CHLOROPHYLL AND PLANKTON OF THE GULF COASTAL WATERS OF SAUDI ARABIA BORDERING A DESALINATION PLANT[1]

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ABSTRACT

As on land, plants are the real producers in the sea, and on them depend all marine living resources and the basic sustainability of ecosystems. Primary production is performed by chlorophyll-bearing plants ranging from the tiny phytoplankton to the giant kelps through the process of photosynthesis. Zooplankton play an important role as secondary producers and together with phytoplankton they support the vast assemblages of marine food chain with all their diversity and complexity. Data on chlorophyll pigments, phytoplankton and zooplankton are regarded as a sound basis for environmental appraisal of ecosystems. This paper presents and discusses a set of data collected from the Saudi Arabian coastal waters near the desalination plants in Al-Jubail. Materials were collected from six different sites covering the intake and discharge zones during cruises carried out in 1997-98. Analyses of Chlorophyll pigments were made using the spectrophotometric method. Plankton samples were collected using a Nansen plankton net of 75μ mesh size, and analyzed following standard procedures. Chlorophyll a,b,c and Phaeophytin are the most commonly occurring pigment in seawater. Their concentrations showed wide fluctuation. The phytoplankton community was composed of 35 genera representing the Diatoms, Dinoflagellates and Blue- green algae. Zooplankton was composed of Protozoa, Coelentrata,Ctenophora, Aschelminthes, Annelida, Mollusca, Arthropoda, Echinodermata and Chordata. Arthropoda, represented by Cladocera, Copepoda and Crustacean larvae, formed the largest group followed by Chordata. The distribution of phyto and zooplankton are examined and discussed on a seasonal, annual and inter annual basis. In terms of species, over all species composition has not been affected by

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plant discharge. The study brings out a greater understanding of the changes experienced by biotic communities as a result of impingement, entrainment and entrapment consequent to water passage through the plant structures. The study reflects the ecological relationships that the phytoplankton and the zooplankton of the region possess with respect to the intake and discharges. Further, the study has brought to light a very redeeming feature of the ecosystem to sustain its productivity and planktonic abundance. It is observed that seawater temperature, salinity and total suspended solids did not act as limiting factors. Besides throwing much light on the little known biological aspects of desalination sites, the data provided constitute a significant addition to the knowledge base of marine living resources in an industrial zone of Gulf coastal waters.

1. INTRODUCTION

Over ninety percent of the Planet's living and nonliving resources are found within a few hundred kilometers of the coast. Pollution, exhausted fishing stocks, disappearing coastline, rising sea level, increasing surface temperature that threatens the deep ocean currents, more frequent and devastating storms and melting of polar ice caps have become a menacing catalogue of symptoms that threaten the ecological balance of the oceans [1]. Although beset with difficulties, governments have started acknowledging the need for placing a monetary value on environmental impacts. Environmental impact is often assessed by observing changes in the ecosystem in terms of productivity of the natural resources and then monetising the change by applying market or surrogate prices. If one had to pay for all the services and goods the oceans provide, such as regulating gases in the atmosphere, cycling nutrients, biological control, food production, raw materials and recreation, the total bill would come to about US$ 21,000 billion per year, of which 12,000 billion is generated by the coastal ecosystems[2]. There is greater awareness today than ever before that environmental protection needs economic development in order to be successful, and economic development requires environmental protection in order to be sustainable. The world has now entered into an era of sustainable development trying to reap the benefits of this interlocking mechanism involved in all man-induced development activities. The Red Sea and the Arabian Gulf are the principal ecosystems that supply raw seawater for desalination in West Asia. Knowledge on the ecology of the seas adjacent to desalination plants is scanty [3 to 8]. The present study is focused on the depth-profile ecology of the Jubail Sea adjacent to the SWCC desalination plants. Very little data are available on the chlorophyll and plankton of the Arabian Gulf [9 to 14]. Information available was fragmentary on the biological aspects of marine habitats adjacent to the desalination plant. The present study was undertaken to examine the pattern of chlorophyll and plankton production in the context of a desalination plant operation.

