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Correlation of phytoplankton density with certain hydrological parameters along the coastal waters of Veraval, Gujarat

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Original Article

Abstract

The present study was conducted to study the biological diversity of phytoplankton and the impact of abiotic factors on them along coastal waters at two locations *viz.*, Location-1 (Jaleshwar) and Location-2 (Sagareshwar Mandir), Veraval from May 2012 to April 2013. Six classes of marine phytoplankton were identified from these locations. Out of the total 162 species of marine phytoplankton collected, nine could not be identified. Diatoms were the dominant group (133 spp.) followed by dianoflagellates (12 spp.), blue-green algae, brown or orange chromatophores and green algae. The correlation between the density of phytoplankton with the environmental variables *viz.*, Dissolved Oxygen and pH were significantly positive, whereas it was inversely correlated with temperature and salinity. The density of phytoplankton, ranged from 4,90,495 to 8,57,160 cells L^{-1} and 3,87,495 to 8,65,665 cells L^{-1} at Location-1 and Location-2 respectively. Phytoplankton cell count was the highest and lowest in January and March respectively and the diversity was higher in winter than other seasons. The diversity of marine phytoplankton was very high along the coastal waters of Veraval (at both the locations of study) which confirms that the Veraval coastline is very productive and supportive for fish production and also for other marine biodiversity.

Keywords: *Phytoplankton, abiotic factors, seasonal variation, density, Veraval coast*

Introduction

The plankton is the microscopic plant life of the sea and inland waters, which constitute the major primary producers of aquatic ecosystems. Usually, most of them are at the mercy of oceanic currents for their transport to areas that are suitable for their survival and growth (Dawes, 1998; Sandifer *et al.*, 1980). Marine phytoplankton mostly constitutes microscopic and unicellular plants. Diatoms and dinoflagellates commonly predominate in them. Phytoplankton often also includes a numerous and diverse collection of extremely small, motile plants collectively termed as microflagellates.

Growth and productivity of phytoplankton are affected by several physico-chemical factors *viz.*, light, temperature, circulation, grazing and nutrients (Dardeau *et al.*, 1992). Amongst them, variations in salinity affect the rate of their production. They are known to grow well in salinities of 20-30 ppt while diatoms prefer salinity greater than 35 ppt. In the inshore marine environments, sudden decrease in temperature and salinity are associated with the higher availability of nutrients favoring the phytoplankton production. Seasonal changes are comparatively less in the marine systems of tropical waters, but brief growth increments occur (Qasim *et al.*, 1972). Primary production in the Arabian Sea is

amongst the highest in the world because of the semi annual reversals of monsoons (Luis and Kawamura, 2004). The present study gives qualitative and quantitative distribution of phytoplankton, as this information forms the database on the biodiversity and production of phytoplankton species of coastal water bodies of Veraval, Gujarat.

Material and methods

Study sites

The present study was conducted along the coastal waters of Veraval, which is situated along the western coast of Gujarat, India. Observations were made for one year i.e., from May 2012 to April 2013. For the collection of samples, Jaleshwar (Location 1) and Sagareshwar Mandir (Location 2) sites of Veraval (Fig.1) were selected. Samplings were done at fortnightly intervals. The substratum of Location-1 is sandy while that of Location-2 is rocky. The intertidal belt is not uniform and the exposure of rocky shore is not significantly long. The intertidal zone covers a distance of about 60-90 m during spring tides (Vaghela and Khundu, 2012).

