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Biological Management of Indian Solar Saltworks

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ABSTRACT

Salt is manufactured in India from seawater at various places on the east and west coasts, and from inland sources of brine. Seventy-five percent of the Indian production of salt is obtained by solar evaporation of seawater. In India, the seawater is rich in nutrients and is biologically highly productive because of the disposal of sewage and other inorganic wastes into the ocean. Use of this nutrient-rich seawater in saltworks favours algal blooms in reservoirs and evaporators. Altogether 31 species of algae were identified from Indian saltworks. A decrease in species diversity of algae is observed as the salinity increases when the seawater flows through the evaporators. Hypersaline algal species like *Coccochloris elabens*, *Dunaliella salina* etc., form blooms in evaporators colouring the water light green and orange and making it oily and viscous. The density of this brine does not exceed 28°Bé. The filamentous blue-green algae like *Lyngbya majuscula*, *Oscillatoria salina*, *Spirulina platensis* etc., form algal mats and scums on the surface preventing light penetration. The presence of these algal blooms and mats have become nuisances in Indian solar saltworks by hampering the salt crystallization process and production of quality salts. These biological communities are accumulating large amounts of organic matter that retard the rate of evaporation and adversely affect salt crystallization.

INTRODUCTION

An outstanding phenomenon of most of the coastal areas of India is the large number of solar saltworks bordering the coastline. The tropical climate and the availability of seawater have led to the growth of the salt industry which provides direct and indirect employment for thousands of people. In India, salt is produced from seawater as well as from inland brines at various places located in the states of Rajasthan, Gujarat, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal.

A solar saltworks is a series of interconnected ponds (evaporators and crystallizers) in which seawater is evaporated to produce sodium chloride. The solar saltworks in India consist of privately owned small artisanal salt fields and large industrial installations. In a typical saltworks seawater is allowed to enter the primary pond of the evaporators, evaporate and flow to the next pond of the series until the water (by solar evaporation) becomes saturated with sodium chloride. This brine is stored in reservoirs. The brine is then pumped into crystallizer ponds where sodium chloride precipitates. In the traditional salt fields, seawater is pumped directly into crystallizers.

Hypersaline water, previously thought to be lifeless, contains primary producers, consumers and decomposers like any other ecosystem (Borowitzka, 1981). The solar evaporation of seawater to produce

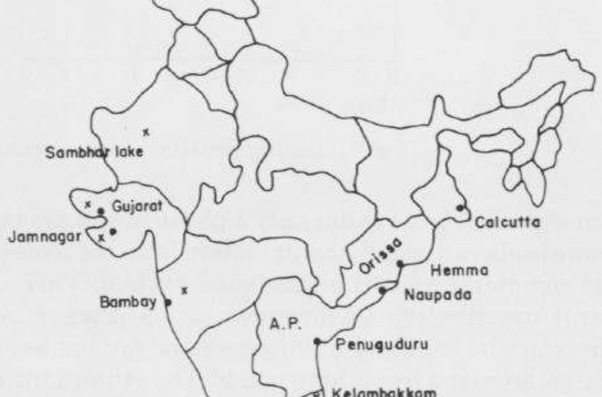

Fig. 1. Salt-producing areas (•) along the coast of India and study area (×).

