VIE ET MILIEU - LIFE AND ENVIRONMENT, 2020, 70 (3-4): 225-233

CAN ABANDONED SALINAS BE MANAGED AS COASTAL LAGOONS?

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ECOSYSTEM-BASED MANAGEMENT
COASTAL LAGOON
SALINA
HALOPHILE
HISTORIC MAPS

ABSTRACT. – Twenty-two of the Mediterranean coastal Salinas in S. France have been abandoned for salt extraction since 1950 and most are now available for nature conservation purposes. Their management is a challenge as the abandoned Salinas are human-modified systems, compartmentalized in salt ponds, with other important modifications in the landscape. These landscape modifications were studied in more detail in two examples by studying historic maps. Thus, for the Salin de Peyriac (Aude), an original endorheic lake (Etang du Doul) was converted into a pre-concentrating pond and nowadays persists as a hypersaline coastal lagoon. Salin des Pesquiers (Var) was created since 1848 within the Etang du Pesquier coastal lagoon. Therefore, the course of the Roubaud River, the tributary to this lagoon, was deviated to flow directly to the sea. Together with the creation of a circumferential canal this resulted in destruction of the original Roubaud delta and its fringing wetlands with ecotones in their freshwater – salt water transition zones. Both abandoned Salinas can in principle be managed as coastal lagoons, because the sediment surfaces of their ponds are located below mean sea level. Nevertheless, the Ecosystem-based management of these systems has to acknowledge a large degree of artificiality. Complete ecological restoration to historic conditions appears unrealistic and is often not desirable. Hence, abandoned Salinas offer many possibilities for creative and experimental management that should be followed by action monitoring and assessed by scientific studies.

INTRODUCTION

At the end of World War II, twenty-nine coastal Salinas along the Mediterranean coastlines in South France were exploited for salt extraction (Fig. 1). The exploited surfaces in the different Salinas ranged in 1950 from 17 ha to 3940 ha. In 2020, only five of those are still used for this purpose. While two smaller Salinas (Salin du Mas des Crottes and Salin de Esquineau) were incorporated into the enlarged Salin de Giraud, salt extraction has been completely abandoned in 16 of the smaller (*i.e.*, < 250 ha) and 6 of the medium-sized (*i.e.*, size in between 250 and 1000 ha) Salinas (De Wit *et al*. 2019), thus liberating 4019 ha for other land uses. This raises a question about spatial demands in society and spatial planning along the coastline.

The Salin de Garrouyas (137 ha) has been converted into industrial areas for the Port of Marseille-Fos; parts of Salin de Sainte-Lucie (70 ha of 441 ha) and Salin du Lion (30 ha of 61 ha) have been used for enlarging Port-la-Nouvelle and the airport of Marseille, respectively (De Wit *et al*. 2019). Projects for coastal developments, including marinas and holiday resorts, had been proposed for several abandoned Salina sites, *e.g.*, in the 1980's by the Société d'Aménagement du Port de Peyriac-de-Mer for Salin de Peyriac (Conservatoire du Littoral website). But, fortunately these projects were never executed and currently most abandoned Salinas are protected areas belonging to the Natura 2000 network (De Wit *et al*. 2019). How should these areas be managed as nature reserves? According to the Interpretation Manual of European Union Habitats – EUR28 (European Commission DG Environment 2013) "the salt basins and salt ponds may also be considered as lagoons, providing they had their origin on a transformed natural old lagoon or on a saltmarsh, and are characterized by a minor impact from exploitation."

The aim of the present study is to assess which environmental settings allow abandoned Salinas to be managed as coastal lagoons and what are alternative targets? Secondly, for the abandoned Salinas that will be managed as coastal lagoons, is it possible to adopt ecosystem-based management (EBS) and what does that imply?

LOCALIZATION, DISTRIBUTION AND ARCHITECTURE OF SMALL AND MEDIUM-SIZED SALINAS; ENVIRONMENTAL IMPLICATIONS OF ABANDONMENT OF SALT EXTRACTION

Figure 1 and Table I present the abandoned and still operating Salinas along the Mediterranean coastlines. These occur along the interior shorelines of coastal lagoons and on their coastal barriers (Languedoc region, Berre lagoon, Hyères). These Salinas have been constructed either directly within the lagoon or on their fringing salt marshes. Etang du Pesquier, the coastal lagoon on

