WHY DO INLAND SALINAS MATTER? INLAND SALINAS AS BIODIVERSITY ISLANDS IN A SEA OF LAND

(A literature review)

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ABSTRACT

Inland solar evaporation salinas and saline wetlands constitute important reservoirs of halophillic biodiversity. These types of habitats, although present in some way or another all over Europe, are especially well represented in the Iberian Peninsula, with over 500 (former) inland solar evaporation saltworks and over 200 saline wetlands and streams. As opposed to coastal solar evaporation saltworks, saline conditions of inland salinas and wetlands only occur on the spot where salt and brine are present, usually in small sized areas surrounded by vast expanses of land, being therefore isolated from each other. Salt making activity in this Iberian-specific type of solar evaporation saltworks is currently anecdotal. The stagnation of the salt making activity, the usurpation of land uses in former saltworks (especially by intensive and irrigation agriculture) and the desiccation of small-sized saline wetlands is threatening the rare and fragile flora and fauna species that used to inhabit these environments. Some of these areas are protected by law, with varying degrees of success, but clearly additional management measures are needed. The present contribution intends to give an overview of the biodiversity values of inland solar evaporation saltworks and wetlands of the Iberian Peninsula and the threats that currently affect them, and proposes management measures to minimise the effect of these threats.

Keywords: saltworks, salt, production, conservation, wetlands, threats, biotechnology, future

INTRODUCTION

Objective of this review

The present contribution aims at showing the importance of biodiversity in inland solar evaporation saltworks, a habitat type usually considered devoid of life by laymen and often simply ignored by the scientific community. Besides from their intrinsic value, this contribution will show that these habitats host species of both scientific and economic interest and are diverse enough to deserve attention and preservation efforts. The threats and challenges faced by these habitats will also be tackled.

Introduction to Iberian inland saltscapes

Given the enormous amount of distinct landscape types that are associated to the presence of salt in nature and in fact conform specific ecosystems (Montes and Martino 1987, Williams 1998), the Association of Friends of Inland Salinas has coined the term “saltscape” to define them as “any landscape type that whose elements are strongly influenced by the presence of salt and forms a defined ecosystem” (Hueso & Carrasco 2008a). Some saltscapes have been artificially created almost from scratch, by pumping underground brine for salt production, which otherwise would have never reached the surface. This is the case of many inland solar evaporation saltworks, which have also been defined by the Association of Friends of Inland Salinas as those “saltscapes dominated by solar evaporation salt making sites fed by evaporitic brine sources” (Hueso and Carrasco 2008a). This type of saltscape, inland salinas, is a typical Iberian phenomenon –even though it exists in many other regions of the world, but certainly in lesser amounts, geographical concentrations and diversity of technical solutions– with remains of over 500 solar evaporation salt making sites away from the sea (Carrasco and Hueso 2008).

From the point of view of wetland types, inland salinas are one of the many different Spanish aquatic ecosystems, which are very diverse due to the climatic, orographic, hydrological and geological features of the Iberian Peninsula. Especially unique are those temporary waters of endorheic origin (Casado and Montes 1995, Álvarez-Uría and de la Cruz 2011), and even more specific in their uniqueness, abundance and fragility are inland salinas (Comín and Alonso 1988, Carrasco and Hueso 2008, Hueso and Carrasco 2009a). This is a very specific type of aquatic ecosystem that needs certain features to exist: A Mediterranean climate, with well defined seasons, dry and warm summers, irregular rainfall, etc.; a flat or slightly depressed topography and a relatively shallow underground water table (Montes *et al*. 2007). Of course, the presence of salt in the immediate underground is essential. This is why most of these salinas concentrate on the eastern half of the Iberian Peninsula, fed by underground brines of Triassic origin that remain from the evaporation of the Thetys Sea that used to cover this part of land 200 million of years ago.

