# A COMPARATIVE ANALYSIS OF THE ECOLOGICAL SYSTEMS OF TWO GREEK SEASONAL SOLAR SALTWORKS (MESOLONGHI AND KALLONI): IMPLICATIONS FOR SALT PRODUCTION

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## EXTENDED ABSTRACT

The spatial variability of the ecological system of two seasonal solar saltworks is studied in the present work. Data were collected from to two seasonal saltworks in Greece: the saltworks of Mesolonghi having an area of 11.22 $Km^2$ and an annual production of 120000 tons of sodium chloride and the saltworks of Kalloni, island of Lesvos, covering an area of 2.5 $Km^2$, with an annual production of 30000 to 40000 tons of sodium chloride. Physical (temperature and density) parameters and macroscopic observations were carried out during summer, at the seawater intake of the saltworks, concentrating ponds of low, intermediate and high density and crystallizers.

Both saltworks exhibit substantial spatial variability among the ponds, reflecting the different phases that the ecological system passes from the seawater intake, to the concentrating ponds and the crystallizers. The density gradient was maintained constant during the summer period, ranging from 4 Baume in the seawater intake to around 30 Baume in the crystallizers. A trend of increasing values was also recorded for temperature from the ponds of low density (around 26$^oC$) to the crystallizers (28-30$^oC$). However, high water temperatures were achieved at the concentrating ponds of the second saltworks of Mesolonghi, probably explaining the small number of *Artemia* presented. This phenomenon along with the high salinity differences between the concentrating ponds lead to a disturbance of the biological cycle that supports the production of high quality salt.

The seasonal solar saltworks salt production can be helped or harmed by the functioning of the brine biological system. The present work is a comparison between two saltworks biological systems, aiming at the understanding of the ecological processes in the brine ecosystem, in order to support management practices for high quality salt production.

**Keywords:** seasonal solar saltworks, brine ecosystem functioning, *Artemia.*

## 1. INTRODUCTION

Salt is produced either by solar evaporation of sea water or inland brines or by mining of rock salt deposits. Saltworks are very special places for a variety of reasons: because of the salt they produce, and their historical, cultural and ecological values, as well as for their landscape: special, even extreme, at the edge of earth, sea and air. Saltworks usually present important wetlands exceptionally rich in biodiversity. They are important storehouses of plants and animals (Dahm, 2004; Petanidou, 2004). Seasonal saltworks

fallow during winters and produce salt only during the summer. Mediterranean solar saltworks are of that type due to the existing climatic conditions (Davis and Giordano, 1996).

One third of the worldwide sodium chloride production is manufactured in solar saltworks (Davis, 2000). Solar salt manufacturing is a natural process that relies on the process of evaporation to concentrate the salts naturally occurring in seawater to such a point that the salt can be recovered. Seawater circulates through successive compartments, from ponds to crystallizers, to an increasing concentration of sodium chloride, releasing along its course the undesirable elements from the brine like gypsum (Petanidou, 2004). A biological system is developed in the ponds of every solar saltworks. The efficient and high quality produced salt is closely depended on the species maintained and reproduced in the saltworks (Davis and Giordano, 1996).

The present study was carried out in two seasonal coastal solar saltworks of Kalloni and Mesolonghi in Greece. Mesolongi saltworks is divided in two systems. The physical and biological parameters were studied and the functioning of the two ecological systems was compared.

## 2.METHODOLOGY

Information was collected during the salt manufacturing period of August 2003 and 2002 from the solar saltworks of Mesolonghi and Kalloni (island of Lesvos), respectively. The saltworks of Mesolonghi has an area of 11.22 $Km^2$ and a potential salt yield production of 120 thousand tons per year. Seawater is provided to the saltworks from the shallow semi-enclosed lagoon of Mesolonghi. It consists of two saltworks with common concentrating ponds of low density. The saltworks of Kalloni (Figure 1) covers an area of 2.5 $Km^2$ and the annual production of sodium chloride is 30 to 40 thousand tons. The saltworks is supplied with seawater from the gulf of Kalloni, a semi-enclosed water body connected to the Aegean Sea through a narrow and rather shallow channel.