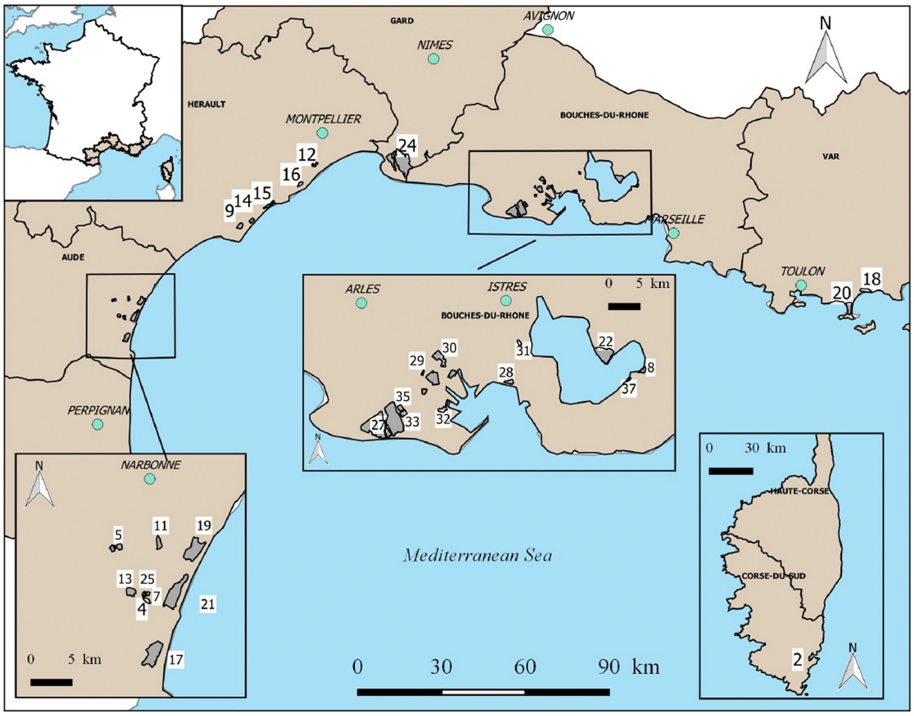

Fig. 1. – Distribution of Salinas exploited shortly after World War II in continental South France and Corsica. See Table I for names of the Salinas, indicating which Salinas have been abandoned and which are still being exploited. Creative Commons Licence, reproduced from De Wit *et al.*, 2019.

the Hyères peninsula, has completely been converted into a Salina. Other Salinas, (Sigean, Bagnas and Rassuen) occurred in depressions at a certain distance from the coastal lagoons, which were interconnected by man-built canals. Two large still operating Salinas and two abandoned medium-sized Salinas occur in the Rhône delta (Camargue) occupying former lagoonal and salt marsh environments. Some Salinas occur directly on the lowland coast, neither in a coastal lagoon nor in a delta (Fos-sur-Mer, Vieux salins d'Hyères). These latter lagoons have been constructed at the expense of salt marshes. Hence, most of the abandoned Salinas occur along the Gulf of Lion coastline, while smaller numbers of abandoned Salinas also exist in the Rhône delta, the Côte d'Azur and one in Corsica. Hence, most of the nowadays-abandoned Salinas were indeed created in coastal lagoons or on salt-marshes (locally designated as "sansouires") either bordering the lagoons or in the Rhône delta and are thus concerned by the citation above from Interpretation Manual of European Union Habitats – EUR28.

Salt extraction in Salinas is based on sun- and wind-driven evaporation and comprises two major steps, *i.e.*, i) concentrating the seawater to about one tenth of its original volume in pre-concentration ponds (Fr. partènements) and ii) using this concentrated brine with a salinity of about 290 g/L, to feed the crystallizer ponds (Fr. tables salantes). This allows to obtain a salt that is highly enriched in NaCl (table salt) in the crystallizer ponds. During the 19th century, experimental scientific studies of chemical composition of seawater and its changes during evaporation (Usiglio 1849) allowed to rationalize the process and improve the purity of the salt obtained. Accordingly, Salinas were designed in such a way that the concentrating seawater follows a flow trajectory across different pre-concentration ponds with increasing salinities. This allows for the sequential precipitation of calcium carbonate ($CaCO_3$) and gypsum ($CaSO_4$), before the brine enters the crystallizer ponds. Finally, from the crystallizer ponds, a highly concentrated brine rich in potassium (K+) and bromide (Br-) that remains after the precipitation of NaCl, is carefully collected and discharged thus preventing the impurities in the salt. This design implies that Salinas are compartmentalized environments comprising "salt ponds" or "salt-pans" of variable sizes, each surrounded by dikes with connections controlled by locks (Fr. martélières). Along the trajectory, the first pre-concentration ponds often have an irregular shape, while many of the next pre-concentration ponds and particularly the crystallizer ponds show very regular rectangular shapes. The latter feature has been used for the automatic assignment of functioning and abandoned Salinas in Corine land-cover (Bossard *et al.* 2000), assigned as Corine Land Cover (CLC) class 4.2.2 defined as salt-pans, active or in the process of abandonment. Nevertheless, this automatic assignment has resulted in a severe underestimation of Salina surfaces as the irregular pre-concentration ponds have been confounded with natural environments (De Wit *et al.* 2019). The dikes of the salt ponds can breach and erode away after maintenance by the salt extraction companies is abandoned, and this erosion particularly occurs in Salinas directly exposed to sea-surges and flash floods. Strong winds, which create wind erosion in exposed environments and strong water currents in

Table I. – List of Salinas abandoned since 1950 and still operating Salinas in South France. See the map in Fig. 1 for localization. Adapted from De Wit *et al*., 2019.

