STUDY ON ECOLOGICAL RESTORATION IN THE SOLAR SALTWORK

Zhi-nan SUN, Hua He, Xue-kui WANG, Zuo-liang SHA, Bo ZHANG

Tianjin Key Laboratory of Marine Resources and Chemistry, Tianjin University of Science & Technology, Tianjin 300457, China

Abstract: By means of Dunaliella viridis and Artemia franciscana inoculation in the solar saltwork, the ecological restoration process in the solar salt-production field which received the concentrated seawater from desalination plant was studied. The experiment was carried out in an area receiving concentrated seawater (1.75×10^4 m^2), and another area receiving original seawater (3.50×10^4 m^2) was used as control. The results showed that ecological restoration can be achieved by inoculation of Dunaliella viridis and Artemia franciscana in the salt ponds at suitable salinity.

Keywords: Solar salt-production; Saltern ecosystem; Ecological restoration; Dunaliella viridis; Artemia franciscana

INTRODUCTION

In the 1950's, the concept of the saltern ecosystem and the relationship between the saltern ecosystems and solar salt production were first proposed by Carpelan [1]. It has been proved that the balanced saltern ecosystem plays an important role in solar salt production [2]. The biological control at all levels of the production area, not only ensures the balance of the concentrations and volume of brine at all levels, but also maintains the balance of the entire saltern ecosystem. In this way, the maximum benefit from solar salt production fields can be achieved.

Phytoplankton , zooplankton and halophilic bacteria constitute the food chain of saltern ecosystem. Phytoplankton is the producer, which is the only food and energy source for consumer and decomposer. Zooplankton is the consumer, which consume phytoplankton and their carcasses offer energy for the decomposer in saltern ecosystem. Halophilic bacteria are the decomposer, which mineralize the carcasses of phytoplankton and zooplankton and release the inorganic nutrients into the environment. These inorganic matters are then reabsorbed and reused by the producer. In the solar salt field, the ecosystem and salt production interacts each other. A balanced ecosystem improves the quality and quantity of solar salt; on contrary, an unbalanced ecosystem has negative effect on the quality and quantity of sea salt.

The effluent from desalination plant is concentrated in salt (hereinafter referred to as the "concentrated seawater"). Compared to the original seawater, the concentrations of all kinds of salts in the concentrated seawater were doubled. For example, $6.0^0Be'$ concentrated seawater contains 47.72 g/L NaCl and 61.68 g/L total salt. As raw

material, the solar salt produced from the concentrated seawater is the most economical, convenient and environment friendly. And if solar salt is produced with the concentrated seawater, the low salinity area for preparing the $6.0^0Be'$ brine in solar salt production is no longer exist. However, the biological communities in the concentrated seawater are damaged during the desalination process. Lack of food for biological communities (such as Artemia) in the middle salinity area destroys the balance of the saltern ecosystem and hence affect the quality and quantity of the salt. Therefore it is necessary to find a way to restore the saltern ecosystem in the concentrated seawater. In this paper, method of saltern ecosystem restoration in solar salt field was studied by inoculating Dunaliella viridis and Artemia franciscana in the concentrated seawater. The results were compared with the normal solar salt production system in which the original seawater was used.

MATERIALS AND METHODS

Experimental set up

The experiment was carried out in the solar salt field of Tanggu Saltworks located in Tanggu, Tianjin city. The surface of test area is about 1.75×10^4 m^2 in order to meet the requirement of salt production (mainly the surface ratio of evaporation and crystallization) where the concentrated seawater was used as the raw material for salt production. For comparison, a control area was built up just beside the test area. The raw material used in the control area is directly concentrated from original seawater. An extra area of 1.75×10^4 m^2 was build for the preparation of the $6.0\text{-}7.0^0Be'$ brine. And the normal salt production process was carried out in both areas.

In the test area, the concentrated seawater after desalination was pumped. Dunaliella viridis was inoculated in lower salinity ponds ($6.0\text{-}7.0^0Be'$), and Artemia franciscana was inoculated in middle salinity ponds ($10.0\text{-}11.0^0Be'$). In the control area, the seawater was directly taken from the sea, and then was concentrated in the extra area by solar energy. Upon reaching $6.0\text{-}7.0^0Be'$, the brine was transferred into the control area, no extra organisms was introduced into the control area. During the procedure of salt production, the biological composition in the solar salt field was investigated.