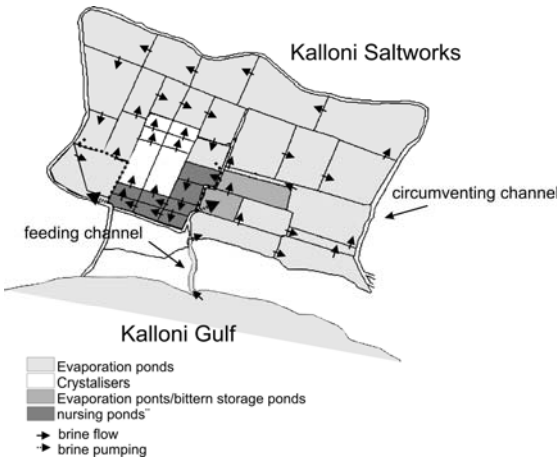


**Figure 1:** View of the Kalloni saltworks, island of Lesvos: water circulation.

Samples were taken from the common low density concentrating ponds of the two Mesolonghi saltworks (CP7, CP13A and CP10B). Samples from two concentrating ponds of medium and high density (CP9, CP11C), from three crystallizers (CR1, CR2 and CR4) and from the channel (CA) supplying brine to the crystallizers were collected from the first saltworks. In addition, samples were collected from the second saltworks of Mesolonghi from two medium density concentrating ponds and one high density concentrating pond (CP12C, CP14A and CP15A), from four crystallizers (CR1, CR2, CR3 and CR4) and the four brine supplying channels to the crystallizers (C1, C234, C23A and C23T). Moreover, samples were collected from four concentrating ponds (CP6, CP14, CP22 and CP26) of increasing density, two crystallizers (CR1 and CR5) and from the channel supplying

seawater to the ponds of the Kalloni saltworks. The physical parameters measured were temperature in Celcius ($^{o}$C) and density in Baume (Be) degrees. Finally, the biological parameters were obtained by suitable dilution and usage of inverse microscope type LEITZ 200x zoom.

## 3.RESULTS AND DISCUSSION

The temperature profile of the two saltworks of Mesolonghi is shown in Figures 2 and 3. Figure 2 shows that in the first saltworks, there is a temperature drop at the two medium and high density concentration ponds possibly due to evaporation losses. Generally the temperature has an average value of 29$^{0}$C. Figure 3, presents the temperature variation of the second saltworks. It can be observed that an unstable temperature profile exists. High temperature values of 35$^{0}$C are reached in the concentrating pond CP15A and minimum in channel C1.

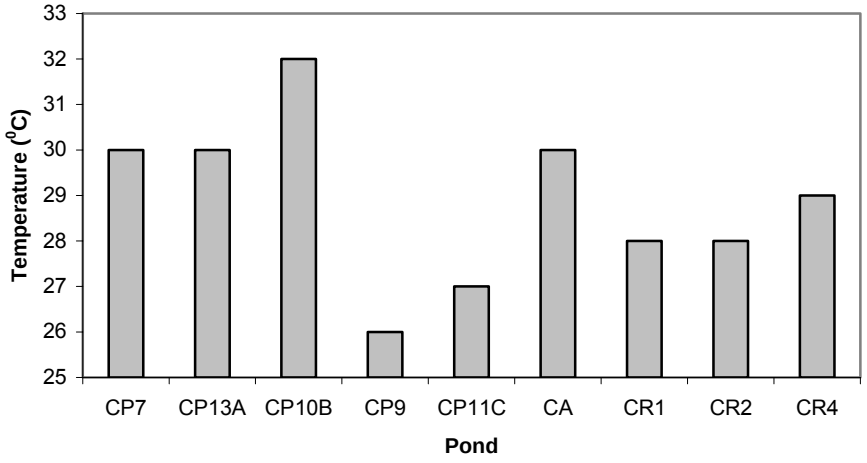


**Figure 2:** Temperature distribution during August 2003 in the four concentrating ponds (CP7, CP13A, CP10B, CP9, CP11C), the brine channel to the crystallizers (CA) and the crystallizers (CR1, CR2 and CR4) of the first solar saltworks of Mesolonghi.