Number (see Fig. 1)	Name of the salina	Creation date	Closure date	Owner[1]	Spatial planning designation[2]	Exploited surface 1950 (ha)
ABANDONED SMALL (< 250 ha) and MEDIUM-SIZED (> 250 ha and <1000 ha) SALINAS						
Narbonnais (Gulf of Lion)						
4	Salin de Tallavignes	1803	1962	Conservatoire	PA-CdL / N2000	37
13	Grand Salin de Sigean	1300	1968	Conservatoire	PA-CdL / N2000	96
25	Salin de Ferrand	1800	1962	Conservatoire	PA-CdL / N2000	17
7	Salin de Grimaud	1795	1962	Conservatoire	PA-CdL / N2000	19
21	Salin Sainte Lucie	1831	2005	Conservatoire	PA-CdL / Regional NR/ N2000-70 ha for Harbor	441
5	Salin de Peyriac	1300	1967	Conservatoire	PA-CdL / N2000	80
11	Salin de Campignol	1880	1963	DPM	N2000	75
Coastal lagoons of Thau and Palavas (Gulf of Lion)						
9	Salin de Bagnas	1789	1975	Conservatoire	PA-CdL / National NR / N2000	285
14	Salin de Castellas	1779	1967	Conservatoire	PA-CdL / N2000	173
15	Salin de Villeroy	1779	1968	Conservatoire	PA-CdL / N2000	186
16	Salin de Frontignan	1338	1968	Conservatoire	PA-CdL / N2000	218
12	Salin de Villeneuve	1100	1969	Conservatoire	PA-CdL / N2000	100
Camargue and Berre Lagoon						
29	Salin du Caban	1882	1970	Port of Marseille-Fos	N2000	567
30	Salin du Relai	unknown	1970	Port of Marseille-Fos	N2000	485
32	Salin de Garrouyas	1882	1950	Port of Marseille-Fos	Industry-Harbor	137
28	Salins Fos-sur-Mer / La Marronède	1833-1836	1985	Municipality of Fos-sur-Mer	N2000	205
31	Salin de Rassuen	1808	1953	Municipality of Istres	N2000- ENS	36
37	Salin de Jai	1923	1955	Communauté des communes	ENS	17
8	Salin du Lion	(822)-1802	1955	Communauté des communes	ENS, 30 ha Extension airport Marseille	61
Hyères (Côte d'Azur)						
20	Salin des Pesquiers	1848	1995	Conservatoire	PA-CdL / N2000	424
18	Vieux Salins de Hyeres	1200	1995	Conservatoire	PA-CdL / N2000	331
Corsica						
2	Salin de Porto Vecchio	1795	2001		Shortlisted for PA	29
SALINAS STILL EXPLOITED FOR SALT EXTRACTION IN 2020[3]						
Narbonnais (Gulf of Lion)						
17	Salin de La Palme	1884	2005	DPM	Salt extraction	412
19	Salin d'île Saint Martin	1910	2006	DPM, Municipality of Gruissan	Salt extraction	392
Camargue and Berre Lagoon						
24	Salin Aigues Mortes	13th century	–	Salins	Salt extraction	3940
27 (+ 33 + 35)	Salin de Giraud[4]	1856	–	Conservatoire, Salins	Salt extraction (5000 ha as PA-CdL / N2000)	2891 (+ 75 + 69)
22	Salin de Berre	1100	–	Salins	Salt extraction[5]	428

[1] Conservatoire: Conservatoire du Littoral (the French coastal protection agency), DPM: Public maritime domain (state-owned), Communauté des communes (a local public body of collaborating municipalities), Salins: Groupe Salins (multinational company dedicated to salt production).
[2] Abbreviations: PA-CdL: Protected Area owned by the Conservatoire du Littoral, N2000: Site belonging to Natura 2000 network, NR: Nature Reserve, ENS: "Espace Naturel Sensible" (a designation based on the Urbanistic code).
[3] Salt extraction was completely interrupted in the Narbonnais from 2006 to 2012.
[4] The Salin de Giraud (27) integrated the Salin de Esquineau (33) and Salin du Mas des Crottes (35), it was strongly enlarged between 1950 and 1975 to 12,000 ha. Since 2009 only about 7,000 ha is still exploited for salt extraction.
[5] Salin de Berre does not use seawater, but rather a brine from a salt mine.

coastal lagoons and salt ponds, can also contribute to the degradation of the dikes. Nevertheless, particularly at the more sheltered sites, more or less degraded dikes may persist as a vestige for many decades.

The above-mentioned rational well-organized management of the Salinas requires a fine-tuned hydraulic management. The small tidal amplitude in the NW Mediterranean is not sufficient to efficiently drive the hydraulic flow trajectories in the Salinas, as *e.g.*, used in the artisanal systems in Guérande on the Atlantic coast. Hence, pumping has been used in Salinas in the NW Mediterranean. The localization of the pumps depends on the topography and bathymetry of the Salina. Hence, Salinas with the soil surface above mean sea level have used pumps to take in the water from the sea and fill the first pre-concentration ponds. Gravitation force, sometimes combined with additional pumping has been used to drive the hydraulic flow trajectories. In contrast, Salinas created within coastal lagoons with the sediment surfaces located below mean sea level often functioned differently. In these cases, seawater intake into the pre-concentration ponds was often based on the principle of communicating vessels; the tendency of decreasing level in the successive pre-concentration ponds due to evaporation was compensated by inflow. Nevertheless, the flows driven by evaporation and gravitation were often not sufficient to drive the flow along the entire trajectory in the Salina and often pumping has been used to fill the crystallizer ponds. Pumping is expensive both in terms of energy costs (electricity) and in terms of maintenance (strong corrosion of metal parts in engines). As a result, abandonment of Salinas by the salt-extracting firms has resulted in all cases of immediate arrest of pumping.

