6.0 General Discussion

In Chidambaranar district, generally the water management practices for salt production in the salterns included maintaining shallow depths that led to high water temperatures and pond irrigation procedures that resulted in abrupt salinity changes. Such practices limited the size of *Artemia* population as well as prevented its spread into the numerous ponds of the salterns. Barring the few condenser ponds of the five salt works studied, the water depths of the salt ponds of Chidambaranar district were maintained below the recommended levels of 40 – 50 cm. In those salt ponds with high water depths and high salinity, the *Artemia* population has been reported whereas in the shallow water depths (below 40 cm) the *Artemia* population were kept from increasing (see also Sorgeloos *et al*., 1986). In some salt ponds the low water depth resulted in high bottom illumination and high phytobenthos production. These phytobenthos upon breaking up floated to the surface, hindering the phytoplankton productivity (Sorgeloos *et al*., 1986; Kurruppu and Ekaratne, 1995).

The Microalgal species observed in the salterns of Chidambaranar district was not uncommon. More or less similar groups of microalgae were reported in several salterns with ***Artemia*** population (e.g. Alviso salt ponds: Carpeland, 1957; Yauaros salterns: Ortega-salas and Martinez, 1987; Mahalewaya saltern: Kuruppu and Ekartne, 1995).

The microalgal production was supported by the nutrient rich water intake into the salt works. Water intake from the thickly growing ***Ulva, Enteromorpha*** and animal life on the intertidal rocks of the area near the salt works of Burgos, Bulgaria provided evidence for the nutrient – rich water intake. The other sources of nutrients for the salt works include land runoff, sewage and nitrogen fixation within the ponds (Pavlova *et al.*, 1998). Though the microalgal production is essential to the *Artemia* population they must be metabolized in time, if not, the algal excretion as well as the dissolved carbohydrates upon decomposition act as chemical trap and prevent the early precipitation of gypsum. The organic impurities such as the algal agglomeration, which turns black upon oxidation, will also contaminate the salt and induce the formation of small crystals. This ultimately affects the salt quantity. In this situation, the brine shrimp ***Artemia*** in sufficient numbers plays a vital role. The *Artemia* population helps to control the earlier algal bloom due to their continuous filter feeding habit. The decaying ***Artemia*** provide micronutrients for the development of halobacterium in the crystallisationpond. (See also Jones *et al.*, 1981).

The low concentrations of soluble nitrogen and phosphorus indicated immobilization by the developing planktonic and benthic communities. Davis (1993) has reported that similar accumulations in other salt works are largely of organic matter, and are the results of high concentrations of nutrients flowing into the ponds, inadequate numbers of ***Artemia*** and wide variations in salinity within and between ponds. Although the quantity of black deposits is related to the age of a salt works, Davis and Giordano (1996) have suggested that accretion rates of bottom communities may be controlled by using appropriate biological management techniques. Active brine shrimp populations ingest and oxidize much of the plankton and organic particulate in brine, release waste products in faecal pellets, decrease the organic content of the water and clear the brine (Davis, 1993). Davis and Giordano, 1996. Stressed the importance of large ***Artemia*** population for salt production.

In Yavaros salinas about 15 kg of ***Artemia*** cyst and 486 metric tons salt were harvested from one ha area. The natural production of Artemia has not been exploited properly and with an adequate use, the exploitation could be significantly increased (Ortega-Salas and Martinez, 1987).

One of the reasons for the poor quality of salt as well as the low quantity of salt production in salt pans was due to the micro and macro algae. The microbial mats embedded in the sedimentary surface acts as a kind of soft tissue which effectively alters the properties of surface structures (Reineck *et al.*, 1990). The lateral and vertical growth of the microbial mats resulted in the accumulation of organic matter (Gerdes *et al.*, 1991. Cornee *et al.*, 1992). The accumulation of the organic matters results in decay upon their burial. In the salterns, the microbial mats and biofilms develop and increase sediment surface stability by their fibrillar properties and extra cellular polymeric substances. (Gerdes *et al.*, 1993a). The inter play between microbial stabilization of the sediment surface and gas formation in the sediment, as a result of the bacterial decay of organic matter reveals a variety of different biosedimentary surface structures (Gerdes *et al.*, 1993b). Working on the role of microbial mats and biological activity in the

Port Fouad salina, Egypt, Taher *et al.*, (1995) emphasized the importance of biological activity. Biological activity within the brines of salinas can have an effect upon the yield and quality of the harvestable salt (Davis 1978 a,b). The algal species *Dunaliella* and *Halobacteria* in large quantities in the crystalliser of Port Fouad salina caused red colouration of the brine and helped to increase the water temperature by absorbing the radiant energy. This biota also controlled the surface tension of the water, and this in turn affected the evaporation rate. This biological assemblage ultimately helped to produce salt in economic basis (Taher et al., 1995). The behaviour of the iron in the biological system underneath the aerobic zone of cyanobacteria is responsible for the color of the final salt and its purity. As salt workers in the salina stir up the brine in the crystallisers, the underlying reduced black mud is exposed and caused a reducing environment in the brine. Thus the iron dissolved in the brine is held as Fe++ and prevents the red or brown colouration of the salt. The presence of halobacteria and square bacteria in the brine reduces the formation of surface salt crusts which otherwise would have to be destroyed by salt workers.