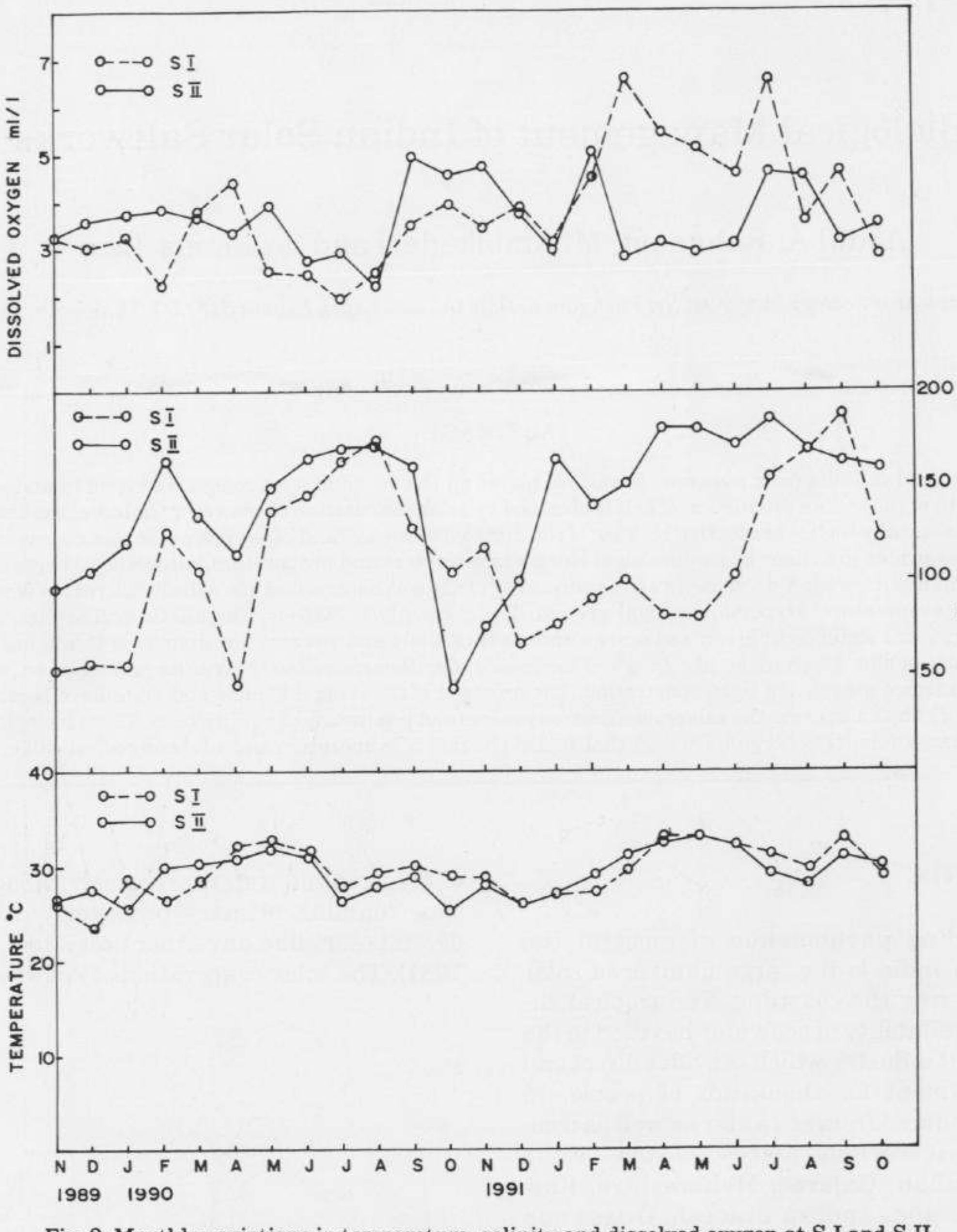

Fig. 2. Monthly variations in temperature, salinity and dissolved oxygen at S-I and S-II.

concentrated brine is not only a physical process but there is also an organic contribution from the biological communities within the pond system. This organic contribution to the evaporation process can therefore be expected to influence the production of the salt derived from these ponds. Thus the quantity and quality of the salt production is strongly influenced by the hydrobiological activity in solar salt operations (Davis, 1980).

The biological community existing in the saltworks ecosystem is beneficial as well as harmful to salt production. *Artemia* plays an important role in the biological management of solar saltworks. Planktonic components such as halobacterium serve to increase solar absorbtion by colouring the water, bright red and the algal mats in the bottom prevent leakage of water from the ponds. Certain species of algae may develop into blooms that colour the water and make it oily and viscous. This, in turn, retards the process of evaporation. Decline in salt production due to algal contamination has been reported from the saltworks of Rajasthan (Lall, 1987) and Karnataka (Rao, personal communication, 1990).

Solar salt production in India can be greatly improved by proper biological management of the solar saltworks. The main objective of this investigation

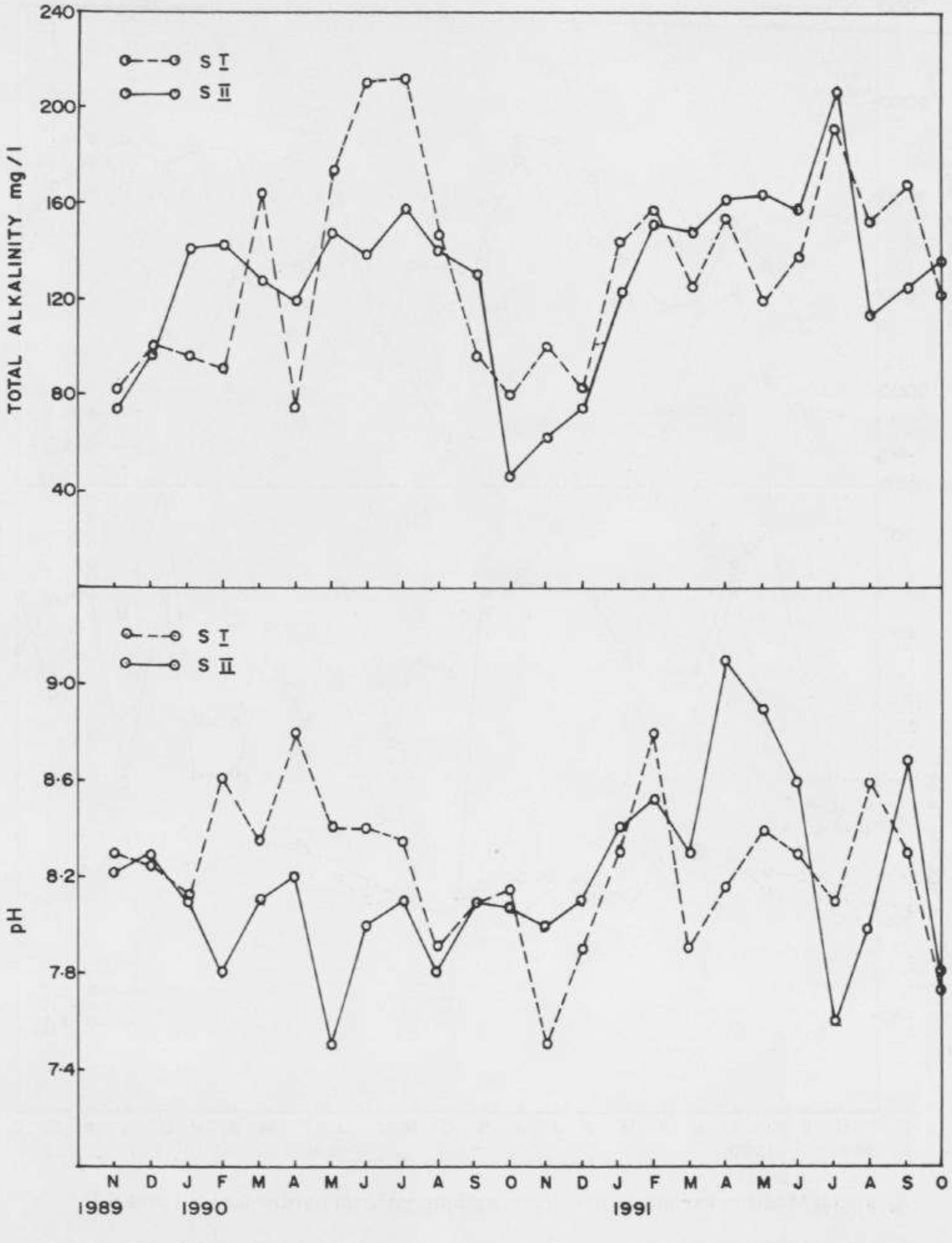

Fig. 3. Monthly variations in pH and total alkalinity at S-I and S-II.

was to collect sufficient information on the changes in the ecological features for a proper understanding of the plant and animal communities which are essential for quality salt production. This paper provides a review of the hydrobiological activities in some Indian solar saltworks.