2. MATERIALS AND METHODS

Materials required for the study were collected from six stations (Station 1: Intake Bay, Station-II: Open Sea, Station-III : Outfall Bay, Station-IV: Recovery Zone 1, Station-V: Recovery Zone 2, and Station VI: Recovery Zone 3) in the coastal waters of the Al-Jubail plant during the monthly cruises carried out during 1997-98 (Fig. 1). Surface and bottom water samples were collected for the determination of chlorophyll pigments and water quality parameters and they were analyzed following standard procedures [3,15]. Plankton samples were collected from stations I-V and analyzed following the methods given by Omori and Ikeda [16], Santhanam et al.[17] and ROPME [18]. Estimation of phytoplankton and zooplankton density was made by counting 1 ml sub-sample of the well mixed standard sample in a Sedgwick Rafter Counter Chamber. The counts were converted to number of cells or organisms per cubic meter of seawater. Settling volume and dry weight of plankton were also recorded.

3. RESULTS

3.1 Chlorophyll Pigments

The sea is a massive, inexhaustible farm where photosynthetic production by plants sustains the multiplicity of food webs and supports the role of the sea as the principal source of food and a vital “sink” for atmospheric carbon dioxide. Throughout the euphotic zone where sunlight penetrates, photosynthesis takes place utilizing the carbon dioxide in the water and releasing oxygen into the medium, which is needed by all marine organisms for their survival. The presence of chlorophyll pigments is of paramount importance in the economy of any aquatic biotope. The seasonal trend showed that the production of Chlorophyll a pigments remained below detection limit during the fall season. The surface water Chlorophyll a remained the highest during the summer season at all stations except the Outfall Bay, where the highest value was recorded in winter. Data on the seasonal production showed that the values were below detection limit during the fall period. A comparison of the seasonal data showed that there was only a slight variation in the production of Chlorophyll b in the Outfall Bay, closely followed by very impressive production levels in the Recovery Zones. Chlorophyll c was the highest in June. Recovery zones showed higher values in the surface and bottom layers during June. Phaeophytin was detected only during February, March, May, June and August. The surface water values remained the highest at Stations I, II and III during winter and at Stations IV and V during the summer. The data on chlorophyll pigments showed that the standing crop of phytoplankton remained impressive during most of the seasons. The trend of recovery of chlorophyll was very fast in the recovery zones and it even surpassed the production in the Intake Bay and Open Sea on an annual basis.

3.2 Plankton

3.2.1 Biomass

Settling volume and dry weight of plankton are considered as a reliable measure of planktonic biomass production. The monthly values for plankton biomass by volume showed wide fluctuation during the course of one annual cycle. When the station-wise incidence of plankton was examined it was seen that the peak value for the fall and the spring was noticed at Station V, that for winter was noticed at Station IV and that for summer was seen at Station I. The dry weight of plankton showed wide and irregular variations within sites and at the different sites. When the settling volume and the dry weight trend was compared it was seen that both the parameters showed relatively higher values during the spring and the summer seasons. A previous observation during 1995 in the same region showed that both values were higher during the winter season. This is indicative of a inter-annual variation which is part of the natural biological cycle in the sea.

3.2.2 Phytoplankton Abundance and Distribution

The relative abundance of phytoplankton during the present study was impressive. Seasonal variation in the density of phytoplankton is given in Table 1. The phytoplankton in the present study was composed of three classes of marine algae, namely the Bacillariophyceae, the Pyrrophyceae and the Cyanophyceae.

Bacillariophyceae formed the largest group in the annual cycle. Phyrrophyceae was highest at Station V followed by Station IV. Cyanophyceae was maximum at Station III, the Outfall Bay.