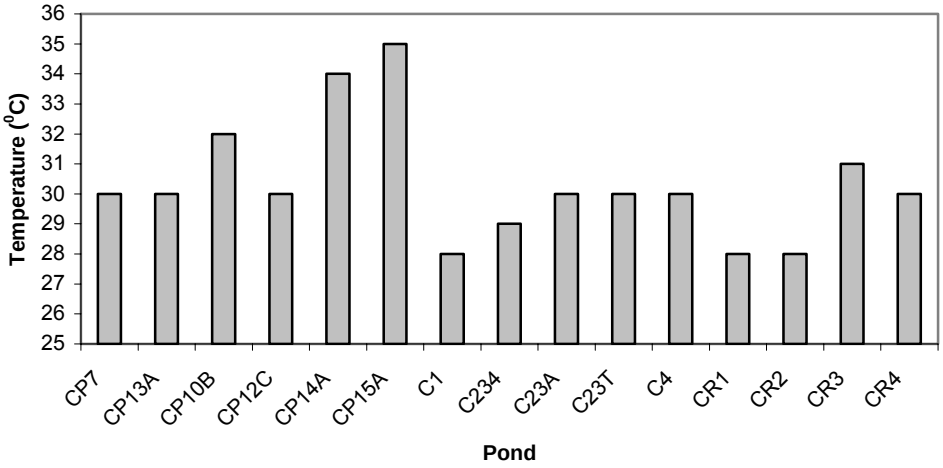


**Figure 3:** Temperature distribution during August 2003 in the six concentrating ponds (CP7, CP13A, CP10B, CP12C, CP14A, CP15A), the brine channels to the crystallizers (C1, C234, C23A, C23T, C4) and the crystallizers (CR1, CR2, CR3 and CR4) of the second solar saltworks of Mesolonghi.

The distribution of temperature in the seawater intake, the concentrating ponds and the crystallizers of Kalloni saltworks is shown in Figure 4. A small decrease of temperature is observed between the seawater channel and the first sampled concentrating pond (CP6), probably related to the loss of energy for evaporation. A trend of temperature increase is observed along the density gradient in the concentrating ponds and the crystallizers. The maximum temperature was observed in the crystallizers where the minimum in the three concentrating ponds of medium density.

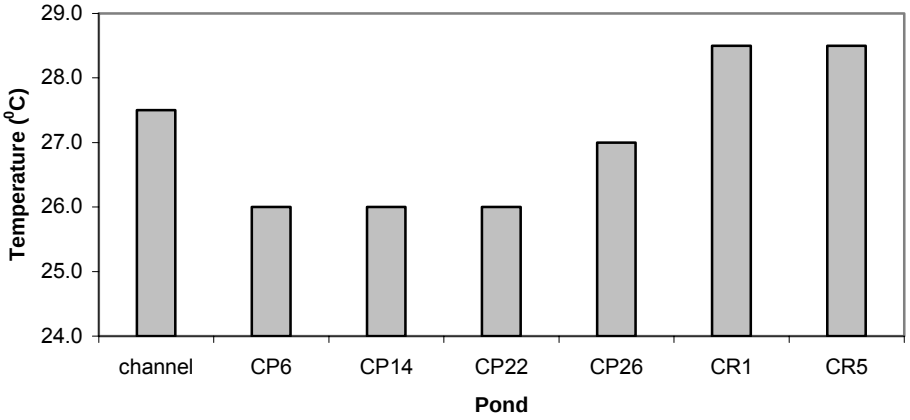


**Figure 4:** Temperature distribution during August 2002 in the seawater channel, the four concentrating ponds (CP6, CP14, CP22, CP26) and the crystallizers (CR1 and CR2) of the solar saltworks of Kalloni.

