

COMPARISON OF SOLAR SALTWORKS WITH SALINE COASTAL WETLANDS

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EXTENDED ABSTRACT

Salt is one of the world's best-known minerals and the chemical substance most related with the history of human civilization. Its significance for the creation of life itself on the planet and its importance as a commodity are paramount.

Solar Saltworks produce salt by solar evaporation since the dawn of human civilization. Nevertheless, the development of a unique coastal ecosystem in parallel with the salt production process evolution, it is not very well known. The biological process that develops along with the salinity vector in the evaporating ponds and crystallisers, produces excellent food for many kinds of birds, which for this reason rest, feed and breed in Solar Saltworks. The low salinity ponds and especially those that are close to sea salinity produce very tasty fishes and many people use the high salinity ponds for brine and mud bathing. Artemia is a high value commodity that is used to feed nurse fish. The basic steps in the evolution of solar salt production process and their similarities-differences with the saline coastal wetlands are identified. It is shown that especially modern Solar Saltworks are not just salt production plants but they also function as integrated saline wetlands. Their ecological importance consists of the fact that they comprise the characteristics of both regular and hyper saline wetlands.

Hundreds of endangered and/or protected bird species feed and/or nest in solar Saltworks similarly with the natural wetlands.

The operating scheme of coastal saline wetlands is also identified and compared with Solar Saltworks and the transformation of "Alikí" wetland into Solar Saltworks is outlined. (The Lemnos project).

Keywords: Solar Saltworks, Production process, Biological process, Wetlands, Lemnos, Alikí Lake.

INTRODUCTION

Salt, the common name for the compound of sodium (Na^+) and chloride (Cl^-), is the first substance after water to have attracted humans' attention in their evolution from wilderness to civilisation. Both its significance in the creation of life itself on the planet and its importance as a commodity are paramount.

It is common knowledge that life began in the oceans, where the first monocellular organisms were created. Although some creatures left their marine environment after a long evolutionary process, they continued being dependent on salt. Nowadays, we know that sodium chloride is the basic extra-cellular electrolyte of the human body and that the salinity levels of the environment where human foetuses develop are similar to those of the sea! Therefore, salt has remained a necessary element for the survival and proliferation of not only herbivorous animals, which take the necessary quantity of salt by

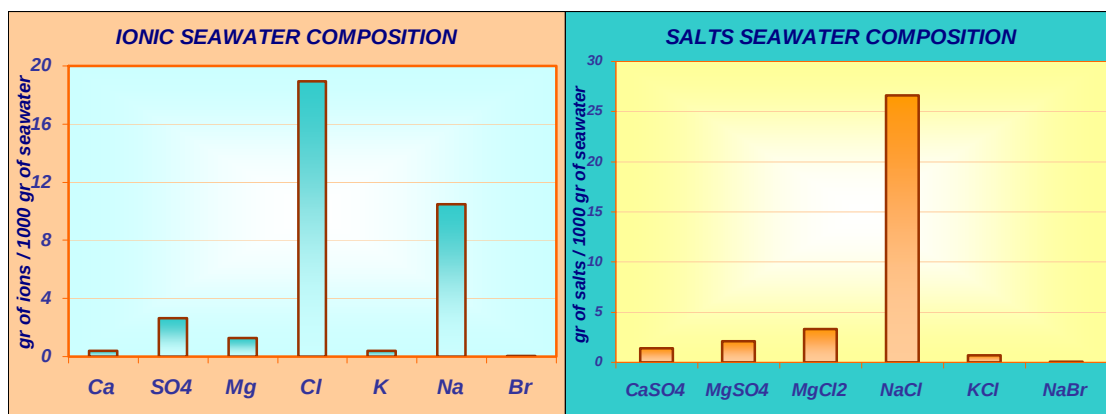
licking the salty soil, but also for carnivorous ones, which ensure the necessary intake of salt from the blood of their prey (Young 1977).