The Bacillariophyceae was represented by 12 species of phytoplankton. They belonged to four families under the order Centrales and two families under the order Pennales. Class Pyrrophyceae consisted of order Prorocentrales and order Dinophysiales represented by one genus each and order Peridiniales represented by four genera. Class Cyanophyceae was represented by the Genus Trichodesmium Ehrenberg. Species abundance was richest at Station II followed by Stations III and IV. When the species abundance was compared, there was practically no difference between the open sea ambient conditions and the Outfall Bay indicating that the overall species composition was not affected by the discharge of effluents in the sea.

Out of 28 species of phytoplankton, 21 species occurred at Station I, 23 at Station II, 22 at Station III and 22 at Station IV indicating that the relative incidences was normal within the range of normal variabilities expected in natural ecosystems. The total phytoplankton population in the Jubail sea did not show signs of stress. An in depth study at the community level is needed to understand the ecosystem level effects from a long-term perspective. Seasonal variation in the density and distribution of 12 major genera of phytoplankton was examined in greater detail. Seasonally, summer was the most favorable time for the presence of Lauderia, Rhizosolenia, Chaetoceros, Bacteriastrum, Navicula, Nitzschia, Protoperidinium, Gonyaulax and Ceratium. Lauderia sp. occurred at all stations and in all seasons. The whole year percentage abundance of Rhizosolenia sp was the highest at Station I and lowest at Station III. The incidence of chaetoceros sp. was confined almost wholly to the summer season. The annual station-wise percentage abundance of Bacteriastrum sp. was the highest percentage in the Open Sea and the lowest in the Outfall Bay, with density staying low at the Recovery Zone. When the total incidence was examined, 68% of the population occurred during the summer. Biddulphia sp. showed their presence at all the sites. The population of Navicula sp. at different stations was very low. Navicula sp. appeared in abundance when the sample was rich with Lauderia sp., Rhizosolenia sp. and Chaetoceros sp. Like Navicula sp., Nitzschia sp. also was low in abundance. About 80% of the total population occurred at Station V, showing the highest abundance. The data show that the ecological parameters like temperature and conductivity did not act as a limiting factor for the incidence of phytoplankton in the Outfall Bay and the Recovery Zones. The suspended solids in the seawater also did not affect the abundance and variation of phytoplankton.

3.3 Zooplankton Composition and distribution

Zooplankton in the sample was composed of ten Phyla, namely, Protozoa, Coelenterata, Ctenophora, Aschelminthes, Chaetognatha, Annelida, Arthropoda, Mollusca, Echinodermata and Chordata. Arthropoda represented the largest assemblage of zooplankton (39.34%) followed by Chordata (37.22%) and Protozoa (11.72%). Chaetognatha formed the smallest component in the collection. Coelenterata consisting of the Jellyfish formed 7.41% of the total zooplankton. Representatives of all the phyla occurred at all stations and at all times of the year. Data on zooplankton population at the level of the Phyla are given in Table 2. The station-wise density of zooplankton phyla is given in Table 3. In terms of population, Station I was the richest zone followed by Station III, the Outfall Bay. Protozoa was present at all the study sites throughout the year. The population was very rich in the outfall bay during winter (Table 3). The whole year abundance in the Jubail Sea was the highest during the summer and the lowest during the fall. Largest abundance was seen at the Intake Bay. Tintinnida formed the most abundant protozoa during the summer and the Intake Bay appeared to be the richest site for their incidence. Coelenterata was represented by medusae and jellyfish. The annual abundance of medusae was highest during the summer (76%) and lowest during the fall (0.1%). Jellyfish was poorly represented during the current year of study. Arthropoda consisting of Cladocera, Copepoda and larvae formed the largest zooplankton community in the Jubail Sea. Crustacean larvae occurred very sparsely in the samples at all the stations and in all seasons. It is remarkable to note that 87% of it occurred during summer. Station III represented 90% of the total larvae in their incidence. The fact that the larval incidence in the Intake Bay was very low indicates the absence of any major macrofouling problem in the plant during 1997-98 from the settlement of Balanus, the well known crustacean biofouler. The absence of crustacean larvae indicates that the area was not a rich habitat for shrimps in the Gulf during 1997-98. This could be the reason for poor shrimp catches during the year, a concern that is discussed by the fishing industry in the Kingdom. The distribution of Mollusca showed that their incidence was maximum at Station III and minimum at Station II. Their occurrence being sporadic and density being very low, they did not appear to have caused any major macrofouling problem in the intake structures, or further in-stream in the plant. Mollusca in the collections was composed of larval bivalves or juveniles of them having a temporary planktonic stage. Larvaceae, commonly called Appendicularia formed a major component of zooplankton. Fish eggs were regularly present at all the Stations indicating that the breeding activity of the fish fauna in the region was very much normal.