To improve the yield and guarantee the stability of the salt-extraction process, the operating Salinas along the shorelines need to be protected from freshwater inflow from tributaries and runoff. Therefore, most of the Salinas have used a circumferential canal to intercept these freshwater flows from the catchments and deviate them directly into the lagoon or the adjacent sea. Such outlets were spatially separated from the intake of saline water into the Salina. The circumferential canal has often also been used for shipping the harvested salt (Fig. 2). In some cases, the course of tributaries was even deviated. These changes in the landscape destroyed the freshwater – saltwater gradients with their ecotones (De Wit 2011a). After abandonment of salt extraction, these gradients are not recovered spontaneously, because the natural course of the freshwater flow remains forced by the canal and is obtruded by dikes surrounding the ponds.

In conclusion, the abandoned Salinas that have become available for nature conservation management have inherited many features that imply a large degree of artificiality. At the same time, while pumping and salt-extraction have stopped, the artificial ecosystems have been subjected to a strong modification of their salinity regimes.

Fig. 2. – Boat used for transportation of salt harvest in a circumferential canal of a Salina in Languedoc. Note also the aerial electricity cables used for powering the pumps of the Salina. Reproduced from Leenhardt (1939, opposite page 66).

Hence, particularly the hypersaline environments of highest salinities have often disappeared. Below, I discuss in more detail the major modifications in the landscape and ecosystems for two abandoned Salinas.

MAJOR LANDSCAPE AND ECOSYSTEM MODIFICATIONS REALIZED BY HUMANS FOR THE CREATION OF THE SALINA AND AFTER ITS ABANDONMENT; TWO EXAMPLES

Peyriac Salina and adjacent Etang du Doul

The Salin de Peyriac was created around 1300 (De Wit *et al.* 2019) in a semi-enclosed bay of the Bages-Sigean lagoon (Fig. 3A), to the north of the village of Peyriac-de-Mer. The Salina is clearly shown on the maps of Cassini (Fig. 3B) representing the situation about 1770 and the ordnance survey may (Fig. 4A) of the 19th century (Etat-major 1820-1866), which was based on field measurements realized in 1852 (Cavero 2010). Both maps show a valley adjacent to the Salina with a lake, the Etang du Doul. The valley of the Etang du Doul is an enclosed depression delimited by small hills (30-70 m) that was naturally endorheic (David & Carozza 2013). A threshold separated the valley from the semi-enclosed bay where the Salin de Peyriac was created. In the past, the volume and extension of this endorheic lake was thus the result from losses through evaporation and inputs from runoff and groundwater flows from its surrounding watershed, perhaps sometimes also by overtopping of water from the lagoon. The topographic map of 1950 (Fig. 4B), shows that at some time between 1852 and 1950, this area was modified to incorporate the Etang du Doul valley into the salt extraction enterprise at Peyriac-de-Mer. An inlet canal was created from the inlet in the lagoon and cut through the barrier into the valley (Fig. 4B, D). The Etang du Doul increased in volume. An outlet canal (Fig. 4B, D) was created to connect it with the pre-concentration ponds in the original Salina. Hence, since then Etang du Doul functioned as a pre-concentration basin in the extended Salina. Salt extraction was stopped in 1967. This did not impact the level of the Etang du Doul (see Fig. 4C, E, F) as it continued to exchange with the Salina and lagoon through the inlet and outlet canals. The salinity in the Etang du Doul has been maintained at around 1.5 to 2 times seawater salinity (Boutière 1974). However, occasionally the lake level decreased and its salinity increased when these exchanges were obtruded, and current management, therefore, aims to maintain these exchanges (Conservatoire du Littoral website).

Salin des Pesquiers (Hyères)

As shown by the Cassini map (Fig. 5A, B), in the 18th century, the Etang du Pesquier was a coastal lagoon located on the peninsula of Giens south of Hyères. This system represents a tombolo connecting the mainland to the island of Giens comprising two parallel coastal barriers with the coastal lagoon in between. The river Roubaud had its outflow located on the northern shore of the Etang du Pesquier (Aboucaya *et al.* 2011), where it created a small delta (see Fig. 5B). The Salina was created since 1848 in the northern part. Therefore, the Roubaud River was deviated and a canal was created (local name

