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EFFECT OF SODA ASH INDUSTRY EFFLUENT ON SEAWEED EPIPHYTIC AND AMBIENT FAUNA IN *IN SITU* CONDITION IN NORTHWEST COAST OF INDIA

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ABSTRACT

The soda ash industry effluent has significantly reduced the species diversity of epiphytic fauna and planktonic fauna of seawater, their numerical density, fresh and dry weight, total number of groups and group diversity as compared to control. However, the reverse trend was shown by benthos. Therefore, considerable degradation in the water quality of seawater as well as epiphytic and planktonic fauna has been observed due to discharge of effluent. Some of the species of epiphytic fauna were specific to effluent affected as well as control sites. The epiphytic molluscan larvae and fish eggs were observed only from effluent affected and control sites respectively. Quite a number of species showed host specificity under effluent affected as well as control conditions. The maximum numerical density on seaweeds under effluent affected and control conditions was shown by Copepods and Foraminiferans respectively. Most of the species of seawater zooplankton as well as benthos from effluent affected as well as control sites were also present as epiphytic forms on different seaweeds. The epiphytic fauna contained significantly higher number of groups and species diversity compared to zooplanktonic and benthic fauna. The Decapods were observed only in benthos whereas Cladocerans, Coelenterate larvae, Cyclopoids, Ostracods and Molluscan larvae were found only in epiphytic fauna. In general, most of the physicochemical parameters of effluent, diluted effluent as well as effluent affected seawaters were many magnitude to considerably high as compared to control seawater. However, magnesium in effluent as well as sulphate and phosphate in the effluent affected seawater showed reverse trend. In general, the effluent has significantly affected the species diversity and biomass production of epiphytic and planktonic fauna. The reduction in growth of epiphytic fauna and zooplankton in the effluent affected region is inhibited due to high concentration of different salts present in effluent affected seawater. However, such salts promoted growth and species diversity of benthos.

INTRODUCTION

The macro and meiofauna as well as seaweeds are important link in the marine food web. The relation of the phytal fauna with the seaweeds is very diverse. The seaweeds can be looked upon as the feeding and breeding ground for a multitude animal life. Apart from providing shelter from current and waves and predators, the ecological advantages of the seaweed regions as a breeding habitat and feeding ground for young and juvenile fish have been emphasized (Fuse 1962a,b, Mukai 1971). The seaweed regions provide an abundant oxygen for a variety of animals. The small epiphytic algae including diatoms and the detritus material deposited on algae provide food for a number of animals. Many are known to feed on the algae itself while others depend on the rich particulate matter composed of detritus and microscopic organisms in the water when the algae are submerged. The significance and productive potentialities of phytal macrofauna in the littoral system are increasingly realized because of the ease with which the predators can find them, their high nutrient value and high turnover rates. In seaweed regions the phytal animals contribute more than the benthic animals towards fish production (Mukai 1971).

The pollution caused by the soda ash industry effluent may seriously affect or alter the above said relationship adversely. The literature search including search through internet has not yielded any published literature on the effect of soda ash industry effluent on the fate of seaweed epiphytic fauna and other fauna growing in effluent affected seawater. However, the effect of complex effluent like domestic sewage on the epiphytic fauna of seaweeds is reported (Smith 2000). Sufficient literature is available for the intertidal epiphytic fauna of seaweeds from India (Sarma & Ganapati 1973, Sarma 1974a,b, Sarma et al. 1981, Rao et al. 1982 and Muralikrishnamurty 1983) and from other parts of the world (Colman 1940, Wieser 1952, Hagerman 1966, Jansson 1967, Mukai 1971, Gunnil 1982, Edgar 1983, Stoner 1985, Taylor 1998 and Brooks & Bell 2001). These authors have not considered ambient fauna inhabiting seawater, sediment and rock surfaces, although such organisms may affect quality and quantity of epiphytic fauna. The soda ash industry near the study site manufactures soda ash by Solvay process. It produces 40300 tons of dense soda ash and 16350 tons of sodium bicarbonate per annum. In this process it generates 1,70,000 m^3 effluent per day. The effluent is mainly composed of calcium chloride, calcium oxide, sodium chloride, ammonia, calcium carbonate and iron and aluminium oxides (Personal communication with industry authorities). The discharge of such effluent might have significant impact on the epiphytic and other ambient fauna. Therefore, it was thought desirable to study the effect of such effluent on the species diversity, numerical abundance, biomass and ecology of epiphytic, benthic and adjoining seawater fauna.

MATERIALS AND METHODS

The soda ash industry effluent is being discharged in the coastal waters at lat. 21°39'N, long. 69°38'E. The effluent is discharged at 220m away from the highest high water mark by submarine pipeline. The seaweeds grow luxuriantly in this area. The control site is situated at lat. 21°39'N, long. 70°47'E. This area is free from any anthropogenic pollution (Fig. 1). Seaweed samples were collected from the rocky intertidal region of both the stations during lowest low tide of December 2003 when seaweed growth is luxuriant. In the present study different species of seaweeds, belonging to green, red and brown algae, were sampled based on their luxuriant growth/abundance from both the stations (Table 1). One kilogram of each species of seaweed was collected in triplicate from both the stations and transferred into separate plastic containers. The seaweed samples were preserved with 5% formalin in 1:2 ratio of seaweed/formalin solution and kept overnight. The epiphytic fauna from the preserved seaweed samples were separated by vigorously shaking 1 kg of seaweed with 10 litres of filtered seawater for 10 minutes on a rotary shaker and the resultant seawater was filtered through 62µm sieve. The same seaweed was used another two times with another 10 litres filtered seawater at each time to separate attached fauna by above process. The fauna, retained on the sieve at each time, were pooled together and preserved in 150 mL of 4% formalin with seawater. The epiphytic fauna from each species of seaweed were separated like this. The numerical density and biomass of epiphytic fauna were expressed per 100 g wet weight of fresh alga.

