riverside (Figure 5.10). It produces most of the coarse salt, accounting for 25-30,000 t/yr.

Figure 5.10.
Salt heap at industrial saltworks in Castro Marim (Portugal) (photo by Noa Sainz, 2015).

5.6. Biodiversity/ Ecosystem

Saltponds are recognized as ecosystems that hold an important biodiversity and are considered as important conservation areas with unique food webs, directly link to the salinity gradient. Saltponds are known for holding a wide variety of resident and migratory birds (Figure 5.11.A and 5.11.B).

Figure 5.11.
(A) *Phoenicopterus roseus* (flamingo) at the industrial saltponds of Castro Marim and, (B) Footprints of *Himantopus himantopus* (black-winged stilt) in one pond of the traditional saltworks in Castro Marim (photos by Noa Sainz, 2015).

Saltponds provide a series of ecosystem services, such as: food, biological regulation, hydrological balance, atmospheric and climate regulation, flood/storm protection, erosion control, cultural amnity, recreational, aesthetic, education and research.

5.7. Weaknesses and threats of artisanal salt production

Although protected under several treaties/legislation, saltworks are currently under different threats. The estuary of the Guadiana River is under several low and medium pressures which affect as well the saltworks indirectly:

- Some areas of the saline ecosystems have been converted to hold tourism infrastructure, such as golf courses and marinas, especially at the Spanish side. Apart from land reclamation, urbanization can represent a source of pollution, particularly as solid waste reaches abandoned saltworks, converted into illegal dumpsites. Since 2008 financial crisis, urbanization has stopped sharply in both countries.
- Agriculture and aquaculture have replaced salt harvesting in some areas, especially at the Spanish river side, where several aquaculture companies occupy former saltworks due to a conversion trend that took place in the 1980s when there was no nature protection policy in place. On the contrary, the Portuguese side accounts for only one installation, a 32 ha semi-intensive fish farm, as well placed in former saltworks. Due to environmental regulations, no more aquaculture units are allowed to operate in the Guadiana River estuary, since large scale aquaculture leads to the impoverishment of saltpans landscape, it can aggravate conflicts with farmers, and it can cause environmental impacts, such as:

decrease of available emerged area for birds and other species; increase of nutrient concentrations; diminish dissolved oxygen levels; and introduce hormones, antibiotics, pesticides and various compounds, affecting the rest of the ecosystem. However, the conversion of saltworks and wetlands into aquaculture ponds is considered an activity that increases economic output from coastal areas, as declared in the Strategic Plan for Aquaculture of the Portuguese Government for 2013-2020.

One matter that can be a threat to the estuary, can also be an opportunity for the saltworks; this is salinization, as it can help on the recovery of abandoned saltworks by means of reducing the minimum required time for salt harvesting and make the activity more efficient. The revitalization of saltworks would create jobs and preserve biodiversity of this ecosystem. Salinization of the Guadiana River estuary is due to the excess number and capacity of upstream river dams that limits freshwater reaching the river mouth (the biggest dam, closed in 2002, can retain 4,150 hm^3 of water 60 km upstream, in the council of Alqueva). Moreover, climate change will affect the saltmarshes, especially at the Spanish margin of the estuary where there will be risk of flooding due to sea-level rise together with lack of sediment supply, partially caused by upstream damming that causes sediment retention.

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