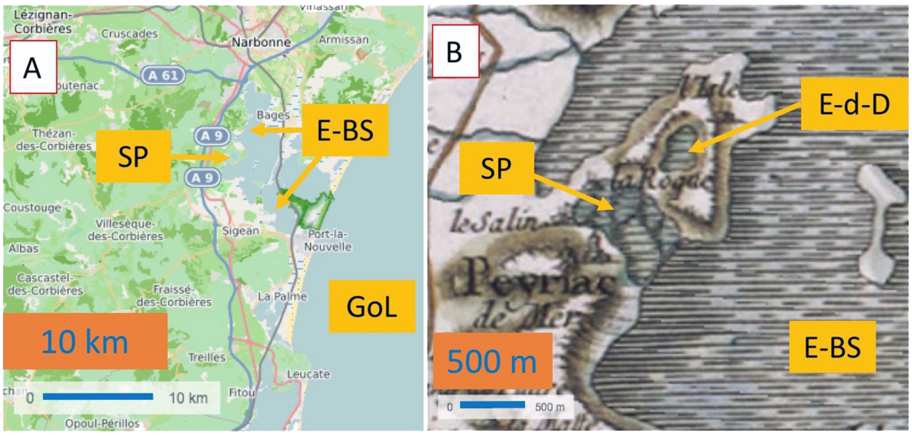

Fig. 3. – Salina in Peyriac-de-Mer (N° 5 in Fig. 1 and Table I). **A**: OpenStreetMap showing the location of Salin de Peyriac in a semi-enclosed bay of the Etang de Bages-Sigean; **B**: Carte de Cassini showing the Salin de Peyriac and the adjacent depression with the Etang du Doul endorheic lake in the 18th century. E-d-D: Etang du Doul, E-BS: Etang Bages Sigean, GoL: Gulf of Lion (W Mediterranean Sea), SP: Salin de Peyriac. Note difference in scale between panels. Source: IGN géoportail.

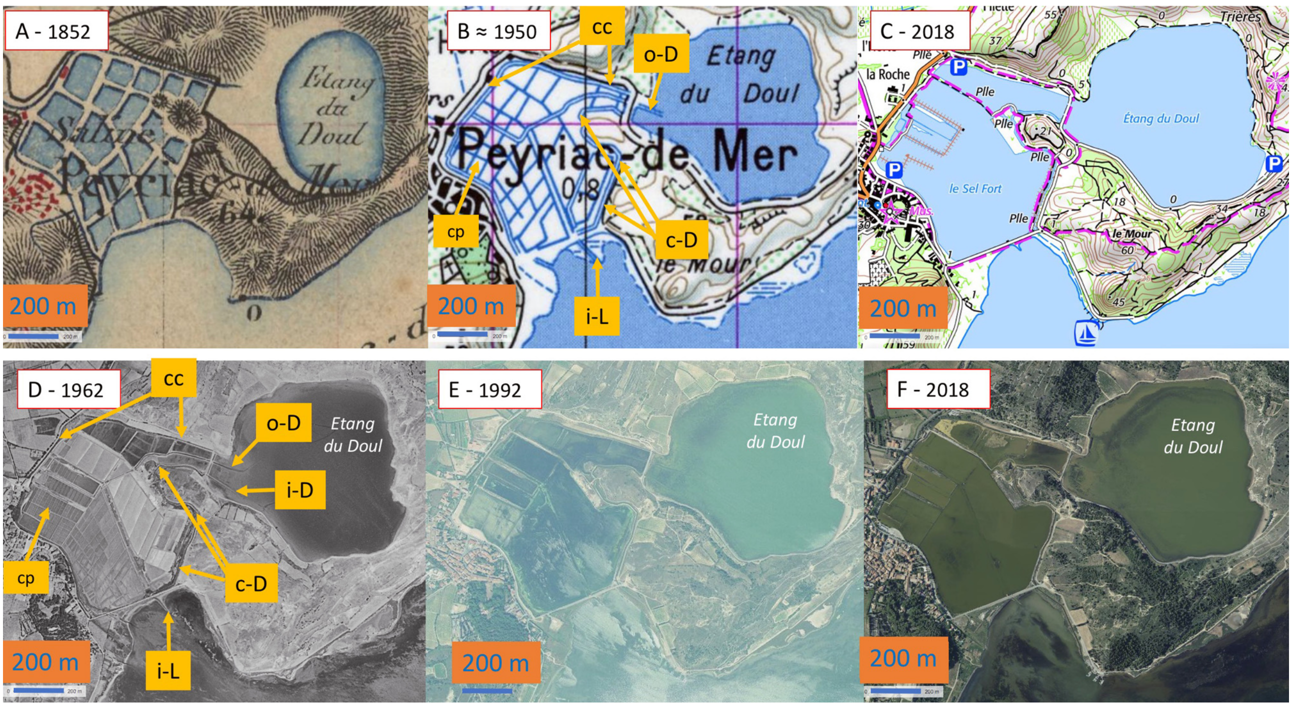

Fig. 4. – Salina in Peyriac-de-Mer. **A**: 19th century ordnance survey map (Etat-major 1820-1866) based on field measurements 1852 (Cavero 2010); **B**: 1950 IGN Topographic map; **C**: 2018 IGN Topographic map; **D**: Aerial photograph 1962; **E**: Aerial photograph 1992; **F**: Aerial photograph 2018. cp: crystallizer ponds, cc: circumferential canal, i-L: inlet from the lagoon into the canal connecting to Etang du Doul, c-D: canal connecting lagoon to Etang du Doul, i-D: inlet from canal into Etang du Doul, o-D: outlet from Etang du Doul into pre-concentration ponds in original Salina. Note same scale for all panels A to F. Source: IGN géoportail.