The time when humans began engaging in farming activities and became settlers coincides with their search for salt, which is provided by nature in abundance. Salt along with water, cereals (bread) and the meat of domestic animals constituted the staple basis of human society in its infancy (Baas-Becking 1931). Humans must have found salt where it can still be found, that is, in concave rocks of coastal areas or in lagoons where seawater gets trapped and deposits salt as it evaporates in the sun. At a certain point in their history, humans must have copied nature and produced salt on their own by evaporating seawater via either solar energy or ebullition.

Originally, salt was used to cater for the needs of human diet but later, it was discovered that it had significant food preserving property. This particular property made salt one of the most important commodities for centuries. The significance of salt as a commodity is only comparable to the importance of oil in our times. Although after the industrial revolution the use of salt as food preservative and its overall economic significance gradually began to decline, people's needs in salt did not follow the same trend. On the contrary, the extensive use of sodium chloride in industry and in particular, its use as raw material in the chemical industry have increased dramatically salt consumption worldwide, with annual figures reaching 200 million tonnes nowadays. One third of this is produced in solar Saltworks. About 20% of the international salt production is destined for human consumption, whereas 55% is used in the chemical industry and 15% is spread on roads to thaw ice or snow in winter.

SALT RECOVERY FROM SEAWATER

The present work refers to the Solar Saltworks production process, where salt (NaCl) is recovered from seawater by solar evaporation. Seawater is an inexhaustible raw material, amounting to approximately 5×10^{16} tonnes.



Production of salt from seawater involves the selective recovery of pure NaCl, free of other soluble or non-soluble salts and other substances. To this end, an appropriate quantity of seawater is concentrated through natural evaporation, which leads to the fractional crystallisation of all salts contained; a process based on their varying solubility. Solar evaporation of seawater results in the successive crystallisation of the less soluble salts (CaCO₃, CaSO₄) first, followed by NaCl and finally Magnesium salts.

Salt workers use the empirical Baume (°Be) scale, to measure the concentration of brines. According to that scale the seawater concentration is approx. 3.5 °Be. The crystallisation of CaCO₃ begins at 4.6 °Be and that of CaSO₄ at 13.2 °Be. NaCl crystallises at 25.7 °Be, followed by the more soluble Mg salts at 30 °Be.

SOLAR SALTWORKS PRODUCTION PROCESS EVOLUTION

As we have already mentioned, originally, humans must have found salt in coastal concavities or in lagoons where seawater is trapped, evaporated in the sun and deposited its salt content. It can be deduced that, after a long period of observation and knowledge building, humans eventually copied nature and began producing salt in quantities meeting their personal and social needs, thus moving away from nature's production rates.

That was therefore, **the first step** and constitutes the **first stage** of the solar sea salt production process hereby described. This method has certain disadvantages since the salt produced contains all the ingredients of seawater and it is very difficult to produce relatively pure NaCl (in fact, it requires great experience). Moreover, this method of salt production is a batch process, with limited production rates.

The **second step** in the process of salt recovery from seawater was made with the division of the evaporation basin into two, (figure 1). The first basin, usually called nurse pan, was used for the production of saturated (with respect to NaCl) brine, which was fed into the second basin, usually called crystalliser.

Thus, it was made possible to:

- Achieve continuous salt production (crystallisation) and to unbound the salt production rate.
- Eliminate those seawater salts, with less solubility than NaCl (i.e. CaCO_3 and CaSO_4), since these crystallise in the first basin and remain there.