MATERIALS AND METHODS

Samples for the present study were collected at monthly intervals from two typical saltworks of Tamil Nadu, located at Vedaranyam (here designated as S-I; 10° 01″N; 70° 50″E) and Kelambakkam (S-II; 12° 08″N, 80° 02″E) for a period of two years extending from November 1989 to October 1991 (Fig. 1). Vedaranyam saltworks has a total area of 93.081 ha and Kelambakkam, 526.5 ha. The salt operation in both saltworks is seasonal, the production period is from January to September. A survey was also undertaken in the saltworks in the Maharashtra State located at Bhayander, Mira Road, Bassein and Muland near Bombay (19°N; 73°E). The production season in these saltworks is from January to May.

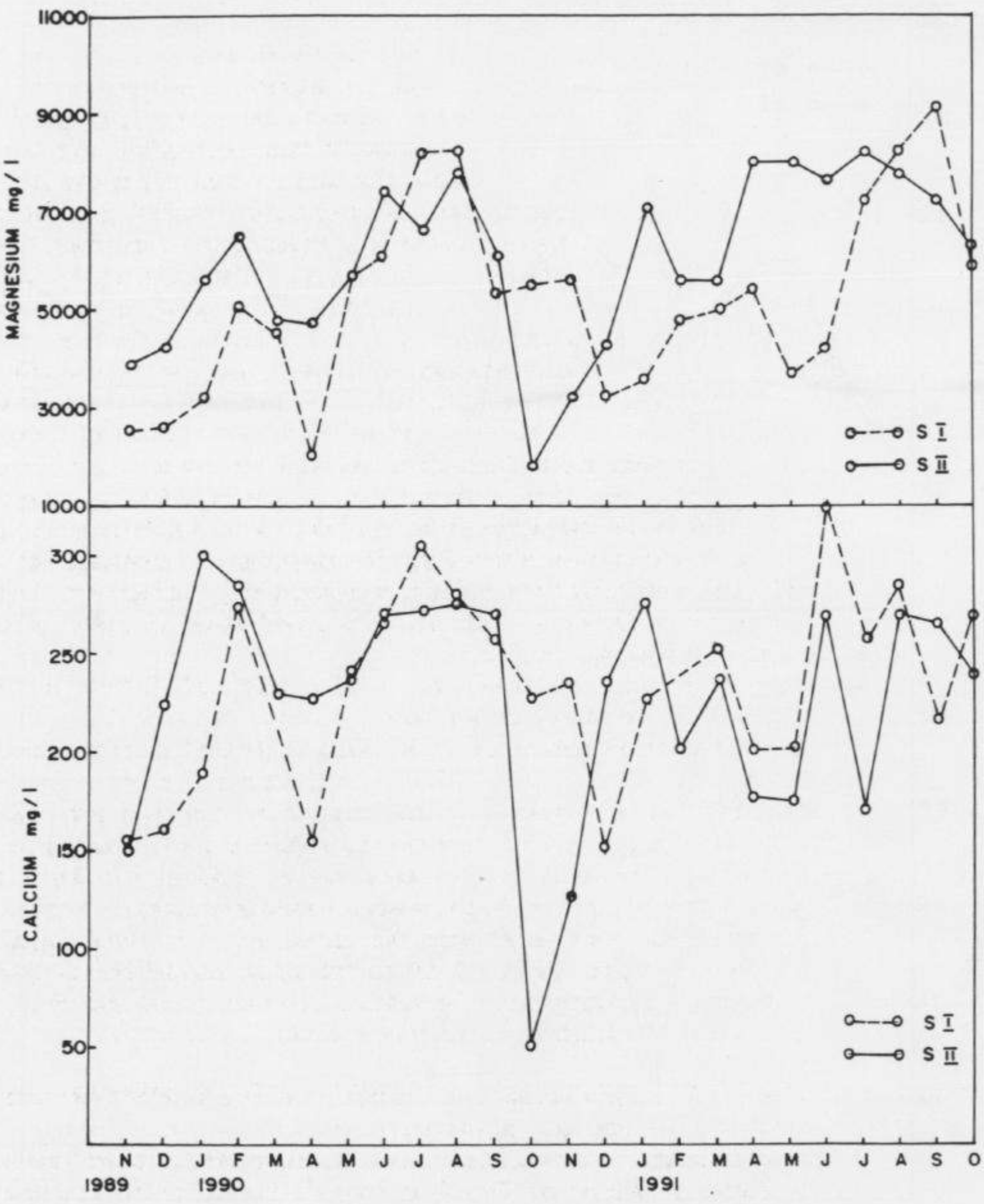

Fig. 4. Monthly variations in calcium and magnesium hardness at S-I and S-II.

The water samples were taken from the evaporators of the saltworks, Hydrographical factors such as temperature, salinity, dissolved oxygen, pH, total alkalinity, magnesium and calcium hardness, total solids, nutrients (nitrite, nitrate, phosphate, ammonia) and primary productivity, were studied along with phytoplankton and zooplankton communities. Water temperature was recorded with a centigrade thermometer, salinity by using a salinometer, and pH with a pH meter. Standard methods of seawater analysis were followed for the estimation of other parameters (Strickland and Parsons, 1972).

Samples for phytoplankton analysis were collected by filtering 50 l of water through a plankton net having a mesh size of 10 µm. For zooplankton studies samples were taken with the help of a 50 µm mesh plankton net. All samples were preserved in 5% formalin and the organisms were identified by using published papers and monographs.

RESULTS

Figures 2–8 illustrate the monthly variations of parameters at S-I and S-II respectively.