The constant winds did not only high evaporation rate (>6 mm/day) and increase of salinity from 35 ppt to

253 ppt and also provide good oxygenation of the water in the salt pan. These environmental conditions supported high growth rate of the ***Artemia***. The ***Artemia*** cyst and biomass were observed in maximum in the evaporation ponds with salinities ranging from 50-100ppt. (Camara, 1996).

The production of ***Artemia*** in North East Brazil is carried out as a byproduct of solar salt industry. The salt industry has traditionally been a very important economical activity in this region as in Tuticorin. In this region around 40,000 ha yielded annual harvest of over 4,000,000 tons of salt by evaporation of the sea water. Chidambaranar district experienced a high rate of salt production compared to the northeastern Brazil. In Northeastern Brazil *Artemia* was found in both mechanized and artisanal salinas. These salinas were located close to mangrove areas of estuaries. The pond soil consists of fine silts and sand of marine algal with the deposit of organic mud. The pond bottoms were covered with cyanophyceae. Camara (1996) found that the mechanized salina produced 150,000 tons of salt in 500 ha area and the artisanal salinas (less than 50 ha), with numerous shallow (less than 50 cm depth) ponds fairly operated and produced small crystal salts of low purity. In North Eastern Brazil the environmental conditions prevailing in both the mechanized and the artisanal salinas meet the requirements for permanent ***Artemia*** presence. The high primary productivity was due to their closeness to nutrient rich mangrove as estuarine areas and the bloom of algae *Dunaliella* where *Artemia* was primarily feeding on, average sea water temperature ranging from 25°C to 35°C for most part of the year, and the conducive pH range of 7-0-8.2 . The constant southeastern winds aided not only the high evaporation rate (more than 6 mm per day) and the salt quantity but at the same time provided opportunities for the exploration of the valuable by-products of *Artemia.*, i.e. cysts and biomass. The drastic decrease of cyst production after an initial high rate of oviparous reproduction has been observed in several tropical biotopes, that have been inoculated with ***Artemia franciscana*** (Tackaert and sorgeloos, 1991).

The methods of *Artemia* production in the salt works can be implemented in a variety of ways. The extensive culture technique is basically the tapping of natural production in large operations with big ponds. These large ponds are indeed not very easily managed with regard to fertilization, pond modification, pond preparation and controlling of environmental parameters. Only very management practices, such as strain selection, controlled inoculation and screening of intake against predators can be implemented in extensive culture systems. Such practices in one or other ways have been attempted in the salt works of TATA chemicals Ltd., Gujarat and they could produce about two tons of cyst in the salt ponds covering about 4,000 ha area by inoculations of the ***Artemia** franciscana* strain. The low production in the region was due to the predatory fish and poor nutrient supply (Marian, 2000). In some salt works featuring medium to large size ponds (up to 20 ha) the improved management technique can be implemented. Bosteels (1994) suggested that in these operations, with well constructed keeper ponds with improved management could significantly increase the production from 1 to 2 kg cysts /ha/month, where the management practices such as strain selection, controlled inoculation predator control by screening of intake water and local eradication of predators, fertilization to increase primary production and cyst collection spot construction can be adopted. TATA chemicals Ltd operate two salt works around Muthappur having a total area of 14,500 ha, and this is the biggest saltpan in India producing 2 million tones of salt per annum. In 1989-90, about 1 ton cyst of *A parthenogatica* was harvested in these salt works and subsequently no cysts were harvested till 1992. In 1993, a pilot project was initiated to develop ***Artemia*** culture in 10 ha salt water area at Aramda using *A franciscana* strain. Similarly *A franciscana* was inoculated in Charakla salt water also and where an unexpected interruption of pumping in the evaporation area resulted in poor production of ***Artemia*** cysts. In Aramda, by adopting semi-intensive batch culture method 30 *kg A franciscana* cysts were produced in about three months. But the quality of the cysts was so poor that the hatching percentage was <20% and this was mainly attributed to the improper processing of the cysts. The fatty acid (HUFA) content of the cyst was about 6.2 mg/g. (Marian, 2000). In these salt works the production can be improved if the primary production is optimized by better fertilizer management, proper keeping up of ponds or digging of a peripheral ditch, construction of wave barriers, cyst collection spots construction of screened gates at the pond intake and control over environmental parameters to enhance cyst production as adopted in the Delphin salt works, Tuticorin (0.1 ha area) and Rajakkamangalam area (0.02 ha) by the private sectors who could produce 4.2 and 4.6 kg/ha/month of cysts respectively. This production was due to the management of ponds with organic and inorganic fertilization and rice bran supplementation at the rate of 40 kg/ha/month at the frequency of once in 10 days. These cyst production was activated by increasing the salinity (>130 ppt) with simultaneous reduction in the oxygen content (<2.5 mg/l) (Marian, 2000).