4. DISCUSSION

Ocean is the cradle of life. Until recently, it was considered that man couldn't change the ocean and the delicate web of food chain that supports its biodiversity. These views are no longer tenable. Changes have taken place all over the world, more especially in the coastal waters pausing serious risk of loss of species, food chain changes and consequent changes in fish stock and other exploitable living resources. The present study is part of a long term plan to monitor the marine ecosystems bordering Saudi Arabia.

4.1 Chlorophyll Production Vis-à-vis Plant Operations

Chlorophyll is a unique parameter that influences the primary productivity of aquatic ecosystems. The present investigation has covered all the contrasting situations adjacent to a desalination plant throughout its operation for one annual cycle and it was seen that the sea was very productive. The sea being generally shallow, the photosynthetic production of chlorophyll occurred at impressive levels both in the surface and bottom water. The present range of values was greater than those reported from the same area for the years, 1989-90, 1990-91 and 1995. Among the various pigments, the active pigments in plankton production are Chlorophyll a and Phaeophytin. In the present study, phaeophytin occurred in its greatest abundance. The recovery zone of the outfall location was more productive than the other sites. Planktonic blooms were observed in the region of Station VI, ahead of the Ras Al-Ghar sea wall. The production of Chlorophyll a was 5.15, Chlorophyll b 6.71 Chlorophyll c 8.28 and Phaephytin 9.37 mg/m^3 in the recovery zone during the summer season. The phenomenon of planktonic blooms deserves to be investigated further. A chlorophyll production of 5 to 20 mg/m^3

have been reported from the upwelling waters of Oman [19]. In the mixed central and shallow water zones of the Arabian Gulf, it ranged from 0.2 to 0.86 mg/m^3 [20].

4.2 Status of Plankton Community

4.2.1 Seasonal/Inter-Annual Variation of Phytoplankton

Planktonic organisms have been recognized as indicators of water masses and their movements [21]. They were also used as indicators of past and present structure and function of plankton communities and as simple models for pelagic ecosystems [22]. It is also reported that the coastal zone throughout the Western Arabian Gulf coast is already exposed to major conflicts on resource utilization [9]. A taxonomic study of the Diatom flora in the Jubail coastal water was carried out during 1989-91 [12]. A total of 89 Taxa of phytoplankton consisting of 48 diatoms and 41 dinoflegellates were observed then. A population increase of 25 to 25% was seen during 1990-91 compared to the year 1989-90. During both the years phytoplankton was maximum during the summer. The numerical abundance of phytoplankton noticed during 1995 indicated the possibility of planktonic blooms resulting in the occurrence of the “Red Tide ” phenomenon in the region [3]. During the present study 28 species of phytoplankton were observed. Planktonic blooms were seen in the sea during May and August 1998. The population density of phytoplankton showed that the highest production was seen at Station V, in the recovery area and the lowest in the Intake Bay. During a previous study, the Intake Bay was characterized by higher phytoplankton abundance [8]. When the incidence of major groups of phytoplankton was compared with earlier data, it was seen that the composition remained the same, and Bacillariophyceae ranked first in abundance. The data available now show that there is inter-annual variation in the production of phytoplankton biomass and in the relative abundance of major components on a spatio-temporal scale. The cascading discharge, the mixing and the dilution facilitated by the outfall breakwater wall and the input of nutrient from the nearby housing units could be attributed as the reason for the relatively faster recovery of phytoplankton production in the recovery zones. In terms of species, the overall species composition was not found to be affected by the plant discharge. Whether some of the variations noticed in the region is part of the natural phenomenon in the region or is induced by other cause needs further investigation.