Sampling and analysis methods

The location of the test and control area and the sampling points are given in Fig.1. Seven sample points are located in the test area, and five sample points are located in the control area. The test had been carried out for one year and the samplings were done four times a year. The sampling and analysis methods for different kinds of organisms are as follows:

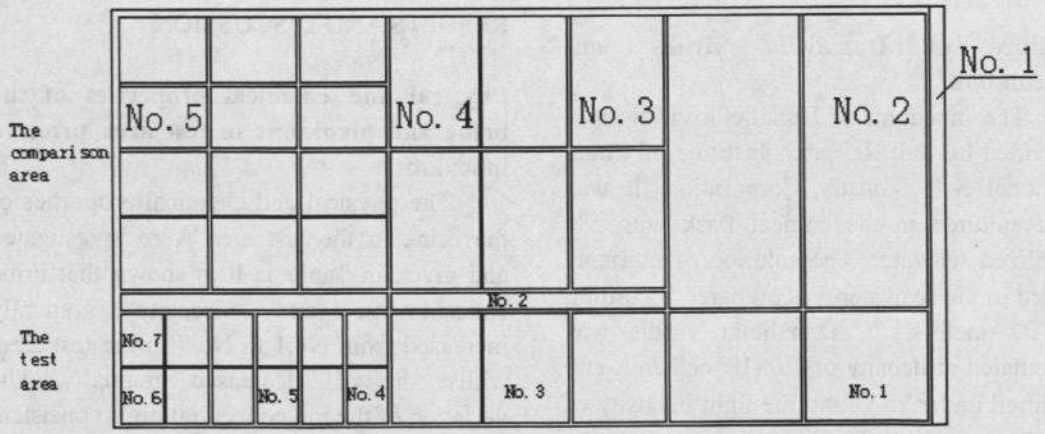

Fig.1 Location of experimental area and distribution of sampling points.

Phytoplankton

1L brine was collected at each sample point by a sampling bottle and added 6-8mL Lugo's solution for immobilizing the

phytoplankton. The phytoplankton in the brine was precipitated in a cylinder funnel for 24h. The supernatant was removed until less than 20mL precipitation was remained in the bottle. The precipitation was then transferred into a scaled tube. The cylinder funnel was washed three times with supernatant to ensure complete transformation of all phytoplankton. The solution in scaled tube is adjusted to 30mL for later counting. Each sample is counted twice using a blood cell counter. The deference between the two results should be less than 15%.

Zooplankton

20L brine was taken from each sampling point, and then filtered with a net (mesh diameter of 0.064mm). The obtained zooplankton was then transferred into a bottle and fixed with 10mL 5% formaldehyde solution. The species of zooplankton and number of each kind of zooplankton were determined.

Halophilic bacteria

The brine was collected with a 500mL sterilized glass bottle. Three suitable dilution degrees were selected for further plate culture. Each dilution degree was duplicated. 0.2mL solution was taken and spread on the surface of culture medium, which was made according to the Gibbons' improved method and 10% NaCl was added [3]. The plates were incubated for one week under 30-32℃ with illumination, and the number of halophilic bacteria in 1mL brine were counted.

Culture of Dunaliella viridis and inoculation

The inoculum of Dunaliella viridis was provided by Salt Research Institute of China National Salt Industry Corporation. It was first cultured in the conical flask with 5% sterilized seawater. The solution of nutrients added in the seawater was prepared according to f/2 method [4]. Dunaliella viridis was inoculated at density of 1.0×10^4 cells/mL and cultured under 25℃ and the light intensity of 53.57μmol.m^{-2}.s^{-1}. Upon the cell density cells reached 1.70×10^6 cells/mL, it was further inoculated into 5L bottle and 60 L plastic tank.