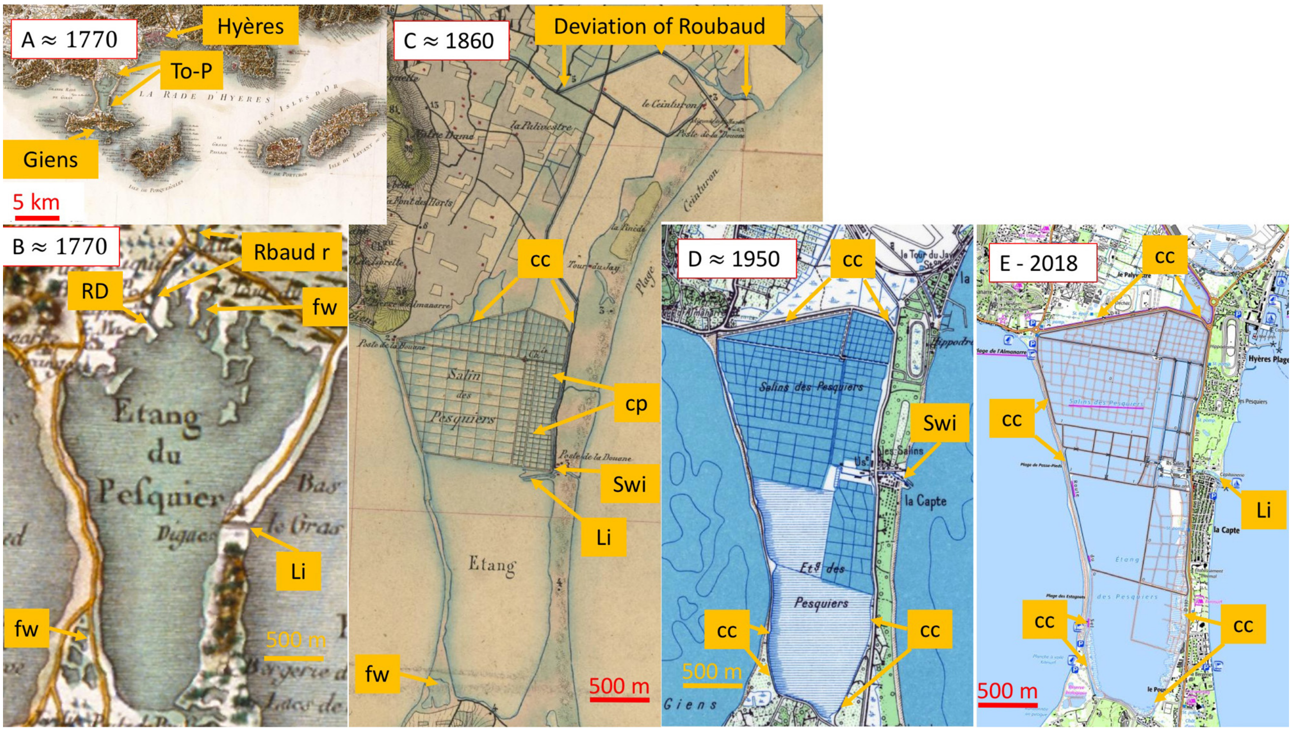

Fig. 5. – Etang du Pesquier and its progressive conversion in a Salina (Salin des Pesquiers). **A**: Carte de Cassini showing Rade de Hyères and Giens connected to mainland by a Tombolo with Etang du Pesquier; **B**: Carte de Cassini showing Etang du Pesquier; **C**: 19th century ordnance survey map (Etat-major 1820-1866), for which field measurements were performed between 1850-1860; **D**: 1950 Topographic map IGN; **E**: 2018 Topographic map IGN. cc: circumferential canal, cp: crystallizer ponds, fw: fringing wetland, Hyères: city of Hyères, Rbaud r: Roubaud river, RD: Roubaud delta in Etang du Pesquier, Li: lagoon inlet, Swi: seawater intake for salt extraction, To-P: Tombolo connecting Giens to mainland. Note same scale for all panels B to E, different scale for panel A. Source: IGN géoportail.

'canal de ceinture') as it is clearly visible on the Ordnance survey map (Fig. 5C). This destroyed the Roubaud delta and the large wetland complex including the former delta in the North became separated from the lagoon. Hence, the freshwater – saltwater gradients with their ecotones in the northern part were destroyed. While the southern part remained a lagoon with a modified inlet and fringing wetlands with freshwater-lagoon gradients still persisting in the SW corner. The Salina was progressively extended to occupy a large part of the southern lagoon as shown on the 1950 topographic map (Fig. 5D). This extension is already visible on the aerial photograph of 1920. During the same period the circumferential canal was also extended to the SW corner of the lagoon, but apparently not along the western barrier (as visible on aerial photograph of 1931). Nowadays, the circumferential canal also runs alongside that latter barrier (Fig. 5D). Salt extraction was finally abandoned in 1995.

Ecosystem-based management of abandoned Salinas

For implementing ecosystem-based management (EBM) in abandoned Salinas it is of paramount importance to document the changes in the landscape engineered by humans and understand how these have affected the ecosystem functioning. As shown before, these changes in the landscape go far beyond the compartmentalization of the Salina itself, but have most often included the fixation of the inlet and the destruction of the freshwater – seawater gradients with their ecotones. Hence, almost all Salinas have been surrounded by a circumferential canal and the Salin des Pesquiers even shows an example where the course of a river was deviated to elsewhere on the coast for restricting the freshwater input into the coastal lagoon. In Peyriac-de-Mer, the Etang du Doul valley, an enclosed depression in the landscape adjacent to the Salin de Peyriac has been completely modified by connecting it to the lagoon and the adjacent Salina. Hence the original natural endorheic lake, which is characterized by fluctuations of lake level and salinities, was converted to a permanent hypersaline lagoon.