The water temperature ranged from 23.5 to 33.1°C at S-I and 24.8 to 33.1°C at S-II. The salinity values varied from 44.0 to 188 ppt at S-I and 41.8 to 187 ppt at S-II. At both stations dissolved oxygen

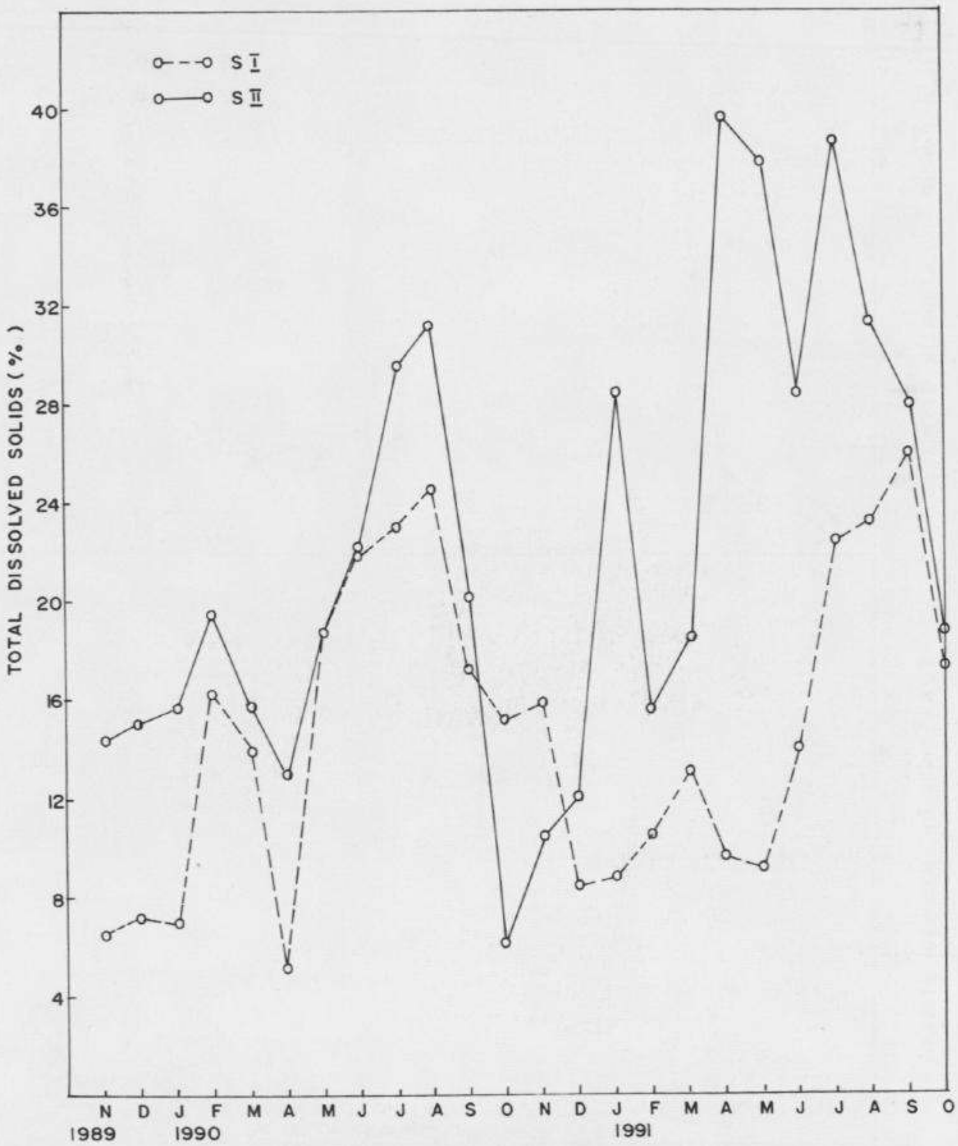

Fig. 5. Monthly variations in total dissolved solids at S-I and S-II.

values were comparatively low, and decreased with an increase in salinity. The dissolved oxygen fluctuated from 1.85 to 6.6 mg/l in S-II and 2.2 to 5.02 mg/l at S-II. The pH values varied from 7.5 to 8.9 in both stations. At both stations, wide fluctuations were observed in total alkalinity in relation to rainfall and salinity the values ranged from 74 to 212 mg/l at S-I and 46 to 207 mg/l at S-II. The magnesium hardness was found to increase with salinity. The maximum concentration noticed in S-I was 9679.0 mg/l and the minimum was 1769.5 mg/l. The maximum value observed at S-II was 8249.1 mg/l and minimum value was 2013.8 mg/l. The calcium concentration was lower than the magnesium concentration in both stations. The calcium concentration varied from 151.13 to 306.9 at S-I and 50.46 to 303 mg/l at S-II. The total solid values ranged from 5.1 to 25.1 ppt at S-I and 6.02 to 39.7 ppt at S-II.

Considerable variations occurred in the concentration of nutrients. The nutrient values were lower at S-II than at S-I. The ammonia–nitrogen values ranged between 0.019 and 5.62 μg at/l at S-I and 0.004 and 3.44 μg at/l at S-II. The productivity values were comparatively higher at Vedaranyam solar saltworks. The values increased from 0.06 to 0.195 mg C/m^3/h at S-I and 0.009 to 0.14 mg C/m^3/h at S-II.