The Dunaliella viridis was further inoculated into 100 L tank containing $10.0^0Be'$ brine. The brine was disinfected by adding hypochloride and nutrients such as nitrogen and phosphorous was added. The culture was carried out with natural illumination and manually mixing. Density of inoculation is 0.57×10^6 cells/mL in No.1 culture tank and 0.71×10^6 cells/mL in No.2 culture tank. Then the algae were transferred into the tank with 6m^2 bottom surface for further culture. Culture conditions were same as used before, but with mechanical mixing. Dunaliella viridis was finally inoculated into the test area, when the density of Dunaliella viridis is reached to 1.00×10^6 cells/mL. The inoculation in the test area was carried out at June 5, 2005 in the area of brine concentration of 6.0-7.0$^0Be'$.

Artemia cysts hatching and inoculation

Artemia franciscana cysts were disinfected by 100 mg/mL formaldehyde solution, and then rinsed with tap water and hydrolyzed for 1h at room temperature. Hatching was carried out in a 0.8 m^3 cylinder tank. 1.2kg (dry weight) cysts were added into each tank. The hatching conditions are as follows: 3% seawater, pH8.5, 30℃ and 17.857μmol.m^{-2}.s^{-1} light intensity. After 24h, the nauplii were collected and inoculated into the test area. The inoculation was carried out at June 20, 2005 in the area of brine density of 10.0-11.0$^0Be'$. The amount of nauplii was controlled at 15 ind./L.

RESULTS AND DISCUSSION

Physical and chemical properties of the brine and planktons in test area prior to inoculation

The physical and chemical properties of the brine in the test area were investigated and given in Table 1. It is shown that brine concentration and viscosity gradually increased from No.1 to No.7 in the test area, whilst the pH decreased gradually. The variation of the ion concentration is consistent with the concentrating law of saltern brine [5]. The investigation results of phytoplankton and zooplankton were given in Table 2 and Table 3, respectively. It showed that there are

12 species of phytoplankton and seven species of zooplankton in the test area before inoculation. The reason why some organisms were observed in the test area could be that this area was constructed on the used salt field, in which, the algae spores or dominant cysts of zooplankton had existed in the sediment of the ponds and survived over winter. When the ponds were refilled with concentrated seawater, the spore germination and cysts hatching occurred. However, the amount of both green algae and Artemia, which are the dominant species in the salt field [6] and benefiting salt production [7], are less than that in control area [8].

Table 1 Physical and chemical properties of the brine (sampled in May, 2005)

Sample points	Specific gravity (20℃)		Viscosity (30℃)	pH (20℃)	Ion composition (g/L)					
	g/cm^3	$^0Be'$	mPa.s		Ca^{2+}	Mg^{2+}	K^+	Na^+	SO_4^{2-}	Cl^-
No.1	1.0432	6.12	0.9077	7.92	0.76	2.27	0.70	18.93	4.84	34.22
No.2	1.0682	9.35	0.9796	7.80	1.16	3.89	1.21	28.86	8.32	52.86
No.3	1.0926	12.37	1.0714	7.73	1.54	5.62	1.80	39.05	11.61	72.40
No.4	1.1285	16.57	1.2438	7.70	1.05	8.71	2.47	54.66	15.44	102.39
No.5	1.1674	20.82	1.4736	7.67	0.74	11.86	3.27	73.18	19.13	137.57
No.6	1.2166	25.81	1.9300	7.45	0.47	16.35	5.04	94.39	24.80	180.31
No.7	1.2302	27.12	2.0834	7.34	0.34	21.10	5.68	91.77	31.18	185.76

Table 2 Composition and distribution of phytoplankton (sampled in May, 2005)

Phytoplankton	Distribution and specific gravity ($^0Be'$)						
	No.1	No.2	No.3	No.4	No.5	No.6	No.7
	6.12	9.35	12.37	16.57	20.82	25.81	27.12
Pyrrophyta							
Glenodinium sp.		+					
Cryptophyta							
Cryptomonas ovata		+					
Bacillariophyta							
P.affine	+						
Nitzschia longissima	+	+					
Nitzschia sp.	+++	+					
Naricula sp.	+	+	+	+			
Cymbella sp.		++	+	+			
Cyanophyta							
Aphanothece sp.					++		
Lyngbya sp.	+						
Chlorophyta							
Dunaliella salina	+	+	+			+++	++
Dunaliella viridis	+	+	+			+	++
Chlorella sp.	+						

Notes: in the table "+" means much; "++" means more; "+++" means the most, the same as the next tables