This particular type of continental aquatic ecosystems usually is ignored by conservationists and policy makers, as they are considered artificial, lifeless, too small (many are smaller than the 1-2 ha required to be even considered a wetland by the Ramsar Convention) and –for those who are better informed– host uncharismatic species such as invertebrates or microorganisms, as will be seen below. However, as Muñoz (2007) states, “it would be regrettable if we lost thousands of species rapidly, simply because they were not charismatic enough”. The presence of salt in inland salinas creates a unique habitat dominated by organisms that are able to tolerate high salinity, which otherwise is toxic for those species that are not well adapted. The physiological efforts required to tolerate salinity makes these halophiles (i.e. salt loving organisms) rare and fragile, as they are likely to disappear when the salt making activity is abandoned. Thus, the richness of rare and endemic species usually found in these environments, together with their reduced population sizes and associated demographic instability, often makes them threatened habitats of great conservation concern (Ribera and Blasco-Zumeta 1998, Diogo *et al.* 1999, Abellán *et al.* 2007).

BIODIVERSITY OF IBERIAN INLAND SALTSCAPES

Saltworks as models

Solar saltworks are excellent study objects: they have been reported to be a very stable environment, as each pond is considered to be at equilibrium and the biota consists of a well-adapted and established community (Pedrós-Alió *et al.* 2000, Dyall-Smith *et al.* 2003). The biota found in saltworks is essential to the salt production process, which is intimately linked to the system’s physicochemical phenomena (Davis 1980, 2006). It is composed mainly of microscopic organisms suspended in the water (the planktonic community) and those attached to ponds floor (benthic communities forming mats), which may aid or harm the salt production (Davis 2006). Knowledge of the ecology of these communities is of utmost importance for salt production, as it is well known that a "balanced" biological system in salt ponds is essential for salt production, whereas an "inadequate" or "unbalanced" system creates problems for salt precipitation (Davis 1980, Sundaresan *et al*. 2006). The planktonic community contributes to salt production, as it colours the brine and increases solar energy absorption and water evaporation (Davis 1974, Javor 1989, Oren *et al.* 1992, Oren and Dubinsky 1994, Oren 1999, 2005; Oren and Rodríguez-Valera 2001, Antón *et al*. 2002, Javor 2002, Moosvi 2006), thereby accelerating crystallization rate and increasing the production of salt. The benthic community retains nutrients from the overlying water, seals the ponds against brine leakage and fresh groundwater infiltration, and prevents excess mucilage production, facilitating the production of high quality salt crystals (Davis 2000, 2009).

An "unbalanced" system may manifest itself by insufficient biota development and poor nutrient availability and would need fertilization or at least artificial colouring of the ponds to reduce albedo and enhance production. Another typical problem, excess nutrients, would produce too much organic matter, which in turn would cause high viscosity of the brine and produce hollow or small salt crystals that may retain contaminants. Management practices should focus on keeping stable conditions and a well balanced, pollutant-free ecosystem, by adjusting brine depth, and, if needed, introducing certain species to control excessive development of cyanobacteria or even chlorinating the brine (Jones *et al.* 1981, de Medeiros Rocha and Camara 1993, Coleman and White 1993, Davis 1993, Davis and Giordano 1996, Javor 2002).

Hence, salt production has become a completely integrated part of man-made saline ecosystems. Saltworks can be considered as particular ecosystems, where human intervention is not only tolerated but necessary to effectively produce an economically viable product while serving a critical role in nature conservation and biodiversity (Korovessis and Lekkas 1999, Petanidou 2000, MultiAveiro 2007, Hueso and Carrasco 2008a, Petanidou and Dalaka 2009).

Species richness and composition along a salinity gradient

Species richness and abundance usually decreases with salinity (e.g. Moreno *et al*. 1997, Millán *et al*. 2002, Gómez *et al.* 2005). Coastal saltworks, which have a strong salinity gradient (from around 3%, i.e. seawater salt concentration, to 30%, i.e. saturation level), show a significant drop in biodiversity when a salinity level of 7-15% is reached (Britton and Johnson 1987, Oren 1994, 2002b, Antón *et al*. 2000, Pedrós-Alió *et al*. 2000, Rodrigues *et al*. 2011). Most inland saltworks are fed by brine springs or sources with a salt concentration well above this level and therefore all ponds are considered hypersaline habitats. So, in the case of inland saltworks it is not a matter of the diversity of their biota, but rather, its rarity and fragility (Abellán *et al*. 2005a, Gómez *et al*. 2005, Hueso and Carrasco 2009b). A reduction of the saline conditions may increase the abundance and richness of generalist or opportunist species, but decrease the richness or abundance of the most halophillic species, resulting in a possible overall biodiversity reduction at a regional level (Velasco *et al.* 2006).