4.2.2 Distribution and Biofouling Potential of Zooplankton

Information on the zooplankton of the Arabian Gulf is few and far between [10,12-14]. Variations in plankton species were observed in different habitats such as saline lagoons, sheltered bays, shallow exposed coastal waters and offshore open waters in the Saudi Arabian Gulf Coast [10]. Offshore zooplankton community was found to be more diverse as compared to near shore and interior bays. Penaeid larval depletion was reported in the aftermath of the 1991 Gulf War. The Saudi Fishery Company had reported a 1% decline in shrimp production along the Saudi Waters, after the Gulf War [23] with the commercial prawn fishery suffering a loss to the tune of about 55 million US Dollars, due to reduction in the spawning stock size of penaeid shrimps. The above studies stress the need for close monitoring of the plankton and fish resources of Saudi Arabian Gulf coast. The only data on zooplankton available from the area is the study carried out by Abdul Azis, et al. [3]. Whereas representatives of only 5 phyla were encountered then, there were ten phyla represented during the present study. The Intake Bay was the richest among the five stations for zooplankton incidence. The protozoan community noticed now was similar to the community of 1995 in terms of composition. Although Tintinnida are widely regarded as environmentally sensitive, their population was the largest in the protozoan community at all the stations studied. Coelenterata, which did not appear in 1995, made their appearance during the current year. The period of present study witnessed the incidence of Jellyfish several times in the Intake Bay. However, Jellyfish incidence did not become a major problem at the intake. Nematoda made their first appearance during the current year. Polychaeta was represented largely by their larval stages, which are only temporarily planktonic. In the adult stage, they colonize the benthic habitat and also occur among biofouling communities. Although Cladocera, Copepoda and Cirripedia occurred during the 1995 study, only the first two groups occurred now. Cirripedia, the larvae of barnacles, a most hardy and feared biofouler, was absent in the current collections. To the Plant, this has meant a drastic reduction in the biofouling potential of the feed seawater. The incidence of Copepoda at Station III and their absence in the recovery zone point to the possibility of a delayed impact of brine discharge in the sea. Whereas pteropods and bivalve molluscs appeared during 1995, gastropods and bivalve molluscs appeared during the present study. The members of the molluscan community in the plankton were mostly larval stages or juveniles drifted by currents and waves prevalent in the sea. The larvae are active associates in any biofouling assemblage. However, the lower density diminished their role as biofoulers. Only Larvaceae (Appendicularia) represented Chordata during 1995. During the current year, besides the above, the community was composed of Thaliaceae, fish eggs and larvae. They occurred in large numbers during summer.