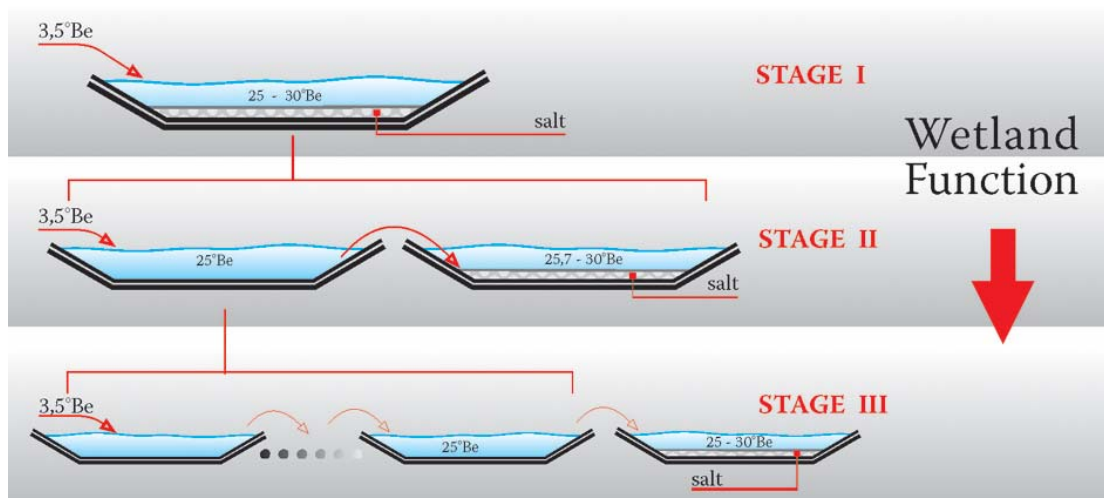


Figure 1. Solar Saltworks production process evolution

The **third and most decisive step** concerned the division of the nurse pan into several interconnected basins. With this design, seawater enters the first basin and, as it flows through the next basins and evaporates in the sun, its concentration increases. Thus, by the time it reaches the last basin, which has now become the nursing pan, it has a concentration of 25.7 °Be, corresponding to the saturated brine in terms of NaCl (Korovessis, Lekkas 2000).

This production method:

- Ensures greater control over the concentrations and quantities of the brines fed through the system, thus resulting in the unobstructed production of much better quality salt,

- Increases dramatically the quantity of the salt produced as the average brine concentration in the system of basins decreases drastically – it is known that there is an inverse proportion between evaporation levels and concentration of brines,
 - Presupposes a system of evaporation pans with increasing concentration (from 3.5 to 26 °Be), which cover around 90% of the total area of the Solar Saltworks and create a complete, living ecosystem, as will be explained further in this paper. This production method is still used nowadays for the recovery of salt from seawater, although there have been improvements and variations, allowing for the production of some hundred to some million tonnes of salt, depending on the size of the area in use.
- It is also very important to notice that in the multiple pond case (stage III) the salinity gradient changes with respect to area (from the first pond to crystallisers) whereas in the single pond case (stage I) it changes with respect to time.

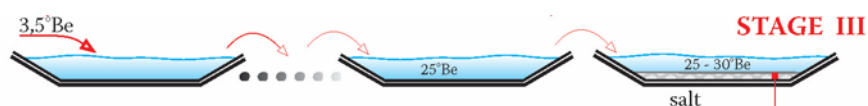
That means that whatever takes place in stage I through a certain period of time in terms of physicochemical and biological processes, in stage III it occurs at any moment of that period. In other words **every pond of stage III is a live phase (a picture) of stage I**, because every pond in modern Solar Saltworks has fixed salinity. It is worth to emphasize here that according to our analysis of the Solar Saltworks production process evolution **we start with a batch and transient process (stage I) and we end up with a continuous and steady state process (stage III)**. Obviously the multiple ponds system is more manageable, stable and integrated ecosystem than the single pond.

These three stages constitute the basic steps towards improving the quality of solar salt making technology. Unfortunately, there are no data or information available confirming the time when the aforementioned production methods were first used, although it is certain that it has not been a uniform process throughout the world. The fact that in Greece, all stages in the evolution of salt making technology are still alive even nowadays is impressive. The Saltworks on the island of Kythera, for instance, still produce salt in concave rocks by the sea.

MODERN SALTWORKS - WETLAND FUNCTION

Modern Saltworks are semi-artificial coastal ecosystems, unique in terms of their architecture. Moreover, they have a special feature, which is highly valued in our times: they **combine their production process with the conservation of the environment**. This is so because such process is not only environment-friendly, but also Saltworks themselves constitute integrated ecosystems.

They consist of a system of shallow basins (15-60 cm deep), connected mainly in series, and their natural bottom has the appropriate clay composition to ensure very low water permeability. Their **operation principle** is basically no different from the one described in the **third stage** of the previous chapter. The only differences that have occurred, since the method was first applied, concern its optimisation as well as the means by which brine is transferred and salt is collected, resulting from subsequent technological progress.