A coherent and instrumental definition of EBM is provided by the US National Oceanic and Atmospheric Administration (NOAA). Accordingly, "EBM is an integrated management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation." (NOAA website). Indeed, as human-engineered ecosystems, the impact of humans cannot be neglected for Salinas. Table II lists the so-called core characteristics of EBM recognized by the NOAA and my recommendations on how this could be imple-

Table II. – Core characteristics of Ecosystem-based management (EBM) according the US National Oceanic and Atmospheric Administration (NOAA website), and the recommendations of the author on how these can be implemented for the management of abandoned Salinas.

Core Characteristics of EBM (NOAA)	Recommendations for management of abandoned Salinas
Adaptive and flexible, responsive	After deciding a target, Implementation of adaptive management supported by monitoring and research
Place-based with geographic areas defined by ecological criteria	Adopting a landscape/seascape approach, using ecohydrology, considering all the modifications engineered by humans that impact the ecosystem functioning (*i.e.*, transition zones, connectivity, etc.)
Cross-sectoral, considering interactions	Knowledge: Combine historic, geomorphological and ecological data and insights Law: Combine legislation on water, biodiversity, spatial planning and maritime issues
Proactive	Ecological restoration (prevent a dogmatic approach) and ecoengineering. Life projects as demonstration sites
Inclusive and collaborative – all levels of government, indigenous people, stakeholders	Discuss and co-construct the different options for targets with the stakeholders, including the local populations, and with local administrations

mented for the abandoned Salinas. The last characteristic in the table, *i.e.*, 'Inclusive and collaborative concerning all levels of government, indigenous people, stakeholders' appears as particularly pertinent for the coastal Salinas. Local populations often recognize the salt extraction activity as an important part of their local identity and are sometimes strongly in favor of keeping the "mémoire du sel" alive as a cultural heritage. Hence, for the abandoned Salina this may result in a demand for bringing back into exploitation and this has indeed been achieved by private initiative in the Salin de la Palme and Salin de l'île Saint Martin (see Table I). This option was also considered for the Salinas in Hyères, although it was finally not adopted. Bringing back into exploitation allows to conserve the hypersaline biological communities along the artificially maintained salinity gradients. The biodiversity of the pelagic and benthic biota in the ponds decreases with increasing salinity, and becomes progressively dominated by micro-organisms (reviewed in De Wit *et al*. 2019). The pigment-containing Alga *Dunaliella salina* (Dunal) Teodoresco, 1905 and extreme halophilic Archaea occur in high densities in the plankton of the most saline preconcentration and in the crystallizer ponds, successively, where they provide beautiful colorations. The hypersaline biodiversity is original as it comprises many strict halophiles restricted to these environments. Hence, the coexistence of small and medium-sized operating Salinas together with natural coastal ecosystems has resulted in increased biodiversity at the landscape level (De Wit *et al*. 2019).

Setting alternative targets for Salinas is a challenging task of primary importance, once it has been decided collectively with the stakeholders and the local public administrations to accept the permanent abandonment of salt extraction in the Salinas. Firstly, the topography and bathymetry of the ponds should be considered.

In the Mediterranean climate, the ponds with the soil above mean seawater level tend to become ephemeral salt ponds, which are submerged after autumn rainfall and dry out during spring or early summer. Their salinity results from the dissolution of the salt accumulated in the soils and increases strongly with evaporation. Such environments function as endorheic environments and provide interesting aquatic vegetation as the angiosperm *Althenia filiformis* Petit, 1829 and Charophytes including *Lamprothamnium papulosum* (K. Wallroth) Groves, 1916 and *Tolypella salina* Corillon, 1960 (Lambert *et al*. 2013; Mouronval *et al*. 2015). Nevertheless, these environments do not correspond to the generally accepted definition of coastal lagoons (Kjerfve 1994), but rather correspond to man-made surrogates of endorheic evaporitic ponds and lakes, which have decreased worldwide (Wurtsbaugh *et al*. 2017). When, these types of environments are subjected to strong wind erosion and breaching of dikes during sea surges and flash floods so-called 'renaturalization' can also be envisioned. Hence, the ponds will become progressively destroyed and finally it is possible to recover natural salt marshes and moving dune systems. This approach has been adopted for the northern part of the Salin de Sainte Lucie and for the 5000 ha in the Camargue that has been abandoned as Salina surface after a reduction of the exploitation in Salin de Giraud (De Wit *et al*. 2019). In conclusion, the abandoned Salinas, that comprise ponds with the soil above mean sea level, provide many interesting opportunities for nature development, although these are not suitable to be managed as coastal lagoons.

Abandoned Salinas that have the soil or surfaces of the sediments of their ponds located below mean sea level can in principle be managed as coastal lagoons. The two studied examples, *i.e.*, Salin de Peyriac and Salin des Pesquiers belong to this category. However, besides acknowledging the artificiality of the compartmentalization of the water body in Salinas, such a target should keep in mind that natural coastal lagoons are linked to a watershed and show a natural inlet that is not fixed by hard structures.