4.3 Process-related Changes on the Marine Biotic Resources

Process-related effects attributable to entrapment, entrainment and impingement have been reported from different industrial situations [24]. This study has brought out a greater understanding of the changes experienced by biotic components of the sea associated with intake structures and processes related to the passage of water through the cooling and discharge circuits. The changes observed were categorized in the above manner as impingement, entrainment, and entrapment effects. Many of the effects, singly or in combination could be observed during the present study. A beneficial effect of embayment was seen in the marginal increase of chlorophyll production in the Intake Bay during winter and spring and a negative effect of substantial depletion during summer when compared with the open sea. The water after passing through the plant structures go out without the usual concentration of dissolved oxygen. The flow of discharged brine through a cascading discharge channel replenished oxygen and led to higher production of chlorophyll pigments in the Outfall Bay which otherwise would have been very low if the discharge was a direct coastal one. The embayment effect was positive with respect to dry weight biomass of plankton during the fall and summer seasons and negative during spring. The impingement and entrainment effect in the Outfall Bay was more during the fall and summer periods. A decrease in diatoms, dinoflagellates and blue-green algae was seen in the Intake Bay as compared to the open sea. The entrapment, impingement and entrainment effects were noticeable in the Outfall Bay in relation to the Open Sea and the Intake Bay for these phytoplankton groups. Whereas the total population of zooplankton showed a 55 per cent increase in the Intake Bay compared to open sea, the increase was 382 per cent for Protozoa, 6 per cent for Annelida, 37 percent for Arthropoda, 68 per cent for Chordata, 9 per cent for Appendicularia and 10 per cent for fish eggs. The stream of current that flows into the Intake Bay brings in an extra load of the passively floating plankton into the Bay. Many groups flourish while others perish. This was an observation similar to the one noticed during 1995 [3]. These variations were found to be closely related to various ecological factors such as temperature, salinity and pH in the bay. There was increase in the production of phytoplakton and many zooplankton groups, particularly the Coelenterata, Aschelminthes, Annelida, Mollusca, Appendicularia and fish eggs prompting the thinking that the ecological characteristics in the Outfall Bay did not cause any significant decline in abundance of these groups.

It may be noted that in any seawater based industrial systems, a certain amount of organisms get trapped due to impingement, entrapment and entrainment and since most of the phytoplankton and zooplankton can produce rapid replacement generations within a matter of hours the potential of natural restoration and rehabilitation in the sea was observed to be pretty good at Al-Jubail. The present study showed that the Recovery zones 1 and 2, lying away from the Outfall Bay showed rapid recovery and restoration of populations. From a regulatory and ecological angle, the situation in the immediate mixing bay, remained perfectly satisfactory and acceptable, since the area is too small to affect coastal living resources of the adjacent sea. A regular monitoring of the marine sites and quantification of the fauna, however are needed for keeping track of changes potentially caused by effluent discharges.

4.4 Potential Ecological Effects

Ecological effects of desalination discharges were reported from a desalination plant in Florida where the effects were confined to the point of immediate direct discharge [25]. Mortality of plankton, benthos and fishes noticed in discharge zones attributed to the thermal pollution and elevated salt concentration brought about by the discharges of warm brine. Acute toxicity at the ecosystem level would happen only when sudden discharges of concentrate with unusual levels of temperature, salinity, metal ions, etc., are made into the sea. It is redeeming to find that the 1.8 km long discharge channel which permits enormous mixing and dilution with its cascading type of flow into the sea, has, in the case of most of the parameters normalised the discharge before it reaches the open sea. The Outfall Bay has been found to serve remarkably well in avoiding all form of acute ecological effects.

Practically no information is available on the cumulative long-term effect of brine disposal from the desalination plant sites in the region. Desalination activity has been cited as a major environmental pressure on the Arabian Gulf ecosystem [26].

According to a report from Abu Dhabi, This rise has been ascribed to the disposal of brine from the desalination plants in the Arabian Gulf coast [4]. Mickley [27] has drawn attention to the possible cumulative effects of long-term exposure to desalination discharges in a particular site. Ecologists have noticed changes in the species composition, shifting of spawning seasons and reduction in the spawning stock size of prawns due to environmental stress in many oceanic regions. The cumulative long-term effect on receiving water bodies and their biodiversity need to be studied in different parts of Arabian Gulf on a priority basis.