The benthos samples were also collected from the region where the seaweed were sampled for epiphytic fauna. To estimate the benthic fauna, sediment samples were collected by using Van Veen grab. The benthic macro and meiofauna were separated by sieving the sediment samples through 500µm and 63µm mesh sieve respectively. The epiphytic macro and meiofauna were also separated like this. The numerical density and biomass of benthos were expressed per m^2 of the sea bottom. The seawater samples were also collected during high tide from both the stations and their physico-chemical parameters and zooplankton density and biomass were analyzed. The undiluted effluent was col-

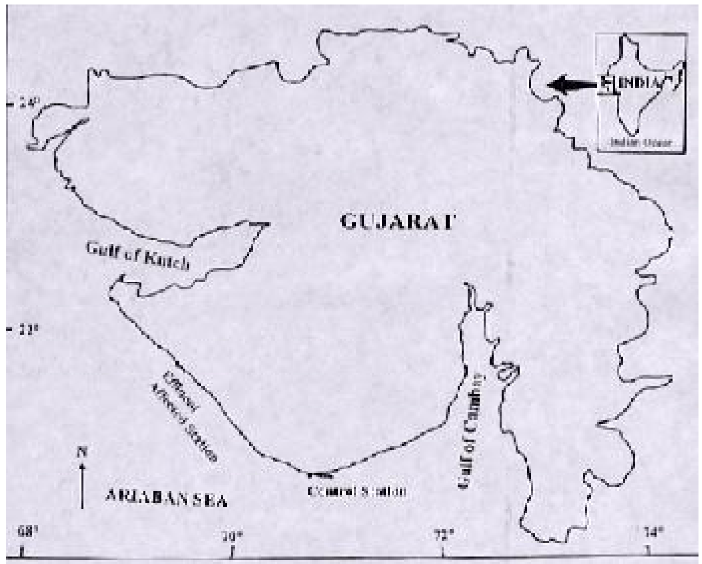

Fig. 1. Map showing sampling stations.

lected from the factory while the diluted effluent (diluted with seawater to meet effluent discharge norms of the Pollution Control Board) was collected from open cement concrete channel before it enters the submarine pipeline. Sodium and potassium were estimated by flame photometer (Model Evans Electro Selenium, EEL) whereas calcium, magnesium, chloride and sulphate were estimated by the methods given by Mendham et al. (2002). The carbonate, bicarbonate and hydroxide were determined by the method described by Scott (1952). The total dissolved solids and COD were estimated by the standard methods (Clesceri et al. 1998a,b). The specific gravity was determined by specific gravity bottle method. All other remaining parameters were determined as per methods described earlier (Tewari et al. 2001).

All the fauna belonging to epiphytic, zooplanktonic and benthic groups were identified at species level by using standard manual and book (Santhanam & Srinivasan 1993, Apte 1998). The species diversity of fauna was calculated according to the Shannon-Weaver (1949) formula.

RESULTS AND DISCUSSION

The results on enumeration of different species of epiphytic fauna were recorded from 20 species of seaweeds from the effluent affected as well as control sites. Sixty three species of epiphytic fauna were recorded from effluent affected as well as control sites. The effluent affected seaweeds had 25.40% species of epiphytic fauna, while contrary to this 22.22% species were recorded only from control site ($p < 0.01$). However, 52.38% species of epiphytic fauna were common to both effluent affected as well as control sites. ***Amhistegina lessonii, Bolivina abbreviata, Gigacuma halei, Globigerinoides ruber, Metis juossemei, Neoconorbina crustata,*** Mysid larva of ***Penaeus indicus, Quinqueloculina seminulum, Q. oblonga, Q. reticulata, Rosalina globularis, Spirillina lateseptata, S. limbata, Triloculina rotunda*** and Veliger larva were recorded only from effluent affected sites. Probably these species are resistant to soda ash industry effluent. The species of ***Cyclogyra involvens, Cymbaloporetta squammosa, Discarbis parisiensis,*** Fish egg, ***Longipedia coronata, Loxostomum*** *limbatum, L. limbatum* var. constulatus, *L. rostrum, L. truncatum, Nannocalanus minor,* Nauplii, *Quinqueloculina lamarckiana* and *Triloculina planciana* were recorded only from control site. *Caulerpa recemosa, Padina gymnospora, Sargassum tenerrimum* and *Cystoseira indica* were recorded from both the effluent affected and control sites. These species harboured 21.74, 54.17, 7.69 and 17.64% respectively less epiphytic fauna at effluent affected site as compared to control site. *Ulva* from effluent affected site contained 27.77% less fauna as compared to control site ($p < 0.01$).