Can these features potentially be recovered together with a destruction of the compartmentalization, and is that desirable? Considering the example of the Salin des Pesquiers, which still was a natural lagoon in the 18th century (Fig. 5A, B). The theory of restoration ecology would consider this system a historical reference (Clewell & Aronson 2013). A dogmatic application of this theory would imply that the ecological restoration (see Table II) should i) destroy all the dikes and clear the lagoon, ii) destroy the circumferential canal, iii) restore the original course of the Roubaud river and restore the fringing wetlands, and iv) restore a natural inlet for which natural movements will be tolerated. This ambitious program appears of course unrealistic and probably it is even not desirable for the local populations, who may want to keep certain vestiges of the salt exploitation period. Moreover, particularly, along the coastal zone, it has to be considered that the historical reference state is probably not sustainable in face of global change (De Wit 2011b). For the Etang du Doul, ecological restoration would imply its conversion into an endorheic lake as still existing in the 19th century, but this solution has also been judged as non-desirable (Conservatoire du Littoral website). Hence, for EBM, the managers of abandoned Salinas have to accept a high degree of artificiality inherited from the exploitation period.

So, what can be done if it is not feasible to return to the historic conditions existing before the creation of the Salina? First of all, one can tolerate and even facilitate the erosion of the dikes in order to create larger ponds of more natural sizes. For the Salin de Peyriac it is shown that this erosion in the SE part of the Salina resulted in a larger water body, while vestiges of dikes remain along the W part, where the crystallizers occurred (Fig. 4E, F). On the other hand, the larger number of ponds also allows managers to experiment different environmental conditions in different ponds. Creative management may include the building of islets within the ponds to favor breeding bird colonies or developing a mosaic of ponds with different depths favoring different bird species. Reconnecting the abandoned Salina more efficiently with the sea allows to enhance the nursery functions for fishes and invertebrates. If oligotrophic conditions can be obtained and maintained in certain ponds, it appears interesting to achieve lower salinities (equivalent to seawater or below) to restore angiosperm meadows (*i.e.*, *Zostera noltei* Hornemann, *Ruppia cirrhosa* (Petange) Grande and *Cymodocea nodosa* (Ucria) Ascherson). Hence, it may be interesting to allow freshwater inflow in certain parts as these may contribute to achieve these lower salinities, while also contributing to locally creating freshwater – saltwater transition zones. This can be done by creating localized inlets from the circumferential canals regulated by locks. Nevertheless, this needs to be done with care, as it should be checked that the freshwater inputs do not carry high nutrient loadings, which will cause eutrophication of the lagoon, or chemical contaminants. The latter shows the importance of controlling water quality as requested by the EU Water Framework Directive (2000), meaning that the lagoon managers have to cope with different legislation, particularly also the EU Habitats (1992) and Birds directives (2009). Nevertheless, abandoned coastal Salinas present an interesting playground for experimental management, although it is most important that the management plan be discussed and concerted with the local stakeholders and public administrations and that the characteristics of EBM (Table II) are respected.

CONCLUSION

Abandoned Salinas that have the soil surface of their ponds below average sea level are good candidates for management as coastal lagoons. In contrast, the abandoned Salinas with soil surfaces above mean sea-level are more prone to be developed as series of endorheic temporal salt ponds or for promoting the recovery of a more natural system of salt marshes and dunes. The latter is possible in more dynamic environments, as *e.g.,* directly on the coast where wind and hydraulic processes are strong enough to reshape the landscape. In all cases, the EBM of the abandoned Salinas has to acknowledge a large degree of artificiality inherited from the exploitation period. The modifications in the landscape go beyond the compartmentalization of the Salina, and particularly have generally included the destruction of freshwater – saltwater transition zones and modified inlets. In addition, in Peyriac-de-Mer these modifications included converting an endorheic lake into a permanent hypersaline lagoon and in Salin des Pesquiers diverging the course of the Roubaud River. A complete ecological restoration to historic conditions before the creation of the Salina is often neither realistic nor desirable. While respecting the core characteristics of EBM, abandoned Salinas offer many possibilities for creative and experimental management that should be followed by action monitoring and assessed by scientific studies.

STUDY SITE AND METHODS

The study site comprised the littoral zone of the Mediterranean Sea in southern France (see Fig. 1) including the Gulf of Lion, the Côte d'Azur and the Tyrrhenian Sea in Corsica.

This paper is a mixture of an opinion paper enriched with a specific study on two abandoned Salinas, *i.e.*, Salin du Peyriac (Peyriac-de-Mer, Aude Départment, 43.088°N; 2.964°E) and Salin des Pesquiers (Hyères, Var Department, 43.066°N; 6.139°E). Figures 3, 4 and 5 have been compiled using websites Géoportail and its dedicated section "remonter le temps". The Casini map corresponds to the so-called "Marie-Antoinette-version". The following aerial photographs have been used.

Salin de Peyriac

IGNF_PVA_1-0__1962-06-30__C2446-0023_1962_F2446-2546_0181.jp2 (Fig. 4D)

IGNF_PVA_1-0__1992-08-06__C92SAA1532_1992_FD11_0097(1).jp2 (Fig. 4E)

Salin des Pesquiers

IGNF_PVA_1-0__1920-03-11__CCF00C-281_1920_CAF_C-28_0018.jp2 -

IGNF_PVA_1-0__1931-01-06__C3346-0561_1931_NP7_1205.jp2

Acknowledgements. – I thank T Changeux, C F Boudouresque, P Astruch and B Belloni for their kind invitation to participate at the Gecomars-2020 conference and their encouragements to pursue this study.

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