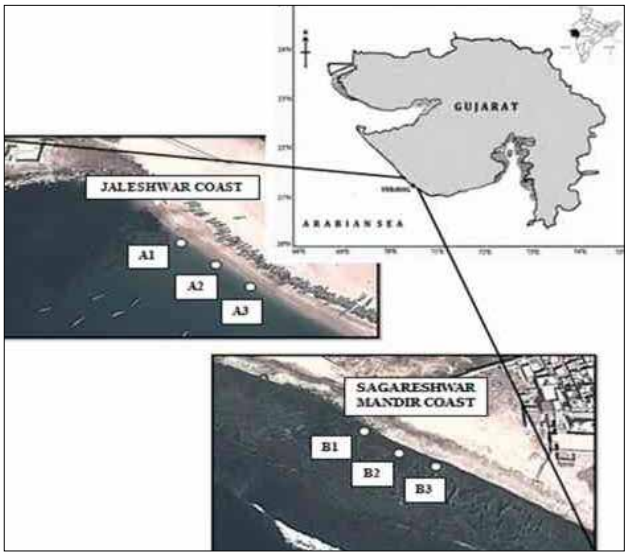

Fig.1. Map of the Veraval coast with the different sampling stations (A1, A2, A3, B1, B2 and B3), Location-1 (Jaleshwar coast) and Location-2 (Sagareshwar Mandir coast)

Sampling procedure and laboratory analyses

Test sieve method was followed for the collection of phytoplankton samples from the selected locations. Fifty litres of water was filtered through sieve unit from all the three sites of both the locations for collecting the phytoplankton samples separately. In the test sieve method, sieves consisting of four different mesh sizes i.e., 37, 53, 125 and 250 μ were used. Plankton samples were collected by filtering the seawater through the horizontally arranged sieve set. The concentrate of water samples containing phytoplankton were collected from the last two sieves (i.e., 53 and 37 μ sized sieves) and they were stored separately in labeled glass bottles adjusting the volume to 50 ml.; such samples were considered as stock sample (1000 dilution).

The collected samples were preserved in 1% Lugols-Iodine solution, in order to avoid damage by bacterial action and autolysis, within 5 min. (2-3 drops) of collection (Harnstorm *et al.*, 2009; Manna *et al.*, 2010; Redekar and Wagh, 2000; Chandy *et al.*, 1991; Baytut *et al.*, 2010). The qualitative analysis and quantitative enumeration was carried out using a Sedgwick-Rafter counting chamber under Stereo Zoom Microscope (Model no.: DCM 130; USB 2.0; Resolution 1.3 Mega pixels). The identification and confirmation of the taxonomic status of the phytoplankton were done using Smith (1977), Isamu (1979) and Santhanan *et al.* (1987). Data on the quality of water (physico-chemical factors) such as temperature (º C), pH, salinity (ppt) and DO (mg l^{-1}) level were recorded at the time of phytoplankton sample collection. Multi-parameter PCSTestr (35 series) was used for the collection of data on temperature and pH, whereas DO meter (DO600) and refract meter (APHA, 1998) were used for dissolved oxygen and water salinity respectively. Abiotic factors were recorded during the sampling time.

Results and discussion

Physical characteristics of sampling locations

Veraval is situated along the Saurashtra coast of Gujarat, India. The substratum of Veraval coast is mainly rocky with a few sandy patches. There is steep vertical decline towards subtidal zone at the lower littoral zone.

Phytoplankton composition and seasonal variation

Six major classes of marine phytoplankton were recorded during the present study. Bacillariophyceae (Diatoms), Pyrrophyceae (Dinoflagellates), Cyanophyceae (Blue-green algae), Chlorophyceae (Green algae) and Chrysophyceae (Blue or Orange Chromatophores; Fig. 2). The community of phytoplankton observed was dominated by Diatoms. Out of the 153 marine phytoplankton species identified (with 9 unidentified), 48 genera (133 species) were of Diatoms. Centrales were represented by 23 genera constituting 70 species and whereas that of Pennales by 25 genera having 63 species (Table 1).