Table 3 Composition and distribution of zooplankton (sampled in May, 2005)

	Distribution and specific gravity ($^{0}Be'$)						
	No.1	No.2	No.3	No.4	No.5	No.6	No.7
	6.12	9.35	12.37	16.57	20.82	25.81	27.12
Crustacea							
Artemia adult	+++	++	+++	+++	+++	++	
Artemia nauplius		+++	+++	+++	+++		
Artemia pre-adult	++	+++	+++	+++	+++	+	+
Acatia bifilosa	+						
Paracalanus	+	+					
Tortanus soinicaudatus		+					
Copepoda	+++	++					
Aquatic Insects							
Ephedra				+	+		
Ephedra larva					+		

Biological investigated results in test area and control area

The biological investigation was carried out in the period of July, 2005 to June, 2006.

Phytoplankton

As shown in Table 4, the results obtained from July, 2005 indicated that phytoplankton collected from test area is consisted of four primary phyla and thirteen species, including one species of cryptomonas, six species of diatom, two species of cyanophyta and four species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata, bacillariophyta such as Naricula sp., Cymbella sp., cyanophyta such as Aphanothece sp., chlorophyta such as Dunaliella salina and Dunaliella viridis.

Phytoplankton collected from control area is consisted of two primary phyla and four species, including two species of cyanophyta, two species of chlorophyta. The dominant species are cyanophyta such as Lyngbya sp., chlorophyta such as Dunaliella viridis.

Table 4 Composition and distribution of phytoplankton (sampled in July, 2005)

Phytoplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$) in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	8.08	8.59	11.40	15.42	18.50	26.86	27.08	10.95	18.69	20.47	22.37	27.93
Cryptophyta												
Cryptomonas ovata	++											
Bacillariophyta												
Pleurosigm pelagicum	+											
P.affine	+	+										
Nitzschia longissima	+	+										
Nitzschia sp.	+	+										
Naricula sp.	+	+	+	+								
Cymbella sp.	+	+	+	+								
Cyanophyta												
Aphanothece sp.	+++	+++	++						+			
Lyngbya sp.									++	++	+	
Chlorophyta												
Dunaliella salina		+	+		+	+++	+	+			+	+
Dunaliella viridis		+	+		+	++	++	+++	+	+	+++	++
Platymonas sp.		+	+									
Chlorella sp.	+	+										

As shown in Table 5, the results obtained from September, 2005 indicated that phytoplankton collected from the test area is consisted of four primary phyla and fourteen species including one specie of cryptomonas, six species of diatom, three species of cyanophyta, and four species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata, bacillariophyta such as Naricula sp. and Cymbella sp., cyanophyta such as Lyngbya sp., chlorophyta such as Dunaliella salina and Dunaliella viridis.

Phytoplankton collected from control area is consisted of four primary phyla and twelve species including one specie of cryptomonas, four species of diatom, three species of cyanophyta, four species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata; bacillariophyta such as Naricula sp. and Cymbella sp., cyanophyta such as Lyngbya sp., chlorophyta such as Dunaliella viridis.

Table 5 Composition and distribution of phytoplankton (sampled in September, 2005)

Phytoplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$) in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	7.38	9.66	12.37	14.68	17.65	26.30	27.03	10.58	16.74	17.43	26.95	29.13
Cryptophyta												
Cryptomonas ovata	+++	+	+	+				+	+			
Bacillariophyta												
Pleurosigma pelagicum	+++	+	+									
P.affine	++	+	+									
Nitzschia longissima	+	+	+					+				
Nitzschia sp.	+	+	++					++				
Naricula sp.	+++	+	+	+	+			+++				
Cymbella sp.	+++	+	+	+	+			+++				
Cyanophyta												
Aphanothece sp.			+						+			
Lyngbya sp.	++	+	+	+	++			+	+++	++		
Chroococcus sp.	+	+						+				
Chlorophyta												
Dunaliella salina					+	+++	+++				+	+
Dunaliella viridis	+			+	+	++	++	+	+	+	++	+
Platymonas sp.								++				
Chlorella sp.	+							+				

As shown in Table 6, the results obtained from November, 2005 indicated that phytoplankton collected from test area is consisted of four primary phyla and twelve species, including one specie of cryptomonas, six species of diatom, two species of cyanophyta, and three species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata, bacillariophyta such as Naricula sp. and Cymbella sp.; cyanophyta such as Aphanothece sp., chlorophyta such as Dunaliella viridis.