Some species of epiphytic fauna showed host specificity. The *Bovilina abbreviata, Metis juossemei*, Mysid larva of *Penaeus indicus*, *Quinqueloculina seminulum, Q. oblonga, Q. reticulata* and Veliger larva showed host specificity as they were found growing at effluent affected site only on *Hypnea valentiae, Gracilaria corticata, Scinia hatei, Sargassum tenerrimum, H. valentiae, H. valentiae* and *Iyengaria stellata* respectively. Similarly, *Cyclogyra involvens, Cymbaloporetta squammosa, Discarbis parisiensis, Longipedia coronata, Gavilinopsis praegeri, Loxostomum limbatum, L. rostrum, L. truncatum, Nannocalanus minor, Quinqueloculina lamarckiana* and *Triloculina planciana* also showed host specificity from control site as they were found growing only on *Dictyota dichotoma, Acrosiphonia orientalis, Caulerpa recemosa, Cladophora prolifera, D. dichotoma, Ceramium rubrum, A. orientalis, Ulva fasciata, D. dichotoma, Cystoseira indica* and *Padina gymnospora* respectively. Other species of epiphytic fauna did not show host specificity. The number of host specific epiphytic fauna in the effluent affected area were 41.67% less as compared to control site (Table 1). The species diversity of epiphytic fauna on *Caulerpa recemosa, Cystoseira indica, Padina gymnospora* and *Sargassum tenerrimum* were significantly less in the effluent affected condition as compared to control. The species diversity of these four species were 82.18, 20.31, 83.41 and 31.82% less respectively in the effluent affected condition as compared to control. However, *Ulva* at generic level showed reverse trend as the diversity was 4.17% more under effluent affected condition than control. The mean species diversity of epiphytic fauna on different seaweeds under the effluent affected site was 45.34% less as compared to control site ($p < 0.01$, Table 1).

The effect of soda ash industry effluent on the numerical density of different groups of epiphytic fauna is depicted in Table 2. The maximum numerical density (97.34%) in effluent affected area was shown by Copepods on *Sargassum tenerriumum* followed by Foraminiferans (94.74%) on *Padina gymnospora*. The least numerical density (0.60%) was shown by Annelid larvae and Ostracods on *Hypnea valentiae* followed by Amphipods (0.75%) on *Spatoglossum asperum*. The maximum numerical density (90.60%) from control site was shown by Foraminiferans on *Cladophora prolifera* followed by again Foraminiferans (88.82%) on *Ceramium rubrum*. The least numerical density from control site was shown by Gastropods and Polychaetes (0.43% each) on *Cladophora prolifera* followed by Crustacean larva and Polychaetes (0.46% each) on *Caulerpa recemosa*. In general, higher numerical density of groups of epiphytic fauna were observed from effluent affected region as compared to control site.

The total number of groups of organisms on four common species of seaweeds indicated that the total number of groups on these seaweeds were significantly more on the algae growing in control sites as compared to effluent affected site (Table 2). The *Ulva* at generic level also showed similar trend of variation as total number of groups were 60% more at control site as compared to effluent affected site. The maximum number of groups (11) from the effluent affected site was observed on *Iyengaria stellata.* In contrast to this, significantly higher total number of groups (13) were observed on control site *Cystoseira indica*, *Dictyota dichotoma* and *Sargassum tenerrimum* ($p < 0.01$). The least number of groups (3) were observed on *Scinia hatei* and *Sargassum tenerrium* from effluent

Table 1: Occurrence and species diversity of epiphytic fauna on different seaweeds.

Seaweed species	Effluent affected station*	Species diversity	Control station*	Species diversity
Green algae				
Acrosiphonia orientalis (J. Agardh) P. Silva	-	- 53,61	2,4,6,7,8,10,11,14,15, 16,18,19,20,25,31,35, 31,35,36,39,45,49.52, 8.928	
Caulerpa recemosa (Forskal) J. Agardh	1,4,6,8,10,13,16,36,38,42, 45,49, 51,52,54,56,57,61	1.472	2,4,6,7,8,12,13,14, 19,20,28,29,33,36, 38,42,49,50, 52,53,56,57,62	8.268
Caulerpa prolifera (Roth) Kutzing	-	-	2,4,6,7,8,13,16,19,21, 22,31,36,37,39,41,42, 45,49,50,53,56,57,61	4.986
Enteromorpha compressa (Linnaeus) Nees	2,8,10,13,16,18,20,36,38, 50,51,53,54,56,57	3.364	-	-
Ulva fasciata De lile	-	-	2,4,6,7,8,13,14,16,20, 26,31,33,36,42,45,50,61	2.470
Ulva lactuca Linnaes	4,6,7,8,13,19,29,36,41,45, 49,50,53	2.573	-	-
Velonia aegagropila C. Agardh	-	-	4,7,8,13,16,19,20,24,31, 36,39,41,45,53,61	3.621
Red algae				
Amphiroa anceps (Lamarck) Decaisne	-	-	6,7,8,15,16,20,31,36,39, 45,49,50,52,53,61	2.672
Ceramium rubrum Auclorum	-	-	2,4,6,7,8,10,16,19,23, 31,36,39,45,49,50	2.442
Gelidiopsis intricata (C. Agardh) Vickers	-	-	2,6,7,8,15,19,20,31,36, 39,42,45,50,52,53,61	1.838
Gracilaria corticata (C. Agardh) J. Agardh	4,6,20,21,27,28, 30,36,45,49,51, 52,53	2.094	-	-
Grateloupia filicina (Lamouroux) C. Agardh	-	-	2,7,8,20,27,35,36,39, 49,50,53,61	1.536
Hypnea valentiae (Turner) Montagne	2,4,5,6,8,13,16,20,29, 31,36,39,41,42,47,48,49,50, 51,53,54,55,58,60,61	1.978	-	-
Scinia hatei Borgesen	20,27,35,39,40,61	0.594	-	-
Brown algae				
Cystoseira indica (Thivy & Doshi) Mairh	2,4,8,16,17,19,28,31,34,36, 38,49,51,52,53,61	2.891	4,16,18,19,20,24,31,33, 35,38,43,45,52,53	3.628
Dictyota dichotoma	-	-	4,8,9,5,16,19,20,32,35, 39,46,50,53,61	3.966
Iyengaria stellata (Borgesen) Borgesen	2,4,6,8,13,14,16,20,31,36, 38,39,42,45,49,50,51,53, 54,61,62,63	1.783	-	-
Padina gymnospora (Kutzing) Sonder	2,19,20,28,31,36,49,50, 53,54,60	1.369	2,4,6,7,8,13,14,16,19, 20,21,24,31,35,36,39, 43,45,49,50,53,59,61	8.251