The density profile of the two solar saltworks of Mesolonghi during August 2003 is shown in Figures 5 and 6. It can be noted a sharp increase of salt density from low density to high density concentrating ponds. However, the density distribution during August 2002 in the selected ponds of the solar saltworks of Kalloni presented in Figure 7 show a different pattern. A gradual increase of density is observed from around 4 Baume (seawater in the supplying channel), 5 to 25 in the concentrating ponds to 27-28 Baume in the crystallizers. Temporal differences were not observed since each pond is maintained in constant density throughout the manufacturing period (April to September).

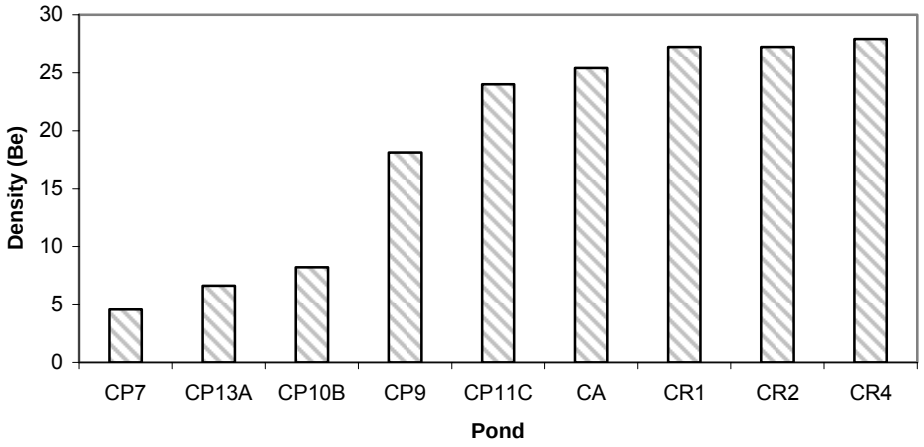


**Figure 5:** Density distribution during August 2003 in the four concentrating ponds (CP7, CP13A, CP10B, CP9, CP11C), the brine channel to the crystallizers (CA) and the crystallizers (CR1, CR2 and CR4) of the first solar saltworks of Mesolonghi.