Phytoplankton collected from control area consisted of four primary phyla and eleven species including one specie of cryptomonas, six species of diatom, two species of cyanophyta, three species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata; bacillariophyta such as Naricula sp. and Cymbella sp., cyanophyta such as Lyngbya sp., chlorophyta such as Dunaliella viridis.

Table 6 Composition and distribution of phytoplankton (sampled in November, 2005)

Phytoplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$) in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	6.82	9.12	12.47	15.68	19.20	26.37	27.37	11.95	17.92	18.63	26.98	28.17
Cryptophyta												
Cryptomonas ovata	+	+	+					+	+			
Bacillariophyta												
Pleurosigma pelagicum	++							+				
P.affine	+											
Nitzschia longissima	+							+				
Nitzschia sp.	+	+						+	+			
Naricula sp.	++	+	+	+	++			+	+			
Cymbella sp.	+	+	+	+	+			++	+			
Cyanophyta												
Lyngbya sp.	+	+			++	++		+	+	+	+	++
Oscillatoria sp.				+	+++			+	+			
Chlorophyta												
Dunaliella salina						+					+	
Dunaliella viridis	+++	+++	+++			+	+	++	++	++	+	+
Platymonas sp.	+	+	+					++				

As shown in Table 7, the results obtained from June, 2006 indicated that phytoplankton collected from test area is consisted of three primary phyla and ten species including five species of diatom, three species of cyanophyta, and two species of chlorophyta. The dominant species are bacillariophyta such as Naricula sp. and Cymbella sp., cyanophyta such as Oscillatoria sp., chlorophyta such as Dunaliella viridis.

Phytoplankton collected from control area consisted of four primary phyla and eight species including one species of cryptomonas, three species of diatom, two species of cyanophyta, and two species of chlorophyta. The dominant species are cryptophyta such as Cryptomonas ovata; bacillariophyta such as Naricula sp. and Cymbella sp., cyanophyta such as Lyngbya sp., chlorophyta such as Dunaliella viridis.

Table 7 Composition and distribution of phytoplankton (Sampled in June, 2006)

Phytoplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$) in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	6.25	7.60	8.28	11.23	12.97	27.21	28.07	13.26	18.11	19.40	21.75	27.67
Cryptophyta												
Cryptomonas ovata									+	+		
Bacillariophyta												
Pleurosigma pelagicum	+	+	+									
Nitzschia longissima	+											
Nitzschia sp.	+	+	++					+				
Naricula sp.	++	+	+	+				+	+			
Cymbella sp.	+	+	+	+	+			+	+			
Cyanophyta												
Aphanothece sp.									+	+		
Lyngbya sp.	+											
Chroococcus sp.	+											
Oscillatoria sp.	+	+	+	+	+			++	+++	+++		
Chlorophyta												
Dunaliella salina						+	+				+	+
Dunaliella viridis	++	++	+	+	+	+	+	+	+	+	+	+

The phytoplankton in salt ponds is originally from seawater. With increasing the brine concentration in salt field, the species of the phytoplankton are reduced gradually because some species cannot tolerant to the high concentrated brine. Phytoplankton investigation showed that the changes in biomass and species of the main algae in both test area and control area are consistent as given in Table 4, 5, 6 and 7. Moreover, there were more species in the high-temperature season than in the low-temperature season. Diatoms and green algae are the main species in both areas. This was in consistence with the results obtained in the same saltworks in 2004[9]. Dunaliella viridis had become a dominant species in high salinity environment in test area. The density of Dunaliella viridis in the test area is lower than the control area just after inoculation (July, 2005 and September, 2005), but became similar afterwards (Nov, 2005 and June, 2006). It is therefore concluded that Dunaliella viridis inoculation in the salt field is effective for restoration of saltern phytoplankton.

Zooplankton

As shown in Table 8, the results obtained from July, 2005 indicated that zooplankton collected from test area contained seven species including four species of crustacea, two species of aquatic insects, one specie of mollusk. The dominant species are crustacea such as Artemia adult, Artemia nauplius,

Artemia pre-adult, aquatic insects such as Ephedra larva.