With respect to the species composition of Iberian inland saltworks, relatively little is known. Most research has been performed in saline lakes, with special attention to macrophytes, crustaceans and birds (Montes and Martino 1987). No comprehensive flora and fauna or food-web structure studies have been performed in inland saltworks, only taxon-specific ones. Perhaps the best known genus is the brine shrimp *Artemia* sp. (Hontoria and Amat 1992), and research shows that Iberian inland saltworks and hypersaline lakes are a reservoir for threatened *Artemia salina* (Amat *et al*. 2005, 2007, Green *et al.* 2005), as will be seen. Other researchers have focused on microorganisms found in inland saltworks and saline lakes (e.g. Martínez-Cánovas 2004, Martínez-Checa 2005). Under hypersaline conditions, only these type of organisms are found, with one specific family, *Halobacteriaceae*, which includes 29 genera and over 100 species (Oren 1999). With respect to vegetation, most inland saltworks are surrounded by gradients of halophytes from extreme true halophiles, including submerged waterplants, to halotolerant species, located in narrow fringes of decreasing salinity. These plants are common at seashores and coastal salt marshes, but become rare and fragile when found far inland and at relatively high altitudes and many are protected by European and regional laws (Montes and Martino 1987, Comín and Alonso 1988, Casado and Montes 1995, Sadoul *et al.* 1998, Cirujano and Medina 2002, Martín *et al.* 2003, Hueso and Carrasco 2008b).

Isolation and dispersion

Being endemic means “occurring nowhere else” (Brown and Lomolino 1998), thus organisms can be unique to a geographical location of any scale. Inland salinas are rich in endemisms because they constitute isolated habitats with extraordinary conditions for life, as if it were islands of salinity surrounded by a sea of a less saline land. They usually present hypersaline conditions in and around the brine source and the crystalizer ponds, with rapidly decreasing salinity fringes as we move away from these spots. Other challenges for life found in these habitats are the high UV light intensity, their ephemeral condition (due to the short salt production season), seasonal and/or irregular fluctuations in brine depth and surface and low oxygen solubility in water and therefore anoxic conditions (Williams 1981).

Numerous specialized organisms inhabiting highly fragmented inland saline environments and certain steppe areas usually show extreme disjunct distributions across the Mediterranean basin and central Asia (Ribera and Blasco-Zumeta 1998). These organisms, particularly those showing low dispersal potential, are likely to have had a wider distribution range during the late Tertiary, probably after population expansions during the Messinian salinity crisis at the end of the Miocene (5.3 Mya; Krijgsman *et al*. 1999), and they may have persisted through the incomplete glaciations of the Iberian Peninsula during the Pleistocene to the present day, constituting relict populations (Ribera and Blasco-Zumeta 1998, Alonso 1990, Campillo *et al.* 2011). Although studies lack on the biodiversity of inland saltworks, it may be possible that some of these isolated, relic species found in natural saline habitats might have benefitted temporarily by spreading to nearby saltworks, but may now be under threat due to alterations in the underground and surface water regimes.

Organisms adapted to life in these conditions have difficulties dispersing to similar habitats, because the distances to the nearest saline sites are too far. Aeolian and bird dispersion do occur but are unlikely to easily find adequate locations. Physiological adaptations to life under extreme conditions involve a high energetic expenditure which limits their growth capacity and their ability to adapt to other habitats, as well as to compete with generalist species or defend themselves against predators, which are usually absent in their own habitats (Herbst 2001).

BIOTA OF INLAND SALINAS

Microorganisms

As mentioned above, the increase in salinity causes a decrease in the number of different groups of the three domains of life. Remaining organisms usually consist of dense planktonic communities of the family *Halobateriaceae* (domain Archaea), unicellular green algae *Dunialiella salina* (almost the sole representative of the domain Eukarya) (Javor 1983, Oren 2002) as well as some representatives of the genus *Salinibacter* (domain Bacteria) (Antón *et al*. 2000, 2002, Oren and Rodríguez-Valera 2001, Benlloch *et al.* 2002,). They are most predominant above 10% salinity. Moderate halophilic bacteria are the most abundant in the 10–20% salinity range, while extreme halophiles are most predominant above 25% salinity (Sandaa *et al*. 2003). These halophilic microorganisms are a very diverse group, both from the taxonomic point of view as from their morphology, physiology, biochemistry, molecular biology and genetics (Casamayor *et al*. 2002, Oren 2005).