According to this method, the basins are divided into two basic groups. The first group, usually called **evaporating pans or pans**, is where seawater is concentrated up to saturation point in terms of NaCl (25.7 °Be). The second group, called **crystallisers**, consists of the basins where salt is crystallised and produced via further evaporation of

the brine up to 28-29 °Be. What basically elevates Solar Saltworks to ecosystems is the fact that for seawater to be concentrated up to the point of salt crystallisation, 90% of its water content has to evaporate, thus requiring a vast surface. For this reason, pans take up approximately 90% of the Saltworks production area. Their bottom is totally natural without any intervention and the concentration of contained brine covers the whole range from 3.8 °Be (almost seawater) to 25.7 °Be, corresponding to the last pan which feeds the crystallisers continuously with the required saturated brine (nurse). Crystallisers take up the remaining 10% of the production area. These basins are specially designed and have their bottom levelled and concentrated, aiming to facilitate and optimise the collection of salt with machinery.

The first pan of the Saltworks is fed with seawater (raw material) usually via pumping. As seawater flows from basin to basin, its concentration rises continuously through natural evaporation. The evaporation (concentration) of brine is achieved by exposure to solar radiation and with the help of the prevailing microclimate in the area, especially the winds, rainfall, air temperature and humidity and duration of sunshine. So a salinity (concentration) vector is created throughout the basins of the Saltworks with a simultaneous and continuous reduction of the volume of seawater, which initially entered the system of pans. This is the **physicochemical process** of salt production.

However, apart from the physicochemical process described above, a biological process develops in the evaporating and crystallising ponds, which is equally important to the production of salt. Surprisingly enough, despite rising salinity, life in the basins of the Saltworks does not stop. Seawater organisms gradually disappear as they move from the initial pan to the hostile environment of the others. However, other organisms develop in their place and, as there is no competition, they proliferate. Such large populations are able to survive in areas with different concentration levels (that is, in different pans) because of their varying sensitivity to the ion composition of the medium they inhabit (J. Davis 1974). Thus, in parallel with the physicochemical process, a chain of organisms is developed in the evaporating ponds (pans) system, constituting the **biological process** of the salt production process. Such a chain is similar to those of naturally saline or hyper saline coastal ecosystems.

The biological process of Solar Saltworks is sensitive and depends on the:

- Prevailing conditions in the basins (ponds), temperature, depth and brine turbidity
- The rational control of the natural (physicochemical) process during salt production and,
- The overall design of the Saltworks.

As can be seen in figure 2 (J. Davis, 1993), the small crustacean **Artemia Salina** (brine shrimp), is the key organism in this biological chain.

It constitutes the link between the organisms living in low concentration pans and those of high concentration pans. Organisms developing in Saltworks that operate efficiently constitute a biological system or ecosystem, which interacts with the physicochemical process and is vital to the production of salt.