In ***Artemia*** ovoviviparity mode of reproduction has been observed in salterns which has minimum salinity fluctuation during the commercial salt production and the climatic conditions are relatively stable (Wear *et al.*, 1986, Wear and Haslett, 1987). The ovoviviparous reproduction has been observed in salt works with year round favourable conditions. (Wear *et al.*, 1986; Lenz, 1987; Lenz and Dana, 1987; Wear and Haslett, 1987). Camara and Rocha (1987) have suggested a drop in primary productivity (and thus in food availability for ***Artemia*** population) as a possible reason for the decline in cyst production in North Eastern Brazil. Although, it is likely that the availability of proper nutritional materials has played an important role in the physiology of cyst producing populations in and around Macau ovoviviparous populations have always thrived under existing food conditions and tons of brine shrimp biomass have been continuously harvested in low salinity pond. (Camara and Tackaert 1991). Camara (1990) has collected ecological data from artificial salinas as well as from highly mechanized salt operations in North East Brazil in order to provide the better characterization and understanding of these hypersaline environment. Even though *Artemia* was present at all sites, cyst production was negligible to a low level in most of the habitats studied. Further more *Artemia* was found to survive, mature and reproduce at temperature as high as 39^0C. Camara (1996) suggested that phenotypical and genotypical adaptation of the inoculated *Artemia franciscana* strain to the stable environmental conditions prevailing in the salt works of North Eastern Brazil have resulted in a sedimental ability for cyst production of the local population. Besides, low level of cyst production has also led to the measured harvesting pressure (order harvesting) probably leading to the removal of genotypes predisposed towards oviparity and eventually contributing to a further decline of cyst production in North – Eastern Brazil. The main objective of aquaculture is to farm aquatic organisms for food and income and to keep such farming options open for future generations (Cataudella and Crosetti, 1993). In this context, the importance of ecological and characterization studies with respect to *Artemia* cannot but be emphasized. Indeed the scarcity of data in this research area has long been considered a major struggle for further progress in the practical use of *Artemia* for aquaculture (Amat, 1985).

Coleman and White (1992) worked in the salina of Queensland, found that variations in the biota due to physico chemical disturbances affect the quality and quantity of salt production. Disturbances of cyanobacterial mats and aerobic brine increased the levels of manganese, which resulted in the formation of opaque crystals with localized occlusions and high manganese concentration. In the Queensland salina, the fragmentation of algal mats due to the mucilage production and photosynthesis by dominating cyanobacteria *Synechococcus sp.* exposed the phosphate and manganese rich soil to the brine, and disturb the biological system causing salt deposits to be fragile. To improve the coastal salinas in terms of productivity, salt quality, medical and health aspects, an integrated mineralogical, geochemical, geomicrobiological and biotechnological approach are required. Hence a number of inter disciplinary studies still need to be carried out fully to understand the complex interaction between evaporitic regime, subsurface processes, and low biological processes (i.e the role of ***Artemia***, microalgae, halobacteria etc) that affect and can improve the salt and ***Artemia*** production in terms of quality and quantity. Hydro-biological management in salt culture can improve the quality and quantity of sodium chloride produced by the salt works.

The recruitment of ***Artemia*** in salt works has been done via its cysts dispersed through wind and water birds which assures the presence and development of sufficient numbers of brine shrimp to guarantee optimal salt operation outputs. In specific situations, however, the salt producer should not rely on this opportunistic dispersion of ***Artemia***, e.g. salt works with short water retention times in their evaporation ponds (quick dilution rate of the ***Artemia*** population); or after a hurricane or season of exceptionally heavy rainfall when the local population has been eliminated or greatly reduced in numbers unable to efficiently cope with the algal blooms; or in the case of a salt work that is isolated from natural ***Artemia*** dispersion. Instead the salt producer should optimize the hydrobiological activity in the evaporation ponds through controlled introduction of brine shrimp. The efficiency of the salt production also depends on the species/strains of ***Artemia*** population. Situations have also been observed, where the local ***Artemia*** population does not ensure an optimal hydrobiological activity for the salt production (e.g. insufficient algal removal) and where the introduction of a foreign strain (better adapted to the prevailing conditions or with better production characteristics) will assure maximum outputs of high quality sodium chloride, e.g. sites where the original natural environment was modified (different physico-chemical conditions) for man-managed solar salt production. It is not possible to formulate a general strategy with regard to ***Artemia*** introductions in solar – salt operations; each situation needs to be analyzed for its specific requirements with regard to selection of the most suitable strain, quality and quantity of ***Artemia*** to be introduced as function of water retention times in evaporation reservoirs, food concentrations, water temperatures etc. (Sorgeloos *et al*., 1986). Proper ***Artemia*** management should lead not only to optimal salt production outputs (quality and quantity), but at the same time provide opportunities for the exploration of the valuable by-product ***Artemia***., i.e. cysts and biomass.