Table cont...

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Sargassum tenerrimum	2,3,6,13,16,18,31,34,36,		4,15,16,18,20,31,33,42,	
(J. Agardh)	44,45,51	2.316	43,45,52,53,61	3.397
Spatoglossum asperum (J. Agardh)	1,2,3,6,8,17,18,20,28,31, 36,37,42,43,45,49,51,5, 53,54,57,61	4.067	-	-
Mean Species diversity		2.227		4.074

- absent

*Species names for the corresponding numbers mentioned in Table 1

1.	*Amhistegenia madagascariensis* d' Orbigny	33.	Nauplii
2.	*Amhistegina lessoni* d' Orbigny	34.	*Neoconorbina crustata* (Cushman)
3.	Amphipod egg	35.	*Neries versicloar*
4.	Bivalve juvenile	36.	*Nonion depressulum*(Walker and Jacob)
5.	*Bolivina abbreviata* Heron-Allen and Earland	37.	*Ocypoda macrocera*
6.	*Calcarina calcar* d' Orbigny	38.	*Paracalanus parvas*
7.	*Cibicides lobatulus* (Walker & Jacob)	39.	*Parathemisto* sp.
8.	*Conchoecia indica*	40.	*Penaeus indicus* - mysid stage
9.	*Cyclogyra involvens* (Ruess)	41.	*Planorbulina mediterranensis* d' Orbigny
10.	*Cymbaloporetta bradyi* (Cushman)	42.	Planula larva of Coelenterate *Aurilia auritta*
11.	*Cymbaloporetta squammosa* (d' Orbigny)	43.	*Quinqueloculina crassa* d'Orbigny var. subcuneata Cushman
12.	*Discarbis parisiensis* (d' Orbigny)		
13.	*Elphidium crispum* (Linne)	44.	*Quinqueloculina seminulum* (Linne')
14.	*Evadne tergestina*	45.	*Quniqueloculina agglutinate* Cushman
15.	Fish egg	46.	*Quniqueloculina cuvieriana* d'Orbigny
16.	Gastropod juvenile	47.	*Quniqueloculina oblonga* (Montagu)
17.	Gigacuma halei	48.	*Quniqueloculina reticulata* (d'Orbigny)
18.	*Globigerinoides ruber* (d'Orbigny)	49.	*Quniqueloculina rhodiensis* Parker
19.	*Globigerinoides sacculifer* (d'Orbigny)	50.	*Rosalina bradyi* (Cushman)
20.	*Hyperia medusarum*	51.	*Rosalina globularis* d'Orbigny
21.	*Littorina scabra* Linne	52.	*Sapphirina nigromaculata*
22.	*Longipedia coronata*	53.	Setiger larva
23.	*Loxostomum limbatum*(Brady)	54.	*Spirillina lateseptata* Terquem
24.	*Loxostomum limbatum var. constulatus* (Cushman)	55.	*Spirillina limbata* Brady var. denticulata Brady
25.	*Loxostomum rostrum* Cushman	56.	*Spirillina limbata* Cushman var. papillosa Brady
26.	*Loxostomum truncatum* Phleger and Parker	57.	Strobila larva of coelentrate *Aurilia aurita*
27.	*Lumbrineries* sp.	58.	*Temora discaudata*
28.	*Macrosetella gracilis*	59.	*Triloculina planciana* d'Orbigny
29.	*Metacalanus aurivilli*	60.	*Triloculina rotunda* d'Orbigny
30.	*Metis juossemei*	61.	Tubiculous polychaete
31.	*Microsetella gracilis*	62.	*Turbo coronata* Gmelin
32.	*Nannocalanus minor*	63.	Veliger larva

affected site while from control site the *Grateloupia filicina* contained least number of groups (5). The average total number of groups at effluent affected site were 64.40% less as compared to control site. The fish eggs were observed on 53.84% species of algae from control site only whereas molluscan larvae were observed only on *Enteromorpha compressa* and *Iyengaria stellata* from effluent affected site.

The numerical density, fresh weight and dry weight of epiphytic fauna on different species of seaweeds are shown in Table 3. The numerical density ranged from 3850 on *Scinia hatei* to 22140 individuals 100/g of *Spatoglossum asperum* in the effluent affected site. Similar results for control

Table 2: Group-wise numerical density (%) of epiphytic fauna in the effluent affected seawater.