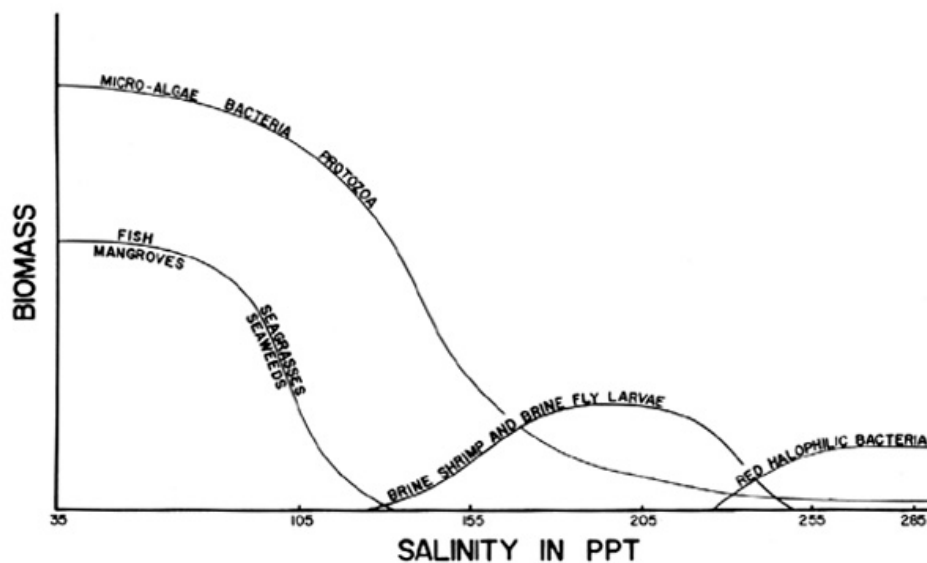


Figure 2. Rough estimate of principal organisms at each salinity range in Solar Saltworks (J. Davis 1993)

The biological system is in admirable harmony with the production process of the Saltworks, in three ways:

- It produces the appropriate quantity of organic matter, which is a source of energy for the various organisms, and reduces the permeability of the bottom of the pans, thus minimising brine losses, particularly at low concentrations,
- It colours red the brines in the crystallisers, thus maximising the evaporation rate of brines, by maximising the rate of solar energy absorption and eliminating solar radiation reflection from the white salt bed. The red colour of the brines in the crystallisers is due to the monocellular seaweed *Dunaliella Salina* (J. Davis 1993) and,
- Finally it creates and maintains the appropriate conditions in the evaporation basins and the crystallisers, for the continuous and maximal production of high quality salt, which is characterised by clear, compact and mainly thick granules, low in Ca^{2+} (0.03-0.05%), Mg^{2+} (0.02-0.04%), SO_4^{2-} (0.11-1.16%) and admixtures of soil (0.01-0.02%).

When the biological system of Solar Saltworks is upset – due to either negligent operation or generally deficient design, or to the pollutants carried in the ponds by the seawater - an excessive quantity of organic matter is produced (J. Davis 1980). Thus, the biological chain is altered and the Saltworks become downgraded with the reduction of the surface of the pans and increased stickiness of the brine resulting in the production of bad and sometimes potentially not marketable quality salt. Therefore, it is clear why the **optimal operation of modern Solar Saltworks is impossible without maintaining, at the same time, a healthy and stable ecosystem** (J. Davis 1993). This was very difficult to achieve in traditional Saltworks, the operation of which was fragmentary and the control of the brine flow negligent. We finally end up with the following surprising, for a production process, paradox, that **modern Solar Saltworks are better and more stable ecosystems than the traditional ones.**

However, the ecological importance of the Saltworks is mainly connected to its **ornithological interest**. Basic organisms of the biological system described above constitute excellent food for a large number of birds living in the Saltworks for this matter. Certain species of birds, especially the Avocet, the Black-necked Grebe, the Kentish Plover etc., depend directly on the productivity of the Saltworks, since their diet is

exclusively based on *Artemia salina*. *Artemia* is also part of the diet of the beautiful flamingos and it is the main reason for the orange colour of their feathers. More than 100 species of birds (average) have been observed in each of the Company's Solar Saltworks (188 in Kitros Saltworks, 1990). Many of them have been identified as endangered species, or are protected by Greek, European Union or international conventions. Finally, another important reason why Saltworks function as bird sanctuaries is because they are totally free of pesticides or other chemical compounds used in farming.

Considering the case of Kalloni Saltworks, located in the north Aegean Sea Island of Lesbos, which was recently redesigned and modernised, we can make the following remarks:

- There was a remarkable increase in bird species and population,
- Ornithologists reported a movement of many flamingos from lake 'Alikí' of Lemnos island to Kalloni Saltworks, (Lemnos is another Aegean Sea Island located north of Lesbos),
- Flamingos built nests in Kalloni Saltworks for the first time in Greece,
- Ecotourism is developed in the area, especially in April and May.

COASTAL WETLANDS

Wetlands are the most highly threatened ecosystems of our planet and in many regions of the world are deteriorating rapidly. People are relying on wetlands for their spiritual, cultural and economic well being. They control floods, protect coastal zones and they host a great diversity of species.