Dinophyceae or Pyrrophyceae (Dinoflagellates) was represented by six genera with 12 species. The six genera

Table 1. Phytoplankton recorded along Veraval coast (May 2012 - April 2013)

Sr No	Species	Stn. 1	Stn. 2	Sr No	Species	Stn. 1	Stn. 2
	Bacillariophyceae (Diatoms)						
1	*Achnanthes* sp.	+	+	81	*N. striata*	+	+
2	*Amphiprora* sp.	+	+	82	*N. vietra*	+	+
3	*A. gigantiea*	+	+	83	*Odontella* sp.	+	+
4	*Amphora* sp.	+	+	84	*O. aurita*	+	+
5	*A. coastata*	+	+	85	*O. granulata*	+	+
6	*A. lineolata*	+	+	86	*O. mobiliensis*	+	+
7	*Arachnoidiscus ornatus*	+	+	87	*O. obtusa*	+	+
8	*Asterionella japonica*	+	+	88	*O. pulchella*	+	+
9	*Bacillaria paradoxa*	+	+	89	*O. rhombus*	+	+
10	*Bacteriastrum hyalinum*	+	+	90	*O. sinensis*	+	+
11	*B. varians*	+	+	91	*Planktoniella sol*	+	+
12	*Camplyloneis* sp.	+	+	92	*Pleurosigma* sp. 1	+	+
13	*Campylodiscus* sp.	+	+	93	*Pleurosigma* sp. 2	+	+
14	*Campylosira* sp.	+	+	94	*P. aestuarii*	+	+
15	*Cheatoceros* sp.	+	+	95	*P. affine*	+	+
16	*C. affinis*	+	+	96	*P. elongatum*	+	+
17	*C. brevis*	+	+	97	*P. galapagense*	+	+
18	*C. curvisetus*	+	+	98	*P. normanii*	+	+
19	*C. decipiens*	+	+	99	*P. rectum*	+	+
20	*C. decipiens forma singularis*	+	+	100	*P. rigidum*	+	+
21	*C. didymus var anglica*	+		101	*P. angulatum*	+	+
22	*C. diversus*	+	+	102	*Podosira* sp.	+	+
23	*C. laevis*	+		103	*Pseudonitzschia* sp.	+	+
24	*C. lorenzianus*	+	+	104	*Rhabdonema* sp.	+	+
25	*C. pendulus*	+	+	105	*R. adriatium*	+	+
26	*C. peruvianus*	+	+	106	*R. punctatum*	+	+
27	*C. subsecundus*	+	+	107	*Rhizosolenia alata*		+
28	*Climacosphenia* sp.	+	+	108	*R. alata forma indica*	+	+
29	*Climacosphenia moniligera*	+	+	109	*R. crassispina*	+	+
30	*Climacodium frauenfeldianum*	+		110	*R. delicatula*	+	+
31	*Cocconeis* sp.	+	+	111	*R. hebatata var semispina*	+	+
32	*C. placentula*	+	+	112	*R. setigera*	+	+
33	*Coscinodiscus* sp.	+	+	113	*R. stolterforthii*	+	+
34	*C. anguste-lineatus*	+	+	114	*Skeletonema coastatum*	+	+
35	*C. asteromphais*	+	+	115	*Stephanopyrix nipponica*	+	
36	*C. excentricus*	+	+	116	*S. palmeriana*	+	+
37	*C. nitidus*	+	+	117	*Streptotheca thamensis*	+	+
38	*C. nudulifer*	+	+	118	*Striatella unipunctata*	+	
39	*C. oculus iridis*	+	+	119	*Surirella* sp.		+
40	*C. subtilis*	+	+	120	*Synedra formosa*	+	+
41	*Cymbella* sp.	+	+	121	*Thalassionema nitzschioides*	+	+
42	*C. marina*	+	+	122	*Thalassiosira* sp.	+	+
43	*Diploneis* sp.		+	123	*T. condensata*	+	+
44	*D. fusca*	+	+	124	*T. hyalina*	+	+