PHYTOPLANKTON

The phytoplankton community consists of members of the Cyanophyceae, Chlorophyceae, Bacillariophyceae and Dinophyceae. The checklist of phyto-

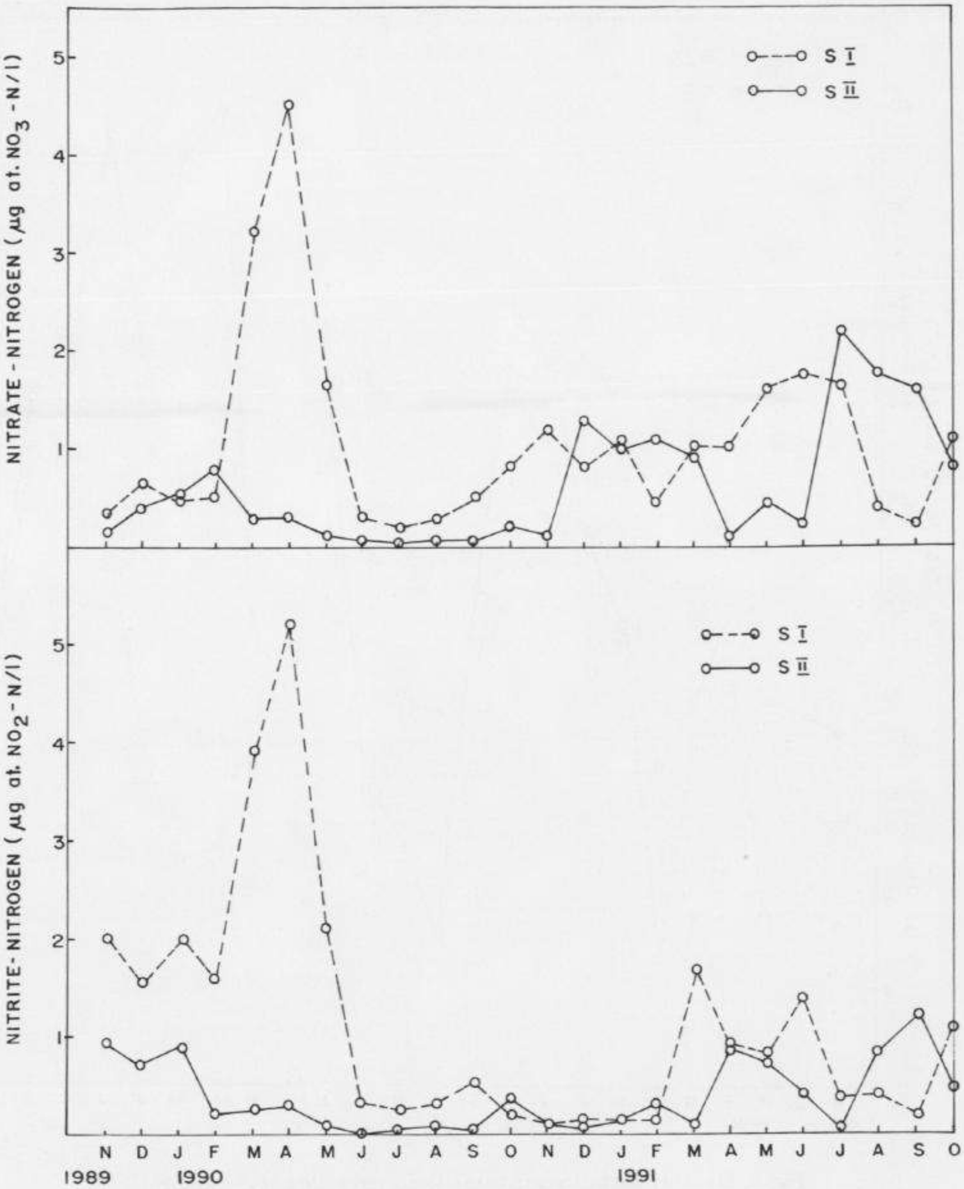

Fig. 6. Monthly variations in nitrite and nitrate-nitrogen at S-I and S-II.

plankton and their salinity tolerances are presented in Tables 1 and 2. Algal species such as *Anacystis dimidiatus, Coccochloris elabens, Lyngbya majuscula, Oscillatoria salina, Spirulina platensis, Xenococcus acervatus* and *Nitzschia longissima* were the most prominent phytoplankton in both stations. These species were also noticed in the evaporators of saltworks located at Bombay.

Species diversity and density of phytoplankton were less in Kelambakkam saltworks when compared with Vedaranyam saltworks. A total of 31 species comprising 20 genera were identified from Vedaranyam (S-I) and 20 species of 14 genera from Kelambakkam (S-II). The species composition were found to increase with decrease in salinity. At higher salinities algal blooms were noticed. A *Dunaliella* sp. bloom was observed in Vedaranyam during October 1989 and April 1990, when the salinities were 223 and 220 ppt respectively. Among algal species *Cladophora* sp., *Rhizoclonium* sp., *Amphora marina, A. salina, Coscinodiscus* sp., *Cyclotella comta, Cymbella* sp., *Mastogloia* sp., *Nitzschia dissipata* and *N. sigma* were present in Vedaranyam but absent at the Kelambakkam saltworks.

In Kelambakkam the water was clear and algal mats were not observed. On the other hand, in Vedaranyam, even though the water was clear, dense thick layers of algal mats occurred. In the Bombay