In this paper we compare the Solar Saltworks with natural coastal and more or less shallow lakes where the seawater undergoes higher evaporation rates than the open sea. We can distinguish two cases of those wetlands:

- a. Wetlands where the sea water enters and renew more or less freely and
- b. Wetlands where the seawater under some special hydro-geological conditions is trapped.

In the first case the concentration of the water is getting higher than the sea but never reaches concentration point (with respect to NaCl) except some areas at the borders of the lake whereas in the second case the water concentrates till salt is crystallised. These wetlands usually undergo a dry period where people usually can walk and collect the produced salt.

If we try to categorise the coastal wetlands according to the scheme we have presented for the Solar Saltworks production process evolution, it is obvious that they belong to the first stage (the single pond case):

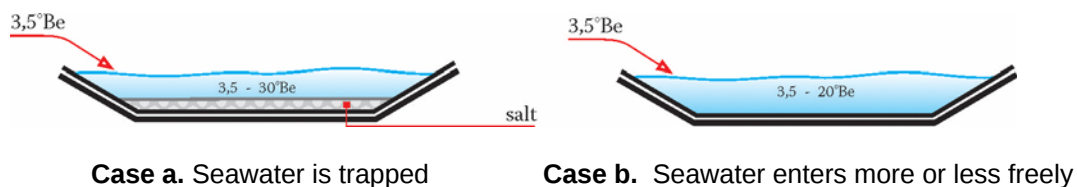
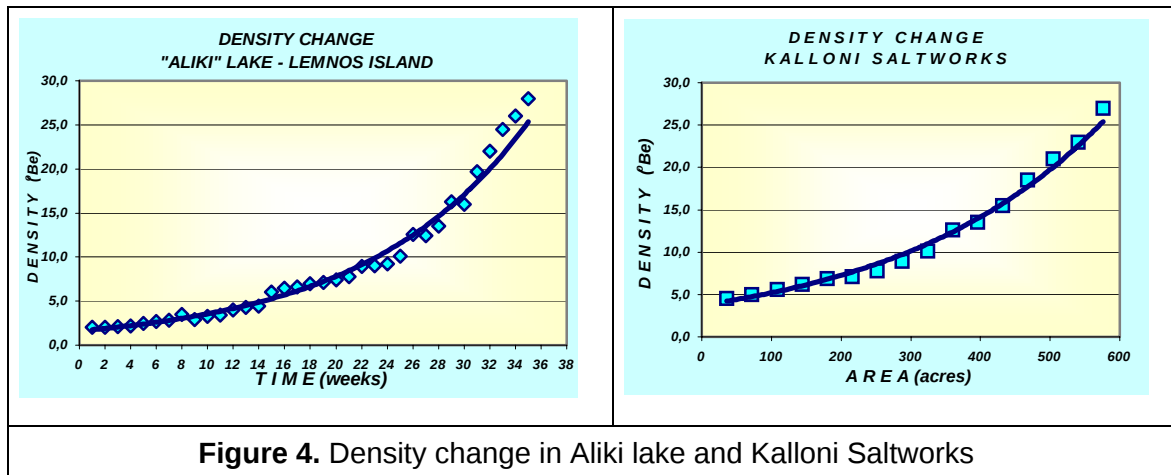


Figure 3. Coastal Wetlands operating scheme

In natural coastal wetlands, within a certain period of time, the water salinity is increasing due to higher evaporation rates than the open sea. In some cases salt is produced and the lake undergoes a dry period in which it doesn't function as wetland and all birds leave for other places.