45	*D. fusca var pelagica*	+	+	125	*T. subtilis*	+	+
46	*D. splendida*	+	+	126	*Thalassiothrix frauenfeldii*	+	+
47	*Ditylum* sp.	+	+	127	*T. longissima*	+	+
48	*D. brightwellii*	+	+	128	*Triceratium* sp. 1	+	+
49	*D. sol*	+	+	129	*Triceratium* sp. 2	+	+
50	*Eucampia* sp.	+	+	130	*T. arcticum*	+	+
51	*Gossleriella tropica*	+	+	131	*T. favus*	+	+
52	*Grammatophora marina*	+	+	132	*T. impar*	+	+
53	*Guinardia* sp.	+	+	133	*T. reticulum*	+	+
54	*Gyrosigma accuminatum*	+	+		Dinophyceae (Dianoflagellates)		
55	*G. fasciola*	+	+	134	*Ceratium belone*	+	+
56	*G. spencerii*	+	+	135	*C. furca*	+	+
57	*Hemiaulus* sp.	+	+	136	*C. tripos*		+
58	*Hyalodiscus stelliger*	+	+	137	*Dinophysis homunculus*	+	+
59	*Lauderia borealis*	+	+	138	*Gonyaulax* sp.	+	+
60	*Leptocylindrus danicus*	+	+	139	*G. polygramma*	+	+
61	*Licmophora abbreviata*	+	+	140	*Peridinium claudicans*	+	+
62	*L. flabellata*	+	+	141	*P. inflatum*	+	+
63	*Melosira* sp.	+	+	142	*P. oceanicum*	+	+
64	*M. juergensi*	+	+	143	*P. pentagonum*	+	+
65	*M. molyniformis*	+	+	144	*Protoperidinium* sp.	+	+
66	*M. nummuloides*	+	+	145	*Pyrocystis fusiformis*	+	+
67	*Navicula* sp. 1	+	+		Cyanophyceae	(Blue-green Algae)	
68	*Navicula* sp. 2	+	+	146	*Oscillatoria* sp.	+	+
69	*Navicula* sp. 3	+	+	147	*Pelagothrix clevei*	+	+
70	*Navicula* sp. 4	+	+	148	*Spirulina* sp.	+	+
71	*N. longa*	+	+	149	*Trichodesmium* sp.	+	+
72	*Nitzschia* sp.	+	+	159	*T. erythraeum*	+	+
73	*N. cloasterium*	+	+		Chlorophyceae (Green Algae)		
74	*N. frigida*	+	+	160	*Halospaera viridis*	+	
75	*N. lanceolata*	+	+		Chrysophyceae (Brown or Orange Chromatophore)		
76	*N. longissima*	+	+	161	*Distephanus* sp.	+	+
77	*N. pungens*	+	+	162	*Mesocena polymorpha*	+	+
78	*N. seriata*	+	+				
79	*N. sigma*	+	+				
80	*N. sigma var intermedia*	+	+				

that represented Pyrrophyceae (Dinoflagellates) were *Dinophysis, Ceratium, Gonyaulax, Pyrocystis, Peridinium* and Protoperidinium. Blue-green algae (Cyanophyceae) comprised of four genera *viz*., *Trichodesmium, Pelagothrix, Spirulina* and *Oscillatoria* with five species. Green algal forms (Chlorophyceae) comprised of one genera *viz*., *Halosphaera* with one species. Brown or Orange Chromatophores (Crysophyceae) were represented by only two genera *viz*., *Distephanus* and *Mesocena* comprising of two species.

The most abundant diatoms species observed were *Coscinodiscus asteromphais, C. subtilis, C. oculus iridis, Coscinodiscus* sp., *Odontella pulchella, O. mobiliensis, O. rhombus, Melosira molyniformis, Asterionella japonica, Grammatophora marina, Thalassiothrix frauenfeldii, Navicula longa, Navicula* sp., *Nitzschia lanceolata, N. seriata, Licmophora abbreviate, Pleurosigma aestuarii and P. normanii.* The composition of species was similar at Locations 1 and 2. In general, phytoplankton density was higher in winter than in summer and monsoon.