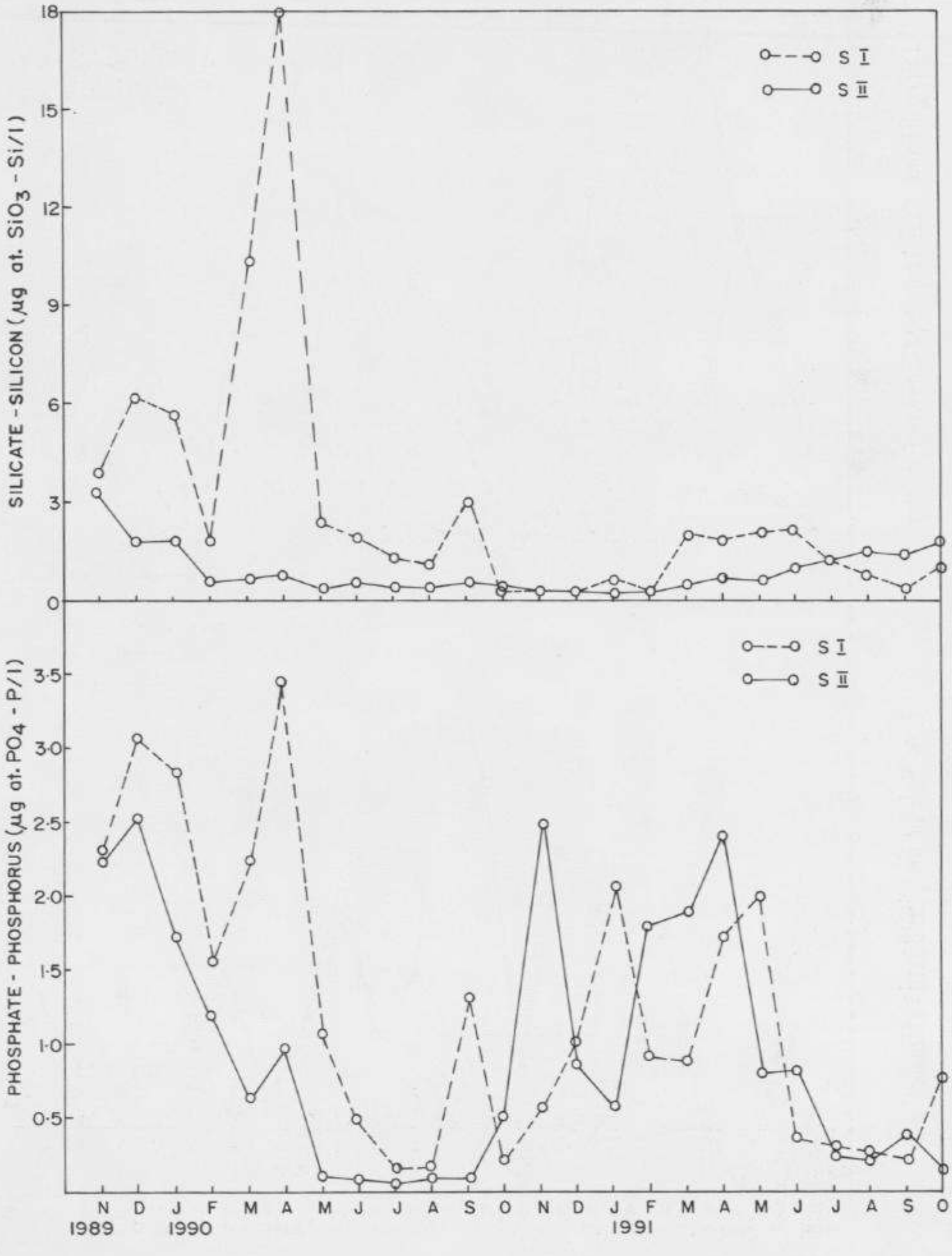

Fig. 7. Monthly variations in phosphate and silicate at S-I and S-II.

solar saltworks, water in the evaporators was very turbid and dense with large quantities of filamentous blue-green algae. However, algal mat formations were not noticed during the survey.

ZOOPLANKTON

When compared with phytoplankton, the zooplankton was generally poor in composition and abundance. Station-wise variation was observed in the zooplankton density and species composition. About 21 species were identified from Vedaranyam saltworks, whereas from Kelambakkam saltworks only 10 species were observed. *Artemia* was the dominant organism in all the saltworks. Even though *Artemia* was reported from the Bombay saltworks (Ansari, 1987), the organisms were absent during the present study. Ciliate protozoans and harpacticoid copepods were the other major components of the zooplankton and were observed throughout the study period. The checklist of zooplankton is given in Tables 3 and 4. Rotifers belonging to *Brachionus* sp., calanoid copepods, amphipods, forminifers, crustacean and molluscan larval forms were encountered in lower salinities. The ciliate protozoan *Bodo* sp. was abundant in all the saltworks.