Station/Seaweed species	Amphipod	Annelid larvae	Bivalve	Cladocerans	Coelenterate larvae	Copepods	Crustacean larvae	Cyclpoids	Fish eggs	Foraminiferans	Gastropods	Molluscan larvae	Ostracods	Polychaetes
Effluent affected Station														
Caulerpa recemosa	-	-	1.79	-	2.69	0.89	-	0.89	-	91.07	0.89	-	0.89	0.89
Enteromorpha compressa	-	9.30	-	-	13.85	-	3.57	-	-	69.02	-	1.56	-	2.70
Ulva lactuca	-	1.05	2.10	-	6.32	1.05	-	-	-	83.16	-	-	6.32	-
Gracilaria corticata	4.04	5.05	1.01	-	-	3.03	-	3.03	-	83.84	-	-	-	-
Hypnea valentiae	7.23	0.60	3.61	-	4.82	2.42	-	0.60	-	71.08	7.83	-	0.60	1.21
Scinia hatei	37.14	-	-	-	11.43	-	-	-	-	-	-	-	-	51.43
Cystoseira indica	0.88	1.77	-	-	-	7.96	-	0.88	-	80.55	3.54	-	0.88	3.54
Iyengaria stellata	20.28	2.70	1.35	2.70	1.35	8.11	-	-	-	54.05	5.41	1.35	1.35	1.35
Padina gymnospora	0.88	0.88	-	-	-	3.50	-	-	-	94.74	-	-	-	-
Sargassum tenerrimum	-	-	-	-	-	97.34	-	-	-	0.88	1.78	-	-	-
Spatoglossum asperum	0.75	2.22	-	-	5.19	2.22	-	2.22	-	84.44	-	-	1.48	1.48
Control Station														
Caulerpa recemosa	2.29	0.92	0.92	0.92	0.92	2.75	0.46	4.58	-	78.90	3.67	-	3.21	0.46
Cladophora prolifera	2.57	1.71	0.85	-	0.85	1.71	-	-	-	90.60	0.43	-	0.85	0.43
Acrosiphonia orientalis	4.88	2.44	1.62	1.62	-	1.62	-	2.44	1.63	69.11	2.44	-	9.76	2.44
Velonia aegagropila	23.12	2.15	1.08	-	-	1.08	1.08	-	-	69.34	-	-	1.61	0.54
Amphiroa anceps	16.95	1.69	3.39	-	1.69	1.69	-	1.69	1.69	45.76	20.34	-	3.39	1.69
Ceramium rubrum	3.12	-	1.24	-	-	2.48	-	-	-	88.82	2.48	-	1.86	-
Gelidiopsis filicina	13.43	5.97	-	-	1.49	2.99	-	1.49	1.49	49.25	17.91	-	2.99	2.99
Grateloupia filicina	22.50	5.00	-	-	-	-	-	-	-	55.00	-	-	2.50	15.00
Cystoseira indica	4.65	3.72	5.58	1.40	3.26	3.26	1.40	0.93	3.26	42.79	13.94	-	5.58	10.23
Dictyota dichotoma	9.42	5.13	2.99	2.56	3.42	2.56	0.85	0.85	2.56	42.74	8.97	-	5.98	11.97
Padina gymnospora	10.21	0.68	2.04	0.68	2.04	0.68	-	1.36	-	58.50	18.36	-	4.08	1.37
Sargassum tenerrimum	8.42	4.95	7.92	1.98	3.47	2.48	2.48	0.99	4.46	34.65	13.85	-	6.43	7.92
Ulva fasciata	10.43	-	1.74	0.87	0.86	1.74	0.86	12.17	0.87	61.74	4.38	-	3.48	0.86

- absent

site ranged from 8069 on *Grateloupia filicina* to 77440 individuals 100/g on *Acroshiponia orientalis*. The fresh and dry weight of epiphytic fauna from effluent affected site ranged from 963 (215 mg dry wt.) on *Scinia hatei* to 5327 (1895 mg dry wt.) 100/g on *Enteromorpha compressa* whereas on control site it varied from 1518 (517mg dry wt.) on *Grateloupia filicina* to 14785 (4415mg dry wt.) 100/g on *A. orientalis*. The numerical density, fresh and dry weight of epiphytic fauna were significantly more at control site as compared to effluent affected site ($p < 0.01$). However, the numerical density and fresh weight of epiphytic fauna on species of *Ulva* were more at effluent affected site as compared to control site. The average numerical density, and fresh and dry weights of epiphytic fauna on seaweeds from the effluent affected site were 39.69, 38.81 and 42.61% respectively less as compared to control site.

The results on numerical density, biomass availability and species diversity of zooplankton and benthos in the seawater and sediments of seaweed growing regions of the study sites are presented in Table 4. The numerical density, fresh weight, dry weight and total number of species of planktonic fauna of seawater were significantly less in the effluent affected region as compared to control site ($p < 0.01$). However, these parameters for benthos showed reverse trend. The numerical density, fresh weight, dry weight and total number of planktonic fauna of the seawater in the effluent affected region

Table 3: Numerical density and biomass of epiphytic fauna on different species of seaweeds.