SOLAR SALTWORKS vs. WETLANDS - THE LEMNOS PROJECT

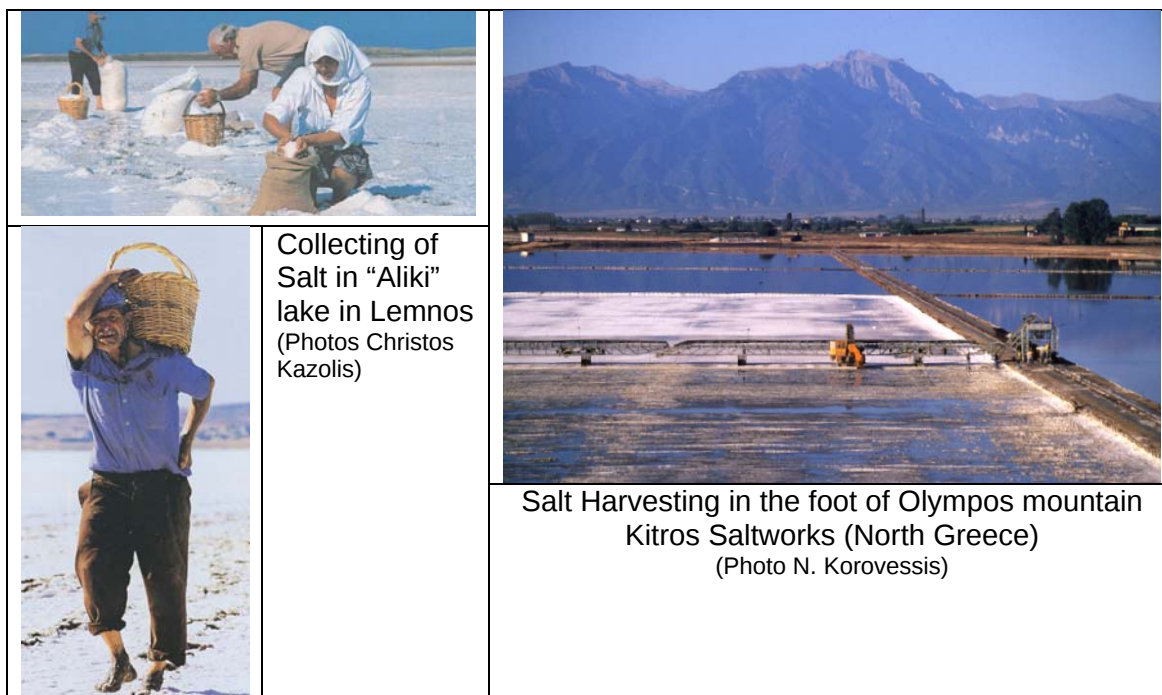
As it has been previously shown Solar Saltworks are more integrated and manageable ecosystems because in their case all phases of wetlands are alive and spreaded to their production area. Consequently the biological process that develops in Solar Saltworks is more rich and stable as it contains ponds (lakes) with wide range of salinity started from seawater and end to over saturated brines.

Solar Saltworks also operate all year without any dry period. Even in the case of seasonal Saltworks evaporating ponds never dry out. During the seized period care is being taken from Saltworks people to feed every pond with the proper amount of brine in order to retain the ecosystem in function. The difference with the operating period however relies in the facts that there is no brine circulation and that the brine salinity never reaches saturation. This is the reason why Solar Saltworks are all the time full of all kind of birds. Important differences in favour of Solar Saltworks derived from fact that they are more than one interconnecting ponds are also the following:

- Birds can find more area in the dikes for nesting
- Small birds find more area with shallow waters, comparing with the case of one big lake, where they can feed.
- Salt is produced in the 10% of the total production area whereas in natural saline wetlands it covers the whole area.

It is also worth mentioning that Solar Saltworks are free of any chemical substances (fertilisers, etc), which are conveying into the natural wetlands with the inflow rainwater.

The lake "Aliki" of Lemnos is a natural coastal lake that belongs to the **(a)** case of saline wetlands as it outlined above. It covers an area of 6,300,000 m². Because of the special hydro geological conditions prevalent in the area, the lake is flooded with seawater in combination with autumn and winter rainfalls. With the influence of the local microclimate, which is highly conducive to evaporation, the trapped quantity of seawater constantly condenses until salt is finally produced without any human intervention. The crystallisation of salt usually starts in June and finishes in July. In early August the lake usually "dries up" of brine and the whole phenomenon repeats itself the following winter. In fact, throughout this natural process, a chain of organisms similar to the one described above develops, constituting the biological system of the lake.



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