Less studied so far is the role of viruses, which are the most abundant biological entities in hypersaline environments such as crystallizer ponds (e.g. Guixa-Boixareu *et al*. 1996, Santos *et al*. 2010). Viruses are known to control the composition and numbers of microbial communities and serve as vectors for gene transfer, thus playing a role in the evolution of microbial populations (Santos *et al*. 2010). This control over microbial communities is especially important in hypersaline systems, where viruses might be the only predators, as bacterivory has not been detected over 25% salinity (Guixa-Boixareu *et al*. 1996, Pedrós-Alió *et al*. 2000).

Although thoroughly studied in coastal sites worldwide, microbial diversity has not been yet as well researched in inland saltworks. Few references exist from different parts of the world, such as Maras, in Peru (Maturrano *et al.* 2006). In 1984, one study detected a 74% of true halophiles of the genus *Halobacterium* in saturated brine at the Imón saltworks (Guadalajara, Spain), the rest being difficult to determine. In contrast, the same study obtained only halotolerant bacteria in a 30% saturated brine from a saline lake, Alcázar de San Juan. Possible reasons for this difference may be the pollution of the latter site and its fluctuating salinity (Soliveri *et al.* 1984). More recently, a study focusing on archaeal diversity identified genera such as *Haloarcula*, *Halorubrum*, *Haloquadratum* and *Halobactarrium* in the inland saltworks of Redonda and Penalva in Alicante, SE Spain (Zafrilla *et al.* 2010).

In any case, halophillic microorganisms are an ever evolving field of study, with new taxons being described and allotted to existing or new groups, and their ecology, physiology and biotechnological applications are yet to be fully understood.

Plants

In inland saline habitats, halophytes can be found in fringes or belts along a salinity gradient. These fringes are usually narrow and may even jump from oligohaline to hypersaline soils without transition (pers. obs.). Stem-succulents (those that accumulate salt in the stems), such as the genus *Salicornia,* and leaf-succulents (those that accumulate salt in the leaves), such as the genuses *Suaeda* or *Salsola,* are at the highest salinity level. These groups are usually followed by recreating halohpytes (those that expel excess salt), such as the genuses *Limonium, Atriplex* or *Tamarix* (Breckle 2002) and the outer belts are dominated by pseudohalohpytes and nonhalophytes. There are few submerged macrophytes that can survive in hypersaline, poorly oxygenated sediments and under large fluctuations in water levels. Some of the genera that tolerate these conditions are *Ruppia, Tolypella* and

Riella, which show a high diversity especially in the extreme saline environments of the Iberian Peninsula, unique to Europe. These plants offer high quality food and refugia for birds (Alonso 1985, Montes and Martino 1987, Cirujano *et al.* 1988, Cirujano and Medina 2002, Triest and Sierens 2009). Although halophytes are not used anymore for industrial purposes (as sources of soda for the production of soap or glass), they have an undoubtful scientific and intrinsic value. Besides, the United Nations Environmental Programme has drawn attention to the use of halophytes to prevent desertification, control erosion, restore degraded lands, provide food for livestock and fix carbon dioxide (Zafrilla *et al*. 2010). Perhaps better known to the general public is *Salicornia*, increasingly popular as a food condiment. Some studies also suggest that some of its species have medicinal properties (Rhee *et al* 2009).