5. CONCLUSIONS AND RECOMMENDATIONS

The Arabian Gulf is a regional sea with immense strategic and economic value and is unique in many oceanographic and biological characteristics. The present study was carried out as part of a long-term plan of SWCC (Saline Water Conversion Corporation) to monitor the sea adjacent to its desalination and power plants in the Kingdom of Saudi Arabia. The data on chlorophyll pigments and plankton indicated that the sea adjacent to the Al-Jubail Desalination and Power Plants was very productive. The values for chlorophyll production obtained now were higher than the ranges previously reported from the Gulf. Twenty eight species of phytoplankton were present and the planktonic blooms that occurred during May and August did not affect the operation of the plant. The discharge from the plant did not affect the overall species composition of phytoplankton. The zooplankton community was composed of ten taxonomic groups and the diversity was richer than that previously observed in the region. Although, the incidence of jellyfish was observed several times, it did not become a major problem at the intake. Representatives of plankton such as the larvae of polychaetes and bivalves, having a potential to cause biofouling in plant structures, were very low in density. The study has thrown much light on the changes experienced by biotic components of the sea associated with intake structures and processes related to the passage of water through the cooling and discharge circuits of the plant and it has been found that the variations were purely temporary. As most of the planktonic organisms have rapid reproductive cycles, the biological status of the intake and discharge sites remained largely rich and stable. The study has brought out an enormous data base on chlorophyll and plankton. It is recommended that the biodiversity of the region may be studied in greater detail and for a longer period of times. Issues of biological concern such as planktonic blooms, jellyfish influx, occurrence of macrofouling larvae and variation ion the species diversity should be examined in greater depth and on a continuous basis.

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Table 1: Seasonal Variation in the Density of phytoplankton (Cells/m³) in the Sea during 1997-1998

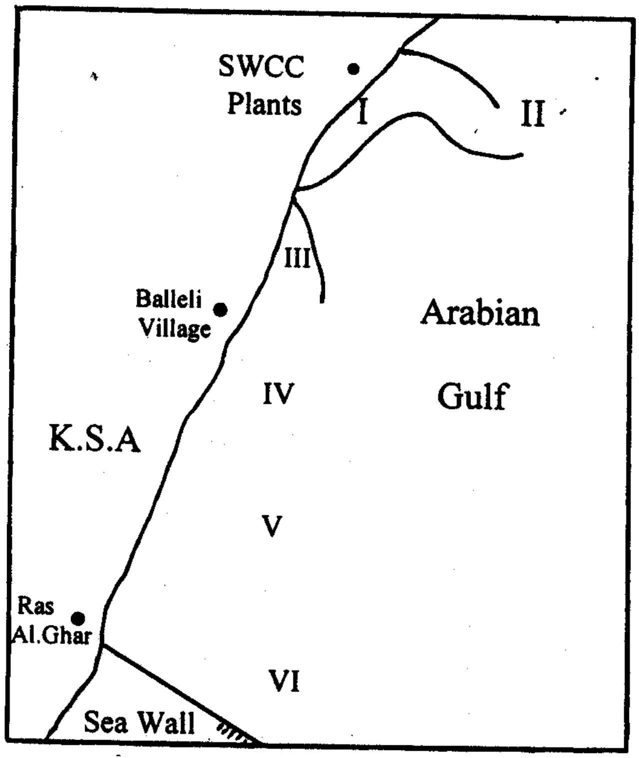
Class	Seasons	Sites St. I Intake Bay	St. II Open Sea	St. III Outfall Bay	St.IV Recovery Zone 1	St.V Recovery Zone 2
Bacillariophyceae (Yellow-green algae	Fall	1.53E+07	2.18E+07	1.17E+07	1.21E+07	1.21E+07
or Diatom)	Winter	1.01E+05	2.86E+05	1.41E+05	1.32E+05	1.21E+05
	Spring	3.26E+05	3.98E+06	1.52E+05	1.63E+05	1.16E+07
	Summer	4.25E+07	2.81E+07	1.75E+07	2.02E+07	7.25E+07
Station wise percentage		21.50	20.00	10.89	12.04	35.57
Pyrrophceae (Dinoflagellates)	Fall	3.25E+05	7.30E+05	2.09E+05	3.95E+05	1.00E+08
	Winter	2.45E+04	3.11E+05	2.85E+03	6.03E+03	3.14E+04
	Spring	5.95E+04	5.46E+04	1.69E+04	9.30E+03	6.12E+03
	Summer	1.66E+05	1.77E+05	1.19E+05	2.24E+05	1.00E+08
Station wise percentage		0.28	0.63	0.17	0.31	98.61
Cyanophyceae (Blyuw-green algae)	Fall	5.70E+04	1.40E+04	6.24E+04	2.04E+05	1.80E+04
	Winter	2.93E+04	1.72E+04	6.40E+02	8.27E+04	7.21E+03
	Spring	2.47E+05	1.35E+06	2.29E+02	1.63E+06	5.79E+06
	Summer	1.70E+05	5.49E+05	4.75E+04	7.24E+04	1.37E+05
Station wise percentage		4.80	18.41	1.06	18.97	56.77