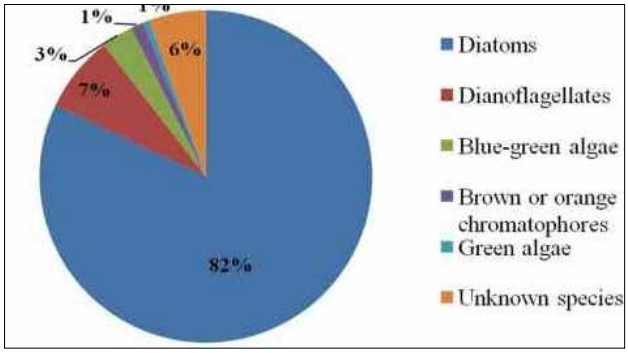

Fig.2. Phytoplankton species composition (%) at Veraval coast

Phytoplankton cell density (standing crop) was higher in winter than that in summer at both locations. At Location-1, phytoplankton cell density ranged from 4,90,495 to 8,57,160 cells L^{-1}, with the lowest count observed in May, 2012 and the highest in January, 2013. At Location-2, phytoplankton cell density ranged from 3,87,495 to 8,65,665 cells L^{-1}, with lowest count in May, 2012 and highest in January, 2013 (Table 2).

An earlier report on diatoms along Veraval coast (Bharadiya, 2008, unpublished data) has revealed the occurrence of 21 species of diatoms. Eight species amongst have been dominant *viz.*; *Coscinodiscus* sp., *Thalassiothrix longissima, Thalassionema nitzschioides, Rhizosolenia* sp., *Biddulphia* sp., *Cheatoceros* sp., *Melosira* sp. and *Nitzschia* sp. the study has also revealed that the lowest cell density during September and the highest during March. The density of diatoms has been more during summer compared to that in monsoon and winter. Temperature has been negatively correlated with diatom cell density whereas that of salinity has been positive, but poor.

Most of the species of phytoplankton reported from Kandla in the Gulf of Kachchh (Kutch), Gujarat belonged to blue-green algae (Cyanophyceae) whereas that of diatoms has been poor throughout the study (Ramamurthy and Dhawan, 1963). During another study along Gulf of Kachchh, 104 species of phytoplankton have been identified constituting 82 species of diatoms, 16 species of dinoflagellates, three species of blue-green algae and two species of green algae (Saravanakumar *et*

Table 2. Variations in mean phytoplankton density (cells ml^{-1}) at study locations of Veraval coast

Sr. No.	Months		Phytoplankton density (cells ml^{-1})					
			Location - 1			Location - 2		
			Fortnight			Fortnight		
			1st	2nd	Mean	1st	2nd	Mean
1	May 2012	Mean	461.66	519.33	490.5	03.66	471.33	387.5
		± s.d.	69.89	48.50	59.19	339.50	44.11	41.80
2	Jun. 2012	Mean	539.33	584.66	562.0	604.00	602.66	603.3
		± s.d.	7.57	61.69	34.63	33.18	26.06	30.12
3	Jul. 2012	Mean	484.00	498.33	491.2	461.00	521.00	491.0
		± s.d.	20.07	11.50	15.78	35.79	31.57	33.68
4	Aug. 2012	Mean	527.33	642.33	584.8	536.33	681.66	609.0
		± s.d.	14.57	32.74	23.65	43.00	34.01	38.51
5	Sep. 2012	Mean	495.00	608.00	551.5	567.65	632.33	600.0
		± s.d.	12.48	35.55	24.02	38.27	17.92	28.10
6	Oct. 2012	Mean	614.00	656.33	635.2	668.66	728.00	698.3
		± s.d.	9.64	24.00	16.82	11.59	25.23	18.41
7	Nov. 2012	Mean	674.00	689.33	681.7	708.66	784.33	746.5
		± s.d.	30.61	28.91	29.76	44.50	37.01	40.75
8	Dec. 2012	Mean	779.00	789.33	784.2	800.66	820.33	810.5
		± s.d.	27.87	21.54	24.71	25.57	22.89	24.23
9	Jan. 2013	Mean	849.66	864.66	857.2	855.33	876.00	865.7
		± s.d.	21.82	7.63	14.73	39.51	19.46	29.49
10	Feb. 2013	Mean	772.33	681.33	726.8	789.66	703.00	746.3
		± s.d.	10.21	11.23	10.72	6.11	16.09	11.10
11	Mar. 2013	Mean	637.00	535.00	586.0	667.66	576.33	622.0
		± s.d.	13.11	24.43	18.77	9.07	20.52	14.80
12	Apr. 2013	Mean	422.66	566.66	494.7	510.00	667.00	588.5
		± s.d.	76.17	32.59	54.38	7.54	28.47	18.01