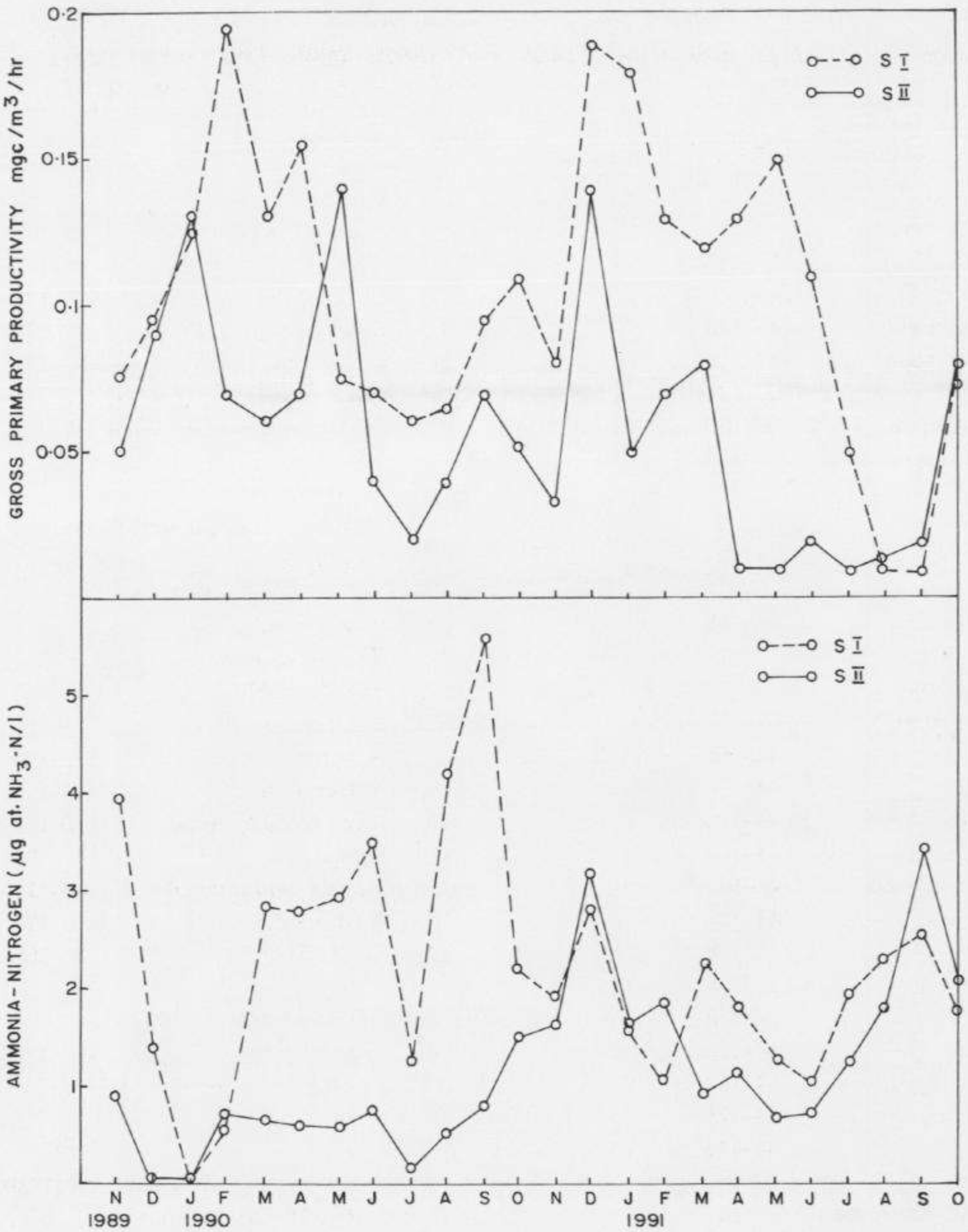

Fig. 8. Monthly variations in ammonia–nitrogen and gross primary productivity at S-I and S-II.

DISCUSSION

A definite relation between physico-chemical and biological factors could not be established due to the complex environmental characteristics of the saltworks, monsoonal showers, water evaporation and pumping of seawater for salt operations. High salinity, physico-chemical instability and low productivity have been the most characteristic features of the solar saltworks. Other hypersaline habitats are also characterized by large seasonal fluctuations in salinity and large diel changes in temperature and dissolved oxygen (Dana, 1981). The calcium content was always less than the magnesium concentration in all the saltworks. The relative ionic proportion for the various elements varies with salinity. The variability in ionic proportion with increasing salinity was also shown by Williams (1964). Extremely saline waters contain high concentrations of Mg^{2+}, SO_4^{2-} and HCO_3^- (Volcani, 1944; Bayly and Williams, 1966; Oren and Shilo, 1982).

A negative relationship was observed between salinity and phytoplankton population. The species diversity of phytoplankton increased when salinities

TABLE 1

Checklist of phytoplankton at Vedaranyam solar saltworks and their limits of salinity tolerance

	Species	Salinity (ppt)
	Cyanophyceae	
1.	*Anacystis dimidiatus*	44–188
2.	*Coccochloris elabens*	52–174
3.	*Gloeocapsa* sp.	44–138
4.	*Lyngbya majuscula*	44–188
5.	*Oscillatoria salina*	44–188
6.	*O. formosa*	44–174
7.	*Spirulina platensis*	56–188
8.	*Xenococcus acervatus*	44–188
	Chlorophyceae	
9.	*Cladophora* sp.	44–128
10.	*Dunaliella salina*	128–220
11.	*Rhizoclonium* sp.	44–168
	Bacillariophyceae	
12.	*Amphora marina*	59–90
13.	*A. ovalis*	44–163
14.	*A. salina*	44–174
15.	*Amphora* sp.	44–128
16.	*Coscinodiscus* sp.	44–105
17.	*Cyclotella comta*	44–163
18.	*Cymbella* sp.	44–128
19.	*Mastogloia* sp.	44–128
20.	*Navicula gracilis*	64–105
21.	*N. mutica*	44–168
22.	*Navicula* sp.	44–168
23.	*Nitzschia dissipata*	44–138
24.	*N. longissima*	44–174
25.	*N. sigma*	44–145
26.	*Nitzschia* sp.	44–145
27.	*Pleurosigma balticum*	44–145
28.	*P. salinarum*	44–174
29.	*Pleurosigma* sp.	44–145
30.	*Surirella* ovalis	44–163
	Chrysophyceae	
31.	*Synura* sp.	56–174

TABLE 2

Checklist of phytoplankton at Kelambakkam and their limits of salinity tolerance

	Species	Salinity (ppt)
	Cyanophyceae	
1.	*Anacystis dimidiatus*	75–187
2.	*Coccochloris elabens*	42–187
3.	*Gloeocapsa* sp.	115–165
4.	*Lyngbya majuscula*	42–187
5.	*Oscillatoria salina*	101–187
6.	*O. formosa*	101–165
7.	*Spirulina platensis*	42–187
	Chlorophyceae	
8.	*Xenococcus acervatus*	42–187
9.	*Dunaliella salina*	42–187
	Bascillariophyceae	
10.	*Amphora ovalis*	96–166
11.	*Anaulus debilis*	96–166
12.	*Navicula gracilis*	75–105
13.	*N. mutica*	96–165
14.	*Navicula* sp.	96–115
15.	*Nitzschia longissima*	115–165
16.	*Nitzschia* sp.	96–115
17.	*Pleurosigma distortum*	96–115
18.	*P. salinarum*	115–170
19.	*Surirella ovalis*	96–165
	Chrysophyceae	
20.	*Synura* sp.	160–170

of water declined during the rainy season.

On a more biological note, relatively large numbers of species and low abundances were noticed in low salinities. However as the salinity increased the species diversity decreased, but the population density of various hypersaline species flourished. A basic relationship between salinity and faunal occurrence was suggested by earlier workers (Bayly, 1978; Bauld, 1981; Rahaman et al., 1990). It is reported that in extremely saline waters only two or three algal species and bacterial species are able to grow and multiply (Volcani, 1944; Davis, 1978, 1979).