Seaweed species	Effluent affected station			Control station		
	Numerical density (No./100g)	Fresh weight (mg/100g)	Dry weight (mg/100g)	Numerical density (No./100g)	Fresh weight (mg/100g)	Dry weight (mg/100g)
Green algae						
Acrosiphonia orientalis	-	-	-	77440	14785	4415
Caulerpa recemosa	6048	1238	426	69760	13289	4327
Caulerpa prolifera				29250	6121	2515
Enteromorpha compressa	21815	5327	1895	-	-	-
Ulva fasciata	-	-	-	12190	2812	992
Ulva lactuca	16150	3786	985			
Velonia aegagropila	-	-	-	23250	5517	1926
Red algae						
Amphiroa anceps	-	-	-	15340	3982	1037
Ceramium rubrum	-	-	-	12880	3620	1028
Gelidiopsis intricate	-	-	-	8375	1712	618
Gracilaria corticata	11880	3238	1215	-	-	-
Grateloupia filicina	-	-	-	8069	1518	517
Hypnea valentiae	8500	1576	628	-	-	-
Scinia hatei	3850	963	215	-	-	-
Brown algae						
Cystoseira indica	15820	3480	1218	26230	5522	1928
Dictyota dichotoma	-	-	-	28548	6237	2618
Iyengaria stellata	7095	1320	446	-	-	-
Padina gymnospora	7296	1487	521	66150	12915	4389
Sargassum tenerrimum	14690	3498	1367	25250	5317	1988
Spatoglossum asperum	22140	4458	1288	-	-	-
Mean	12298.55	2488.27	927.64	30979.38	6411.08	2176.77

- absent

were 32.29, 19.94, 37.33 and 12.50% less as compared to control site. However, for benthos these four parameters were 34.45, 23.97, 30.48 and 11.11% more in the effluent affected region as compared to control site.

Twenty five species of zooplankton and benthos were recorded from seawater and sediment from both the study sites. This comprised of 13 species of zooplankton, 23 species of benthos and 7 species those common to seawater and sediments. The *Calcarina calcar* and *Nonion depressulum* were dominant and subdominant zooplankton (30.77 and 23.07% respectively) in the effluent affected region while *Amhistegina lessonii* and Gastropod juvenile and *Nonion depressulum* were dominant and sub dominant zooplankton (35.00 and 20.00% each respectively) in the control site. The percentage composition of *Cibicides refulgens, Elphidium crispum, Hyperia medusarum* and *Nannocalanus minor* were least (7.69% each) in the overall composition of zooplankton in effluent affected site while the least value (5.00% each) for control site was exhibited by Crustacean larva, *Cyclogyra involvens*, fish eggs, *Microsetella gracilis* and Veliger larva.

The species composition of zooplankton of seawater in the effluent affected and control sites was characteristically different. Out of 13 species of zooplankton, *Calcarina calcar, Cibicides refulgens, Elphidium crispum, Hyperia medusarum* and *Nannocalanus minor* were recorded only from effluent affected site while Crustacean larva, *Cyclogyra involvens*, fish eggs, *Microsetella gracilis*, Gastropod juvenile and Setiger larva were recorded only from control site. The *Amhistegina lessonii* and *Nonion depressulum* were recorded from both the study sites. The species diversity of zooplankton in seawater in the effluent affected region was 30.86% less as compared to control condition (Table 4).

The *Neries versicolar* and Tubiculous polychaete were dominant (22.22%) and subdominant (14.44%) species of benthos respectively in the effluent affected region while *Elphidium crispum* and *Amhistegina lessonii* and bivalve juvenile were dominant (20.35%) and subdominant (18.64% each) in the control area. The least abundance in the effluent affected and control site regions were exhibited by *Cyclogyra involvens*, *Elphidium crispum*, *Globigerina globularis*, *Quinqueloculina rhodiens* and *Rosalina bradyi* (1.11% each) and *G. globularis*, *Microsetella gracilis*, Nauplii, *Neries versicolar*, *Q. agglutinata*, *Q. parkeri*, *R. globularis* and Setiger larva (1.69% each) respectively.

Twenty three species of benthos were recorded from effluent affected as well as control sites. The *Cyclogyra involvens*, fish eggs, *Globigerinoides sacculifer*, *Hyperia medusarum*, *Lumbrineries* spp., *Ocypoda macrocera* and *Q. rhodiens* were recorded only from effluent affected site while *M. gracilis*, Nauplii, *Q. agglutinata*, *Q. parkeri* and Setiger larva were recorded only at control site. Eleven species were common to both the study areas. The species diversity of benthos in the effluent affected region showed reverse trend in comparison to zooplankton of seawater. The species diversity of benthos in the effluent affected region was 45.25% more as compared to control site (Table 4).

The zooplankton and benthos were characterized by presence of 10 groups each in the effluent affected and control sites. Bivalve and Amphipod groups of zooplankton were found only from effluent affected site while Crustacean larva, fish eggs, Gastropod and Annelid larvae were recorded only from control site. The Foraminiferans and Copepods were common to both the sites. In the benthos group, Bivalves and Decapods were found only in effluent affected site while Copepods, Crustacean larvae and Annelid larvae were recorded only form control site. Foraminiferans, Gastropods and Polychaetes were common to both the sites.

Twenty species of zooplankton and benthos were observed from seawater and sediment from the effluent affected region whereas 49 species of epiphytic fauna were recorded from different seaweeds

Table 4: Numerical density, biomass and species diversity of zooplankton and benthos.