Zooplankton collected from control area contained six species, including three species of crustacea, two species of aquatic insects, one specie of mollusk. The dominant species are crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult.

Table 8 Composition and distribution of zooplankton (sampled in July, 2005)

Zooplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$) in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	8.08	8.59	11.40	15.42	18.50	26.86	27.08	10.95	18.69	20.47	22.37	27.93
Crustacea												
Artemia adult	+++	+++	++	+++	+++			+	+++	+++	++	
Artemia nauplius	+++	+++	+++	+++	+			++	+	+	+	
Artemia pre-adult	+++	+++	+++	+++	++			+++	+		+	
Nauplius	+											
Aquatic Insects												
Ephedra				+							+	
Ephedra larva	++		+		+				+			
Millusca												
Gastropoda larva					+	+	+	+				+

As shown in Table 9, the results obtained from September, 2005 indicated that zooplankton collected from the test area is consisted of seven species including five species of crustacea, two species of aquatic insects. The dominant species are crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult, aquatic insects such as Ephedra larva.

Zooplankton collected from control area is consisted of five species including three species of crustacea, two species of aquatic insects. The dominant species are crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult, aquatic insects such as Ephedra larva

Table 9 Composition and distribution of zooplankton (sampled in September, 2005)

Zooplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$)in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	7.38	9.66	12.37	14.68	17.65	26.30	27.03	10.58	16.74	17.43	26.95	29.13
Crustacea												
Artemia adult	+++	++	++	+++	+++	++	+++	+	++	++	+	
Artemia nauplius	+++	+++	+++	+++	+++			+	++	+++		
Artemia pre-adult	+++	+++	+++	+++	+++	+		+	+++	+++		+
Microsetella norvegica	+											
Paracalanus crassirosteris	+											
Aquatic Insects												
Ephedra					+				+	+		
Ephedra larva		+			+		+	+				

As shown in Table 10, the results obtained from November, 2005 indicated that zooplankton collected from the test area is consisted of five species including three species of crustacea, and two species of aquatic insects. The dominant species are crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult, aquatic insects such as Ephedra.

Zooplankton collected from control area is consisted of four species inclding three species of crustacea, and one species of aquatic insects. The dominant species are crustacea such as Artemia adult, Artemia pre-adult, aquatic insects such as Ephedra.

Table 10 Composition and distribution of zooplankton (sampled in November, 2005)

Zooplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$)in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	6.82	9.12	12.47	15.68	19.20	26.37	27.37	11.95	17.92	18.63	26.98	28.17
Crustacea												
Artemia adult adultauplius			+++	+++	+++			+	+++	++	+	
Artemia nauplius		+	+	++	+				++	+		
Artemia pre-adult		+	+++	+++	+++			+	++	++		
Aquatic Insects												
Ephedra	+			+		+	++	+				+
Ephedra larva		+										

As shown in Table 11, the results obtained from June, 2006 indicated that zooplankton collected from the test area is consisted of nine species including seven species of crustacea, and two species of aquatic insects. The dominant species are crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult, aquatic insects such as Ephedra larva.

Zooplankton collected from control area is consisted of four species including three species of crustacea, two species of aquatic insects. The dominant species is crustacea such as Artemia adult, Artemia nauplius, Artemia pre-adult.

Table 11 Composition and distribution of zooplankton (sampling in June, 2006)

Zooplankton	Distribution and specific gravity($^0Be'$) in test area							Distribution and specific gravity($^0Be'$)in control area				
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.1	No.2	No.3	No.4	No.5
	6.25	7.60	8.28	11.23	12.97	27.21	28.07	13.26	18.11	19.40	21.75	27.67
Crustacea												
Artemia adult	+++	+++	++	+++	+++			+	+++	+++	+++	+
Artemia nauplius	+++	+++	+++	+++	+++			+	+	++	++	
Artemia pre-adult	+++	+++	++	+++	++			+	+	++	++	
Acatia bifilosa	++	+										
Oithina similis	+											
Paracalanus crassirosteris	++	++										
Acartia bifilosa	+											
Aquatic Insects												
Ephedra						+						
Ephedra larva	+	+	+	++	+			+				