Table 2 : Variation in Zooplankton population (no/m³) in the Jubail Sea (Arabian Gulf) during 1997-1998

Phylum	Sites St. I Intake Bay	St. II Open Sea	St. III Outfall Bay	St.IV Recovery Zone 1	St.V Recovery Zone 2
Protozoa	111760	23180	73700	46280	82660
Coelenterata	28560	34420	53020	48240	66680
Ctenophora	-	-	-	3300	-
Aschelminthes	8430	22100	13620	18260	8900
Chaetognatha	-	510	180	-	-
Annelida	190	180	1690	3220	-
Arthropoda	303440	221150	271680	205300	224840
Mollusca	1600	6220	4860	14240	2470
Echinodermata	-	2500	2080	520	-
Chordata	365550	217000	184190	186650	206860
Total	819530	527260	605020	526010	592410

Table 3 : Seasonal Variation in the Density (no/m³) of Zooplankton Phyla in the Sea during 1997-98

Zooplankton Phyla/Seasons	St. I Intake Bay	St. II Open Sea	St. III Outfall Bay	St.IV Recovery Zone1	St.V Recovery Zone2
1. Protozoa					
Fall	9580	6520	3060	-	840
Winter	3400	3000	10200	3500	5940
Spring	8460	6860	2400	12680	10000
Summer	56080	6800	20780	19200	31680
2. Coelenterata					
Fall	-	-	180	-	-
Winter	-	-	-	10500	-
Spring	3700	3180	8600	9340	6920
Summer	24860	9080	27680	18000	45060
3. Ctenophora					
Fall	_	_	_	_	_
Winter	_	_	_	_	_
Spring	_	_	_	500	_
Summer	_	_	_	2800	_
4. Aschelminthes					
Fall	540	360	-	-	-
Winter	-	200	2000	2	-
Spring	2110	4180	3440	3840	5000
Summer	5780	15560	8180	14400	3900
5. Annelida					
Fall	190	180	540	-	-
Winter	-	-	100	20	-
Spring	-	-	2200	-	-
Summer	-	-	14060	3200	-
6. Mollusca					
Fall	360	720	180	-	-
Winter	-	4000	-	-	1980
Spring	1100	1500	2380	3840	-
Summer	140	-	2300	-	-
7. Arthropoda					
Fall	12080	13240	15840	8820	420
Winter	78200	56130	14980	31720	55440
Spring	72380	32040	47560	39560	8840
Summer	107660	80960	160180	83600	86640
8. Echinodermata					
Fall	-	-	360	420	-
Winter	-	2000	-	100	-
Spring	-	500	1720	-	-
Summer	-	-	-	-	-
9. Chordata					
Fall	5050	5190	3960	420	420
Winter	141320	36030	8200	21030	19800
Spring	33680	45800	30130	42400	13840
Summer	141340	102280	117060	86400	123800



Study Sites: Arabian Gulf between lat. 26 °52 and 26 ° 55 N and between Long. 49° 45 and 49°52E.
(Map adapted from Admiralty Chart No. 3788 (1986).