Invertebrates

As said before, halophilic invertebrates show a pattern of high population subdivision, regional endemism and multiple glacial refugia within the Iberian Peninsula (Campillo *et al.* 2011). A well studied example is the endangered water beetle *Ochthebius glaber*, an endemic coleopteran of the Júcar, Guadalquivir and Segura river basins in the southeastern Iberian Peninsula (Abellán *et al*. 2005a, 2005b, 2007, Sánchez-Fernández *et al.* 2004). It has strong habitat specificity, requiring hypersaline conditions, and has been found in the salinas of Rambla Salada, La Ramona, La Maturra, Duernas and Hortales. Land use changes and irrigation are real threats for this species. Related species *O. notabilis,* seemingly exclusive of solar saltworks, has been found in the latter two sites, as well as in the salterns of Pinilla, Casas de Ves, Pétrola, Siles and in the far northern Añana (Abellán *et al.* 2007, Picazo *et al*. 2009) and is considered vulnerable in the Red List of Spanish Invertebrates (Verdú and Galante 2006). Other species often cited as typical from hypersaline environments are beetles *Nebrioporus baeticus, N. ceresyi, Enochrus politus, E. falcarius* and hemiptera *Sigara selecta* and *S. stagnalis* (Velasco and Millán 2003, Sánchez-Fernández *et al.* 2007, 2010). The genus *Cephalota* has four halophilous species, three of which with a broad geographic distribution, but the tiger beetle *Cicindela (Cephalota) deserticoloides* is endemic to the few remaining salt steppes of southeastern Spain. Individuals have been found a decade ago in just four locations, among which close to the salina of Rambla Salada (Diogo *et al*. 1999). Another well known example is the halophillic grasshopper *Mioscirtus wagneri,* which requires hypersaline habitats and is strongly associated to stands of *Suaeda vera*, its host plant (Ortego *et al*. 2011). It is basically found in saline wetlands in Los Monegros, La Mancha, and some locations in the SE and SW of the Iberian peninsula (Ortego *et al.* 2009, 2010, 2011). Since *S. vera* is commonly found in the surroundings of many inland saltworks, this specialized grasshopper species may also be found in this man-made type of saline habitat. Quite recently a water mite, *Ignacarus salarius*, has been found in a hypersaline spring close to the Salinas of Maturra in Córdoba and is suspected of being a Triassic relic (Moreno *et al.* 2008). For those species present in or near saltworks, abandonment of the salt making activity appears to be the principal cause of habitat loss for these species (Velasco and Millán 2003, Velasco *et al.* 2006, Sánchez-Fernández *et al.* 2007).

But it is a crustacean, *Artemia*, which is perhaps the most conspicuous and representative organism found in inland saltworks. In Spain, it has been found in more than 20 inland salt making sites (Persoone and Sorgeloos 1980, Vanhaecke *et al*. 1987, Hontoria and Amat 1992, Amat *et al.* 1995, Muñoz *et al*. 2008), most of which were active a couple of decades ago but are now abandoned. According to Amat (*et al*. 2007), *Artemia* has lost 74% of the suitable habitats in Spain in the last 20 years. Already in the 80s it was warned that many of the salt making sites and salt lakes where the presence of *Artemia* had previously been reported had been destroyed or abandoned in subsequent decades (Persoone and Sorgeloos 1980). Hence, salt making seems to have contributed to the maintenance of the genetic diversity of the *Artemia salina* populations in the Mediterranean region (Muñoz *et al.* 2008). On the other hand, the presence of these crustaceans seems to have a positive effect on salt production (Davis 1974), as they clean the brine of organic matter. Abandonment or transformation of saltpans into aquaculture or irrigation agricultural lands may become usuitable habitats for this species. Another threat faced by the Mediterranean brine shrimp, *Artemia salina*, are the biological invasions by alien North American species *A. franciscana.* The latter is widely used as fish food in the aquaculture industry and the pet market and effectively dispersed mainly by gut passage through shorebirds (Green *et al.* 2005). The invasive species easily outcompetes the native one, probably affected by cestode parasitism spread by migratory birds (Georgiev *et al.* 2007), thereby leading to a likely substantial loss of the genetic diversity of the Mediterranean species (Muñoz *et al*. 2008) and to local extinction (Amat *et al*. 2005, 2007). These invasions have been shown in many coastal saltworks of Spain, Portugal, Italy, France and Morocco (Green *et al.* 2005, Amat *et al.* 2005, 2007, Georgiev *et al.* 2007) but most Spanish inland salinas seem to be a reservoir of the native species, perhaps due to geographic isolation and lack of artificial inoculation and as long as they still constitute viable habitats (Gajardo *et al.* 2006, Amat *et al*. 2007).