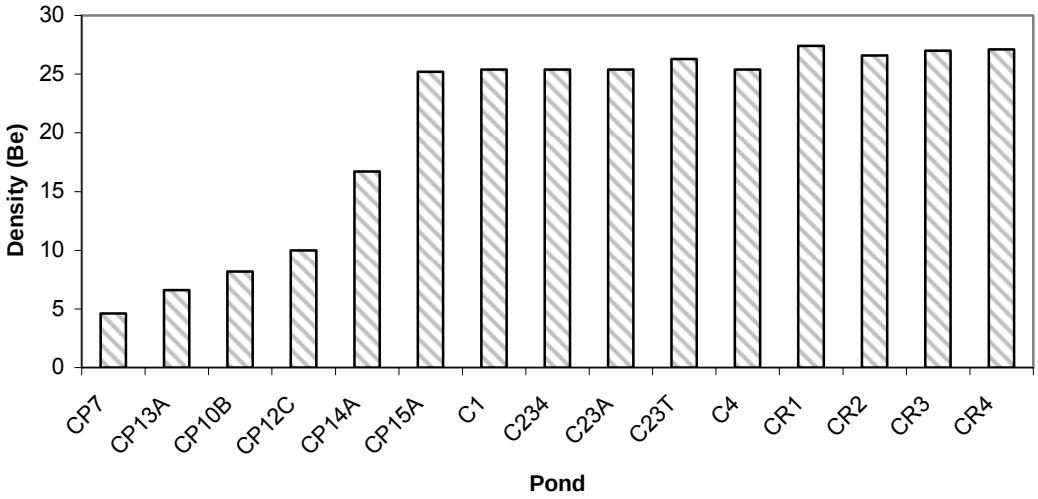


**Figure 6:** Density distribution during August 2003 in the six concentrating ponds (CP7, CP13A, CP10B, CP12C, CP14A, CP15A), the brine channels to the crystallizers (C1, C234, C23A, C23T, C4) and the crystallizers (CR1, CR2, CR3 and CR4) of the second solar saltworks of Mesolonghi.

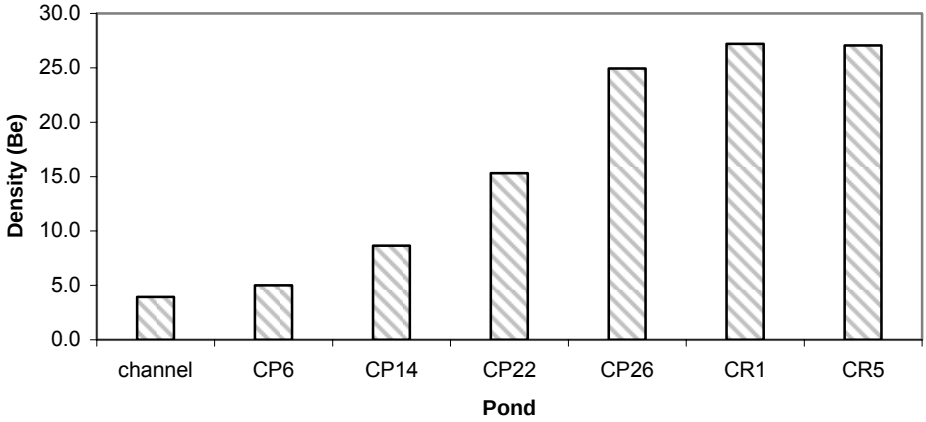


**Figure 7:** Density distribution during August 2002 in the seawater channel, the four concentrating ponds (CP6, CP14, CP22 and CP26) and the crystallizers (CR1 and CR2) of the solar saltworks of Kalloni.

Summary statistics of the macroscopic observation in the water column and sediment at the solar saltworks of Mesolonghi and Kalloni during production period are presented in Tables 1 and 2 correspondingly. The ecological system of the saltworks exhibits a spatial variability along the density gradient, from the intake of seawater until the precipitation of sodium chloride in the crystallizers. It was found that in both Mesolonghi saltworks *Artemia* species were not in a good condition, affecting the salt quality. Especially in the second saltworks, absence of *Artemia* was observed. The death of *Artemia* species could have been caused by high water temperatures above $35^0$C (Sorgeloos, 1988). This probably results to the disruption of the biological cycle that helps to the production of high quality salt and hexagonal crystals were formed in the ponds instead. On the contrary, Kalloni saltworks had a sufficient number of *Artemia* and cubic crystals of sodium chloride formation in the ponds.