With increasing of the brine concentration, species of zooplankton are decreased. The results of zooplankton showed that both in test area and control area have the same community. There were more species in high-temperature season than in low-temperature season. Crustaceans are the main species in both areas. These results were basically in consistence with the results investigated in Tanggu salt field in 2004[9]. After inoculation, Artemia franciscana has become dominant species of zooplankton in middle and high salinity field. At the beginning period of the inoculation, the density of Artemia in test area was lower than control area. After a period of inoculation the density of Artemia in both areas are similar. From the results we can conclude that Artemia franciscana inoculation is effective measure to improve beneficial organisms in salt field.

Halophilic bacteria

Table 12 showed that after inoculation the density of halophilic bacteria in test area was lower than control area. After a period of inoculation, the density of halophilic bacteria in the test area was as much as control area.

Table 12 Number of the halophilic bacteria (ind/mL)

Sampling Date	Test area				Control area		
	No.5	No.6	No.7		No.3	No.4	No.5
September, 2005	650	150	20		1200	330	80
November, 2005	1150	350	80		1300	300	100
June, 2006	850	200	60		720	230	40

CONCLUSIONS

By inoculating Dunaliella viridis in the low salinity area (6.0-7.0 $^0Be'$), the phytoplankton producers have been restored. The investigated results indicated that there are four phyla of phytoplankton including cryptomonas, diatoms, cyanobacteria and

green algae, the total number of phytoplankton species ranged 10 to 14. The highest phytoplankton variety occurred in September, 2005, and the lowest one occurred in June, 2006. The restoration of the phytoplankton supplied food source for Artemia in the middle salinity area, and thus promoted the growth and reproduction of the Artemia.

By inoculating Artemia franciscana in the middle salinity (10.0-11.0 $^{0}Be'$), the zooplankton consumers have been restored. The investigated results indicated that there were three phyla of zooplankton including crustaceans, aquatic insects and mollusks, the total number of zooplankton species ranged from 5 to 9. The highest zooplankton variety occurred in June 2006, and the lowest zooplankton variety occurred in November 2005. The restoration of zooplankton, especially Artemia, constantly consumed large quantities of the phytoplankton. And the carcasses of the zooplankton provided enough nutrients for halophilic bacteria which benefited to the salt production.

In summary, by inoculating of Dunaliella viridis and Artemia franciscana in the solar salt field which receives concentrated seawater from desalination plant, the balanced ecosystem in salt field can be quickly restored. The method introduced in this paper can be used in the treatment of the effluent of concentrated seawater after SWRO for solar salt production.

References

[1] Carpelan, L.H., 1957. Hydrobiology of the Alviso salt ponds. Ecology. 38, 375-390.

[2] Li, K., Bai, J., 1998. Analysis of structure on salt field ecosystem. Marine Sciences. 5, 36-38.

[3] Li, A., Wang W., 1994. Study on Halophilic Bacteria in Balanced Ecosystem of Salt Pan. Journal of Nankai University (Nature Sciences). 27 (4) , 68-71.

[4] Wang, L., Huang, X., 2002. The Growth of Nannochloropsis oculata Cultured in Different Nutrient Concentrations and the Variations of Nitrogen and Phosphorus in Culture Tanks. Journal of Shanghai Fisheries University. 11 (3) , 215-218.

[5] Teaching and Research Group of Salt Making, Department of Salt Industry, Tianjin University of Light Industry. 1997. Salt Making Technics (previous). 37-44.

[6] Javor, B.J., 2002. Industrial microbiology of solar salt production. Journal of Industrial Microbiology & Biotechnology. 28, 42-47.

[7] Davis, J.S., 1980. Experiences with Artemia at solar saltworks. The Brine Shrimp Artemia. 47(3), 51-55.

[8] Li, K., Bai, J., 1998. Biocontrol on the Salt Field Ecosystem. Marine Sciences.6, 38-40.

[9] He, H., Wang, X., 2006. Investigation on Salt Pan Plankton in Tanggu Saltworks in Tianjin. Journal of Lanzhou University (Nature Sciences). 42, 619-624.