Birds

Inland salinas, as compared with coastal saltworks, have little to no relevance for breeding shorebirds (Walmsley 1999). However, they constitute important stopover sites for migratory birds, as they offer water, feeding and occasional breeding opportunities, being as they are isolated in vast expanses of land (per. obs.). Some taxons typically found in inland saline sites are avocets (*Recurvirostra sp.*), black-winged stilt (*Himantopus himantopus*) and plovers (*Charadrius sp.*) (Sadoul *et al.* 1998).

Other vertebrates

Most other vertebrates found in saltworks are freshwater halotolerant species or generalist species and are rarely present inland, where salinity is higher. Perhaps the exception is *Aphanius iberus*, an endangered cyprinodontid fish with scarce populations distributed along the Mediterranean coast of the Iberian Peninsula. Citations include the salinas around the Mar Menor lagoon (Marchamalo and El Rasall) and close to río Chícamo (Rambla Salada de Fortuna), the latter being an inland site, plus an older one in the abandoned salinas of Calpe (Oliva-Paterna *et al*. 2002). The production of salt without adequate conservation measures has proven to be a threat for the population of this fish in the Marchamalo saltworks, in Murcia (Ruiz Navarro *et al*. 2007).

THREATS AND CHALLENGES

Wetlands are being threatened globally: since 1900, more than half of the world's wetlands have disappeared (Casado and Montes 1991, 1995; Barbier 1993, Pearce and Crivelli 1994, Schuyt and Brander 2004). Saltscapes in general and saline wetlands are no different in this respect; they have been under threat almost everywhere around the world and predictably will be in the next decades (Williams 1986, 1993, 1998, 2002; Jellison 2003). Many of them continue to be destroyed or irreparably damaged (Williams 1986, 1993). The main threats they face are:

- ***Climate change***
  A recent evaluation of the threat of climate change on Spanish wetlands concludes that seasonal saline wetlands of endorheic origin may disappear altogether. This is especially the case for the smaller ones. Other possible consequences of climate change may be the alteration of ionic composition, eutrophication, hypersalinization or decreased availability of underground water or brine (Álvarez *et al.* 2005).

- ***Abandonment***
  The abandonment of inland saltworks in Spain is tightly related to the so called rural exodus that had its peak during the second half of the 20th century. When salinas are abandoned, the lack of seasonal water level control and of dyke and pond maintenance also causes profound changes in the biota and in the ecosystem as a whole. The loss of salinas causes the disappearance of valuable halophilic communities, which are being replaced by generalist or opportunist species as soon as salinity decreases (Martins 2005, Carrasco and Hueso 2006, MultiAveiro 2007, Hueso and Carrasco 2008a, 2008b).

- ***Ignorance***
  One of the most important threats to saltscapes is, in fact, ignorance of their existence and therefore of their natural, cultural and even economic values. Scientists such as Williams (1981, 1986, 1998) or Margalef (1983, 1994) have repeatedly defended the study of inland saline waters while limnology –the study of all *inland waters*– has typically restricted itself to fresh waters. Policy makers, on the other hand, seem also not to value fresh and saline waters to the same extent.

- ***Complex regulations***
  Red tape of all sorts may apply to salt making sites, both from a sectorial (nature conservation, agriculture, industry, tourism…) as from a geographical (national, regional, river catchment…) level, and may even be contradictory, making the site's management an administrative challenge.

- ***Drainage, desiccation and waste dumping***
  Although not currently a common practice, in the past many wetlands have been drained or desiccated for health purposes, as they were considered the source of infectious diseases. Later, wetlands have often been used as waste(water) dumps, polluting the soil and the underground water table, and reinforcing the image of unhealthy sites (Comín and Alonso 1988, Casado and Montes 1991, Álvarez 2007, pers. obs.). Today, the drainage of saline floodplains to transform them into useful agricultural and grazing areas dries them well before they would do so naturally. The halophyte communities which depend on gradually fluctuating water levels are affected and their survival is at stake (JCCM 2002a).

- ***Land use changes***
  In the second half of the 20th century, agriculture in Spain underwent an important transformation process, from extensive and low impact, to intensive practices, with comprehensive land reclamations and irrigation projects in large, arid areas, where inland saltworks prevail (Casado and Montes 1991).