	Zooplankton		Benthos	
	Effluent affected	Control	Effluent affected	Control
Numerical density	3250 No./m^3	4800 No./m^3	4072 No./m^2	2669 No./m^2
Fresh weight	927mg/m^3	1156mg/m^3	8.231g/m^2	6.258g/m^2
Dry weight	235mg/m^3	375mg/m^3	2.526g/m^2	1.756g/m^2
Species/group (%)				
Amphipods				
Hyperia medusarum	7.69	-	13.33	-
Annelids				
Setiger larva	-	5.00	-	1.69
Bivalve juvenile	-	-	12.22	18.64
Copepods				
Microsetella gracilis	-	5.00	-	1.69
Nannocalanus minor	7.69	-	-	-
Crustaceans				
Crustacean larva	-	5.00	-	-
Nauplii	-	-	-	1.69
Decapods				
Ocypoda macrocera	-	-	2.22	-
Foraminiferans				
Amhistegina lessonii	15.38	35.00	3.33	18.64
Calcarina calcar	30.77	-	3.33	3.40
Cibicides refulgens	7.69	-	-	-
Cyclogyra involvens	-	5.00	1.11	-
Elphidium crispum	7.69	-	1.11	20.35
Globigerina globularis	-	-	1.11	1.69
Globigerinoides sacculifer	-	-	5.58	-
Nonion depressulum	23.09	20.00	6.68	10.18
Quinqueloculina agglutinate	-	-	-	1.69
Quinqueloculina parkeri	-	-	-	1.69
Quinqueloulina rhodiens	-	-	1.11	
Rosalina bradyi	-	-	1.11	1.69
Rosalina globularis	-	-	2.22	1.69
Gastropods juvenile	-	20.00	3.33	10.18
Pisces				
Fish egg	-	5.00	2.22	-
Polychaetes				
Lumbrineries spp.	-	-	3.33	-
Neries versicolar	-	-	22.22	1.69
Tubiculous polychaete			14.44	3.40
Total number of species	7	8	18	16
Species diversity	0.587	0.849	1.085	0.747

- absent

from the same region. The results indicate that different seaweeds harboured 59.18% more epiphytic fauna from control site as compared to effluent affected site. All the species of zooplankton of seawater from effluent affected area except *Cibicides refulgens* were found in epiphytic form also. However, all species of zooplankton of seawater were recorded in epiphytic form from control site. All the species of benthic fauna were recorded in epiphytic form from both effluent affected as well as control sites except *Globigerina globularis* from effluent affected site as well as *Globigerina globularis* and *Quinqueloculina parkeri* from control site (Tables 1 & 4).

The epiphytic fauna was comprised of 14 groups of organisms from both effluent affected as well as control site whereas only 10 groups of organisms were found from seawater and benthos. Therefore epiphytic fauna contained more groups (28.57%) compared to zooplanktonic and benthic groups. The Decapod was observed only in benthos where as Cladoceran, Coelenterate larva, Cyclopoids, Ostracods and Molluscan larva were found only in epiphytic fauna (Tables 2 and 4). The mean species diversity of zooplankton and benthos from seawater and sediment from effluent affected area was 0.836 and for control site 0.798, whereas it was 2.227 and 4.074 respectively for the epiphytic fauna. Therefore, the species diversity of the epiphytic fauna was 62.46 and 80.41% more as compared to zooplankton and benthos respectively (Tables 1 and 4).

The data on physico-chemical characteristics of soda ash industry effluent and effluent affected seawater as well as seawater from control site in *in situ* condition are presented in Tables 5 and 6. The concentration of all the parameters except magnesium, sulphate and phosphate were many magnitudes more in soda ash industry effluent as compared to seawater of control site. The concentrations of total suspended solids, specific gravity, pH, COD and total dissolved solids in the effluent were 99.22, 6.60, 27.68, 79.09 and 79.38% more respectively as compared to seawater of control site. Similarly, the concentration of sodium, potassium, calcium and chloride were 61.81, 81.81, 98.93 and 84.00% more in the effluent than control. The concentration of sulphate in the effluent was 187.10% less than control. Magnesium and phosphate were not detected in effluent (Tables 5 and 6).

The concentration of different physico-chemical parameters of diluted effluent and seawater polluted with effluent at 250m, 1000m and 3000m away from the discharge point as well as seawater of control site are depicted in Table 6. In general, the concentration/value for total suspended solids, specific gravity, pH, COD, total dissolved solids, sodium, calcium, chloride, NH_4-N, NO_2-N and NO_3-N were more as compared to control site seawater, in diluted effluent and effluent affected seawater at 250, 1000 and 3000m away from effluent discharge point. The concentration of these parameters followed the trend: diluted effluent > seawater at 250m > seawater at 1000m > seawater at 3000m away. The values of sulphate and phosphate in these 4 types of samples were always less than control. The concentration of phosphate followed the trend: diluted effluent > seawater at 250m > seawater at 1000m > seawater at 3000m away. The concentration of bicarbonate ions did not show definite trend of variation in these 4 types of samples (Table 6).

The value/concentration of total suspended solids, specific gravity, pH, COD, total dissolved solids, sodium, calcium, chloride, NH_4-N, NO_2-N, and NO_3-N were 0.52 to 87.09% more in seawater at 250m away and 0.12 to 75.00% more in seawater at 3000m away from effluent discharge point. The concentration of potassium was 28.57% more in diluted effluent as compared to control site seawater but later on it was equal to the control. The concentration of magnesium was 133.33 and 30.23% more in diluted effluent and the seawater at 250m away from discharge point. Later on it was equal to that of control. The concentration of sulphate and phosphate showed reverse trend. The former was 73.67% less while the latter was 60.66% less as compared to control in seawater at 250m away. However, these parameters in seawater at 3000m away were 11.95 and 99.71% less respectively as compared to control. The carbonate and hydroxyl ions were present in effluent but they were not detected in seawater between 250 and 3000m away (Table 5).