**Table 1**: Macroscopic observations in the water column of the solar saltworks of Mesolonghi and Kalloni.

| Water column | Macroscopic observation | | |
|---|---|---|---|
| | Mesolonghi saltworks 1 | Mesollonghi saltworks 2 | Kalloni saltworks |
| Gulf/ Lagoon | Diatoms, flagellates and coccolithofors | | Diatoms, flagellates and copepods |
| Low density pond | Microflagellates and bacteria | Microflagellates and bacteria | Diatoms (*Pleurosigma, Gymnodinium, Navicula* and *Nitzschia*), bacteria and dinoflagellates |
| Medium density ponds | Cyanobacteria, microflagellates *Dunaliella salina* and *D. viridis,* zooplankton debris, well formed gypsum layer and *Artemia* | Cyanobacteria, microflagellates *Dunaliella salina* and *D. viridis,* zooplankton debris | Halobacteria (*Halobacterium salinarium*), microalgae *Dunaliella viridis, Artemia,* |
| High density ponds | Great bacteria population, microflagellates, *Dunaliella salina, D. viridis.* Gypsum crystals, great number of dead *Artemia* species | Great numbers of bacteria and microflagellates populations, presence of *D. viridis,* absence of *Artemia* | Bacteria, Halobacteria and *D. salina, Artemia* |
| Crystallisers | Organic particles, bacteria (RHB) | Organic particles, bacteria (RHB) | Halobacteria and *D. Salina* |

Saltworks operations require having viable *Artemia* populations in order to control the algae blooms which results to the improvement of the quality of the salt produced. The most important physical parameters that affect these hypersaline organisms are temperature and salinity. It has been found that changes in temperature can have major effects on survival and life-history traits in the sexual and parthenogenetic diploid *Artemia* populations. Temperature is clearly an important factor controlling reproductive rates and population success, and therefore might affect the seasonal succession of Artemia populations. Also, tests have shown a significant decrease in maturation with the elevation of salinity because a part of the available energy of the individuals was consumed for homoeostasis and not for reproduction. Studies of *Artemia salina* from Larnaca (Cyprus) under the combined effects of salinity and temperature exhibited a maximum reproduction at $24^0$C and 180 g $l^{-1}$ (Barata et al., 1995; Baxevanis et al., 2004).

The ecologic phytoplanktonic variation of the Mesolonghi saltworks seems to be maintained at least until the first concentrating pond of low density. However, a trend of high phytoplanktonic biomass in the concentrating ponds of intermediate density was observed in Kalloni saltworks.

**Table 2**: Macroscopic observations in the sediment of the solar saltworks of Mesolonghi and Kalloni.

| Sediment | Macroscopic observation | | |
|---|---|---|---|
| | Mesolonghi saltworks 1 | Mesollonghi saltworks 2 | Kalloni saltworks |
| Gulf/ Lagoon | Diatoms (*Cocconeis, Pleurosigma*), bacteria and dead organic matter (decomposing cells, zooplankton debris) | | Diatoms, dinoflagellates |
| Low density pond | Organic matter, small number of diatoms (*Cocconeis*), microflagellates and bacteria | Organic matter, many cells of *Cocconeis, Pleurosigma,* zooplankton debris | Diatoms (*Pleurosigma*, *Navicula* and *Oscillatoria*), bacteria |
| Medium density pond | Cyanobacteria, *Dunaliella salina, D. viridis,* coccolithofors, zooplankton debris | Great number of cyanobacteria, and microflagellates, zooplankton debris | Larvae of *Chiromids,* cyanobacteria (*Phormidium)*, Thiobacteria (*Chromatium*) |
| High density pond | Organic particles, cyanobacteria, *Dunaliella salina, D. viridis, Oscillatoria,* microflagellates | Organic particles, decomposing cells | RHB |
| Crystallisers | Absence of cubic crystal NaCl, hexagonal crystals | Absence of cubic crystal NaCl, hexagonal crystals | RHB |

The results presented above, show considerable spatial variability for most of the measured parameters reflecting the differences of the brine ecosystem of the pond of each saltworks. Comparing the two ecological systems of Mesolongi and Kalloni, it can be concluded that high temperature above $30^0$C and high increase of salinity in the ponds of the second saltworks of Mesolonghi probably raised the mortality of Artemia species and as a consequence resulted to the formation of salt of low quality. The production of high quality sodium chloride from a seasonal solar saltworks depends mainly on the functioning of the brine biological system. This can be controlled by applying the correct management practices, assuming that physical and biological information is continuously gathered and appropriately displayed on the ecological status of the brine system.

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