- ***Agricultural practices***
  Halophyte communities are directly destroyed by ploughing and fragmented by enlargement of cultivated fields. Intensification of existing agricultural land reduces the sources of food for wild fauna. The use of broad spectrum herbicides in nearby fields also poisons invertebrates and birds and kills the halophytes

found on the fringe of the fields. Those found in lower lying land are also affected by its runoff (JCCM 2002a).

- ***Free ranging livestock***
  Large herbivores graze, trample and defecate on halophyte communities, destroying the plants, affecting soil composition and allowing the invasion of species (JCCM 2002a, 2002b).

- ***Wild recreation***
  The flat saline floodplains close to the saltworks are dry in the summer, and recreational vehicles roam free on them. The scarce halophyte individuals present in the next to innermost belt of salinity are thus affected by trampling and mechanical alteration (JCCM 2002a).

- ***Infrastructures***
  Building roads contributes to habitat fragmentation and creates a barrier effect for smaller fauna, also affecting the flooding patterns of the saline floodplains. Other building works, such as dams, have an even stronger destruction potential. The movement and storage of materials needed for the construction of infrastructure also destroys plant communities (JCCM 2002a).

- ***Hunting***
  In some areas, hunting is an important activity. Lead pollution is therefore a relevant source of concern for halophyte communities (JCCM 2002a).

OPTIONS FOR TODAY

In order to find a balance between biodiversity conservation and salt production, a number of actions should be taken:

- ***Raise awareness*** of the stakeholders and the general public of the importance of the biodiversity of inland saltworks. Managers and owners of salt production sites should understand the relevance of keeping a balanced ecosystem to obtain an abundant and high quality salt harvest. Public authorities should contribute with coherent regulations and swift administrative processes and the general public should learn about the natural values of these sites and respect those restrictions that may apply with respect to access and land uses.

- ***Explore new markets*** for salinas, salt and those by-products that are compatible with the conservation of the saline ecosystem. Current trends in biotechnology, biofuels, pharmaceuticals, food industry and cosmetics may open new perspectives into sustainable products to be obtained from functioning saltworks. Specialized forms of tourism, community outreach and organization of events may contribute to alternative sources of income that are compatible with a biodiversity-friendly production.

- ***Introduce ecosystem management practices*** that protect the biodiversity while allowing or even enhancing efficient salt production, in cooperation between salt producers and nature conservation authorities. Active participation of other stakeholders involved may initially complicate the process, but will guarantee the compliance of the measures and regulations agreed upon.

- ***Invest in sound (socio-economic) recovery*** in those saltworks with stagnated activity due to low profitability of salt at the time of abandonment. New products and services may render them profitable again.

OPTIONS FOR THE (NEAR) FUTURE

Some of the halophillic microorganisms described above have potential applications in biotechnology, e.g. as conductors for computing and electronics, in the production of polymers and enzymes, liposomes and other cosmetic applications; in the biofuels industry for e.g. microbially enhanced oil recovery, bioremediation and pollutant removal and manufacture of biofuels and in the pharmaceutical industry, for e.g. the production of antibiotics, cancer detection and other drugs and for drug screening (Margheri *et al.* 1987, Galinski and Tindall 1992, Ventosa and Nieto 1995, Margesin and Schinner 2001, DasSarma *et al.* 2010, Galinski and Louis 2002, Oren 2002, 2010; Kanekar *et al.* 2012). *Dunialiella salina,* being rich in ß-carotene, is already widely used in the food industry as food supplement and colourant (Ben-Amotz and Avron 1989). Besides, halophiles –as extremophiles– are a well known study object for those scientists interested in extraterrestrial life (Mancinelli 2005).

CONCLUSIONS

Saltworks are, as other cultural landscapes, rich in biodiversity *because* of their man-made character and therefore require continuous management to maintain their biological interest (Geslin *et al.* 2002). Thus, in general, the best practice is to prevent abandonment and gain knowledge on how the system works. Biodiversity contributes to the profitability of salt making and provides by-products and services that may further support the viability of the economic activity, thereby truly earning its right to be preserved. Without it, salt production may be poor to non-existent both in quantity and quality and its managers may miss business opportunities that could make the difference between *being there* or not.

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