al., 2008). Diatoms have dominated than other phytoplankton species at this study site. Along Al-Jubail (Saudi Arabia), 89 taxa of phytoplankton were observed, which comprised of eight species of diatoms and 41 species of dinoflagellates (Chandy *et al.*, 1991). They also observed that diatoms were dominant along this coast. The total number of phytoplankton collected and the number of diatoms observed were very high during the present study at Veraval coast, as compared to that from both these locations. This suggests better water quality and higher species diversity at Saurashtra coast.

With respect to the abundance of the species of phytoplankton, similar findings have been reported from Kandla in the Gulf of Kachchh, where majority of the recorded species belonged to *Coscinodiscus, Thalassiothrix, Thalassionema, Biddulphia, Nitzschia* and *Pleurosigma* (Ramamurthy and Dhawan, 1963). The density of phytoplankton in the creek waters of western mangrove of Kachchh, ranged from 2,44,500 to 94,16,667 cells L^{-1} (Saravanakumar *et al.*, 2008). However, along Sundarban estuarine ecosystem (Manna *et al.*, 2010) phytoplankton density has ranged from approximately 3,50,000 to 30,00,000 cells L^{-1}, which was very high as compared to that at Veraval and at Kachchh.

Physico-chemical parameters and phytoplankton variation

The temperature of water at the locations of study ranged from 23.32 to 30.52 °C (Table 3). It was the lowest in January and highest in June. It exhibited significant negative correlation ($p<0.05$) with phytoplankton density, pH and DO, whereas positive correlation with salinity at both the locations. There has been a strong inverse correlation between phytoplankton composition and temperature of the water collected from the Arabian Sea and from the Nova Scotian Shelf (Bouman *et al.*, 2005). In the creek waters of western mangrove of Kachchh, a place close to the present study, the water temperature has fluctuated between 21.8 and 33.5º C, which is in conformity with the present observations.

The salinity of was in the range of 34.33 ppt (July 2012) to 37.45 ppt (June 2012) (Table 4). The assemblages of phytoplankton species have revealed a significantly negative correlation between the species and salinity (Harnstrom *et al.*, 2009) at the Old Port of Mangalore. Along the shallow coastal stations at Bay of Bengal, Eastern Indian coast the total cell count of phytoplankton is reported to have a significantly positive correlation with the environmental variables *viz.*, DO and pH, whereas a negative correlation with the temperature (Choudhury and Pal, 2010). Similarly, the salinity ranged from 36.5 to 42 ppt (Saravanakumar *et al.*, 2008). This upper limit was about 4 ppt higher than that observed at Veraval. The probable reasons may be the much larger and expansive intertidal zone of Kachchh as compared to that at Veraval. However, at Old Port, Mangalore the salinity ranged from 32 to 36 ppt (Harnstrom *et al.*, 2009), indicating only negligible difference from that at Veraval. At Thondi of Palk bay (region of Tamil Nadu) the salinity ranged from 29.6 to 32.8 ppt (Muraleedharan *et al.*, 2010), which was lesser than that at Veraval; due to the higher availability of freshwater. The findings of both these studies are in conformity with that of the present investigation.