Dunaliella salina blooms that coloured the water red have been observed in Vedaranyam saltworks at salinities above 220 ppt (Rahaman et al., 1990). High salt concentration, high light intensity and high temperature stimulate *D. salina* to accumulate carotenoids (Lerche, 1937).

Although it is well known that the biological system in salt ponds is essential for salt production, an unbalanced system creates problems for salt precipitation. In the Indian saltworks photosynthetic algae harm salt production. These organisms utilise nutrients and produce metabolites which adversely influence salt production. The mucilaginous secre-

TABLE 3

Checklist of zooplankton at Vedaranyam and their limits of salinity tolerance

	Species	Salinity (ppt)
1.	*Bodo* sp.	99–188
2.	*Biteptus* sp.	44–72
3.	*Chilophrya labiata*	44–105
4.	*Didinium* sp.	79–174
5.	*Enchlys* sp.	44–105
6.	*Favella* sp.	80–188
7.	*Histiobalantidium* sp.	80–188
8.	*Nassula* sp.	79–168
9.	*Paramecium* sp.	44–72
10.	*Rhabdonella* sp.	64–128
11.	*Vorticella* sp.	44–72
12.	*Brachionus* sp.	44–90
13.	*Diacypris* sp.	44–128
14.	*Artemia*	44–188
15.	Calanoid copepod	44–120
16.	Harpacticoid copepod	44–174
17.	Amphipods	44
18.	Polychaetes	44– 90
19.	Larvae of crustaceans	44–150
20.	Larvae of insects	44–120
21.	Fish	44–64

TABLE 4

Checklist of zooplankton at Kelambakkam and their limits of salinity tolerance

	Species	Salinity (ppt)
1.	*Bodo* sp.	140–170
2.	*Favella* sp.	42–115
3.	*Nassula* sp.	115–180
4.	*Rhabdonella* sp.	115–162
5.	*Brachionus* sp.	42–162
6.	*Artemia*	42–187
7.	Calanoid copepod	42–152
8.	Harpacticoid copepod	75–180
9.	Polychaetes	162–172
10.	Larvae of crustaceans	42–165

tions of algae increase brine viscosity, hamper the salt crystallization process and result in small, hollow crystals contaminated with organic impurities (Sorgeloos, 1983). Such ecosystems should be managed for the better control of the organisms. Biological management is aided by the presence of *Artemia* which act as vacuum cleaners and they do not interfere with the salt production. The *Artemia* ingest suspended particles less than 50 μ in size and the excreta produced by the animals settles at the bottom and provides a suitable substratum for the development of *Halobacterium* (Sorgeloos, 1983) which imparts red coloration to the brine, and enhances evaporation of brine (Jones et al., 1981).

In the present study, the water in Vedaranyam saltworks was found to be more productive than at Kelambakkam. The Cyanophycean filamentous algae like *Spirulina platensis, Anacystis dimidiatus, Lyngbya majuscula, Oscillatoria salina* and benthic diatoms like *Nitzschia longissima* were found to produce benthic algal mats at the bottom of the evaporators. Algal mats of this type were not observed in Kelambakkam saltworks. According to Davis (1978), the benthic cyanobacterial mats are important for efficient salt production because they prevent seepage loss through bottom sediments. The mats effectively seal the pond bottoms and the very low permeability presents a barrier to both liquid and gas transfer across the sediment–water interface (Bubela, 1980). This can be the reason for the high salt production in Vedaranyam salt works, even though *Artemia* is present in both the saltworks. The production of salt per hectare in Vedaranyam saltworks is 39 t/ha and that of Kelambakkam saltworks is 27 t/ha per production season.

The biological diversity is low in Kelambakkam saltworks. Although the species diversity is greater in the Bombay saltworks, the salt pond ecosystem seems to be an unbalanced one. It was reported that in the Bombay salt pans *Artemia* was present only during March through May (Ansari, 1987). Based on these observations it can be concluded that a biological community essential for salt production exists in Vedaranyam saltworks. In the saltworks of the *Artemia* Research Centre field laboratory at Adirampattinam (research project sponsored by the Ministry of Environment and Forests, India), *Tetraselmis* sp. produced intense blooms colouring the water green and making it oily and viscous (M. Ambikadevi, personal. communication, 1991). When *Artemia* was introduced into this system the water became clear. *Artemia* filtered the algal particles and the faecal pellets were found at the bottom. In the Sambhar saltworks of Rajasthan during 1984–1986, the precipitation of very fine salt particles occurred (Lall, 1987). The normal crystal growth had been adversely affected. Besides, the decreased production of salt appeared to be largely due to algal contamination of the ponds. The source of brine in Sambhar saltworks is lake brine and subterranean brine. It was reported that the subterranean brine was free from algae and consequently salt production has not suffered in the areas utilised. On the other hand, deterioration in the quality and quantity of salt has taken place in the crystallizers using lake brine and main reservoir brine in which algae are present. It has also been recorded that the concentrated brine in the lake brine is oily and viscous in nature and the density of brine did not increase beyond 28°Bé.

Salt production in India can be improved by better management of saltworks. Our hydrobiological study can provide information for biological management to provide critical control for enhancing the quality of salt production.

CONCLUSIONS

Proper management of the biological system is essential for the production of high quality salt. The study indicated that the biological diversity decreased with increasing salinity. However the existing species produced dense algal blooms, increasing the population density in higher salinities. Uncontrolled proliferation of microalgae retards the evaporation rate and contaminates the salt. Decomposition products and excretions of algae prevent early precipitation of gypsum which contaminates sodium chloride, and the organic impurities which on oxidation change the colour of salt to black, reduce the size of crystals and inhibit salt crystal formation and precipitation. However, in a balanced biological system, where *Artemia* is present in sufficient numbers, *Artemia* consumes heat absorption and evaporation. A balanced biological system should be established and managed properly to improve the quality and quantity of salt.

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