It is very difficult to discuss the results on the effect of soda ash industry effluent on seaweed epiphytic due to nonavailability of published literature on this topic. However, very meagre published work is available on the effect of chlor alkali industry effluent and some other industrial efflu-

Table 5: Physiochemical characteristics of soda ash industry effluent.

Parameter	Concentration	Parameter	Concentration
Temperature(°C)	92	Ca^{+2} (g/L)	37.6
Turbidity (NTU)	<1000	Mg^{+2} (g/L)	ND
Settleable solids (g/L)	306	Cl^{-} (g/L)	98.93
TSS (g/L)	0.517	SO_4^{-2} (g/L)	0.721
Specific gravity	1.0876	CO_3^{-2} (mg/L)	170
pH	11.16	OH^{-} (mg/L)	720
COD (mg/L)	41888	NH_4-N (mg/L)	9.52
TDS (g/L)	177.48	NO_2-N (µmol/L)	17.0
Na^{+} (g/L)	27.5	NO_3-N (µmol/L)	60.3
K^{+} (g/L)	2.75	PO_4-P (µmol/L)	ND

ents on marine algae (Tewari & Joshi 1998), benthos (Ahn et al. 1995) and zooplankton (Tewari et al. 2001). The present study indicates that the numerical density, fresh weight, dry weight and total number of species of zooplankton of seawater were less in the effluent affected region as compared to control (Table 4). The ship scrapping industry wastes containing different toxic heavy metals have reduced the above mentioned parameters of zooplankton (Tewari et al. 2001). The species diversity of epiphytic fauna and zooplankton of seawater have reduced due to impact of soda ash industry effluent (Tables 1 & 4). Similar reduction in species diversity of seaweeds has been reported due to impact of chlor alkali industry effluent (Tewari & Joshi 1988). It is reported that well developed broad, larger and grape like thalli of seaweeds harbour higher numerical density of epiphytic fauna. Wieser (1951, 1952) stressed that the close relation existed between number of phytal animals and specific surface of algae, which latter is represented by shape, height, consistency and degree of branching. Edgar (1983) states that small animals are more likely to be present on filamentous algae than on plants with wide thalli, while larger animals showed the opposite response. Our results do not coincide with this conclusion as broader thalli like *Sargassum tenerrimum* and *Padina gymnospora* did contain high numerical density of copepods and foraminiferans from effluent affected regions but simultaneously *Cladophora prolifera* and *Ceramium rubrum,* which have filamentous thalli that also have significantly more number of epiphytic foraminiferans (Table 2). The molluscan larvae have been observed only from effluent affected area. Probably the soda ash industry effluent is congenial for the development and growth of molluscan larvae whereas fish eggs are sensitive to this type of pollution as they were not reported from this area. The reduction in growth, number of species and species diversity of epiphytic fauna and zooplankton in the effluent affected region might be due to high concentration of different salts in effluent affected seawater while such salts promote the growth of benthos. The effect of complex inorganic wastes like ore mining, sediments and metals etc. are reported to increase or decrease in benthic fauna depending upon constituents of pollutants in such wastes (Ahn et al. 1995, Morton 1996, Harvey et al. 1998 and Raghunathan et al. 2003). However, Harvey et al. (1998) have implicated the discharge of dredged marine sediment, which results in increase in food supply to the benthic organisms. This may be one of the possible reasons for increase of benthic fauna in the effluent affected region and decrease in epiphytic fauna due to shortage of food material on the algal fronds as biomass of epiphytic fauna is much high in limited area.

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Table 6: Physio-chemical characteristics of diluted soda ash industry effluent, effluent affected and unaffected seawaters from the study sites.

Parameter	Diluted effluent	Seawater 1	Seawater 2	Seawater 3	Control
TSS (g/L)	0.318	0.034	0.019	0.016	0.004
Specific gravity	1.0253	1.0211	1.0210	1.0212	1.0158
pH	8.38	8.31	8.10	8.06	8.07
COD (mg/L)	17174	6664	11043	11043	8758
TDS (g/L)	52.58	41.00	40.80	40.20	36.58
Na^+ (g/L)	19.5	16.9	16.9	16.9	10.5
K^+ (g/L)	0.70	0.50	0.50	0.50	0.50
Ca^{+2} (g/L)	4.16	1.18	0.70	0.70	0.40
Mg^{+2} (g/L)	0.48	0.86	1.16	1.12	1.12
Cl^- (g/L)	24.70	18.20	18.19	18.19	15.82
SO_4^{-2} (g/L)	2.162	1.919	1.849	1.809	2.070
HCO_3^{-2} (mg/L)	213	183	549	366	183
NH_4-N (µmol/L)	8.82	2.27	2.59	0.39	1.23
NO_2-N (µmol/L)	5.30	2.67	2.66	1.08	2.09
NO_3-N (µmol/L)	10.43	3.06	3.05	2.16	2.98
PO_4-P (µmol/L)	1.95	1.5	1.30	0.85	2.41

Seawater 1 = 250m away from effluent discharge point; Seawater 2 = 1000m away from effluent discharge point; Seawater 3 = 3000m away from effluent discharge point

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