The pH of water ranged from 7.88 to 8.30 (Table 5). The monthly fluctuations of pH in the creek waters of western mangrove in Kachchh, has ranged from 7.3 to 8.4 (Saravanakumar *et al.*, 2008). At the Old Port at Mangalore (Harnstrom *et al.*, 2009), the range of pH has been from 7.78 to 7.98. The pH at Parangipettai and Coleroon, two coastal waters along the southeast coast of India, has ranged from 7.0 to 8.3 and from 7.2 to 8.3 (Rajasekar *et al.*, 2010). The pH at the Old Port Mangalore has also exhibited a similar trend to that described herein above. These findings are also in conformity with that of the present study.

The amount of DO ranged from 3.66 to 5.41 mg l^{-1}. The DO level was maximum and minimum in May and January respectively (Table 6). At the western mangrove of Kachchh also the amount of DO has ranged from 4.0 to 5.2 mg l^{-1} (Saravanakumar *et al.*, 2008), exhibiting a similar trend. This may be due to geographical proximity leading to similar climatic and largely other abiotic and biotic water quality parameters. The amount of DO at Thondi of Palk bay has ranged from 5.24 to 7.8 ml l^{-1} (Muraleedharan *et al.*, 2010), which was higher than that along Saurashtra coast. However, along the Parangipettai and Coleroon coasts, the DO content ranged from 3.1 to 7.5 and 3.1 to 7.9 mg l^{-1} respectively (Rajasekar *et al.*, 2010). At both these coasts, the lower ranges have been lower and the higher ranges have been higher than what was observed during the present study and elsewhere along the Saurashtra coast.

At both study locations diversity of marine phytoplankton was very high with diatoms form most dominant category reflecting that coastline is ecologically rich and sound that can support a large ecosystem. The present investigations on the abiotic factors *viz.*, temperature, pH and DO of marine water along Veraval coast revealed that they were significantly correlated with the density of marine phytoplankton. Changes in the biomass of phytoplankton depend on the seasons and the abiotic factors of water. Phytoplankton density attained higher levels during winter (January) than that in summer and monsoon. The higher species diversity and the biomass of phytoplankton along the Veraval coast confirmed that the water was not polluted to have any significant adverse impact on fishery.

Table 3. Variations in the mean temperature (°C) of Veraval coast

Sr. No.	Months		Mean temperature (°C)					
			Location - 1			Location - 2		
			Fortnight			Fortnight		
			1st	2nd	Mean	1st	2nd	Mean
1	May 2012	Mean	28.46	28.93	28.70	28.13	29.00	28.57
		± s.d.	0.05	0.05	0.05	0.05	0.10	0.07
2	Jun. 2012	Mean	31.00	30.03	30.52	30.83	29.36	30.10
		± s.d.	0.00	0.05	0.02	0.28	0.05	0.17
3	Jul. 2012	Mean	27.36	26.40	26.88	27.46	26.53	27.00
		± s.d.	0.11	0.00	0.05	0.11	0.05	0.08
4	Aug. 2012	Mean	25.10	27.20	26.15	25.33	26.50	25.92
		± s.d.	0.00	0.26	0.13	0.05	0.10	0.07
5	Sep. 2012	Mean	26.43	26.86	26.65	26.20	26.66	26.43
		± s.d.	0.05	0.05	0.05	0.00	0.32	0.16
6	Oct. 2012	Mean	25.66	24.73	25.20	25.86	24.70	25.28
		± s.d.	0.05	0.15	0.10	0.05	0.26	0.16
7	Nov. 2012	Mean	23.73	23.86	23.80	23.96	24.06	24.01
		± s.d.	0.11	0.05	0.08	0.20	0.05	0.13
8	Dec. 2012	Mean	23.63	23.46	23.55	23.83	23.80	23.82
		± s.d.	0.05	0.05	0.05	0.05	0.00	0.02
9	Jan. 2013	Mean	23.23	23.40	23.32	23.46	23.53	23.50
		± s.d.	0.05	0.10	0.07	0.05	0.11	0.08
10	Feb. 2013	Mean	23.10	23.83	23.47	23.33	23.73	23.53
		± s.d.	0.10	0.11	0.10	0.05	0.05	0.05
11	Mar. 2013	Mean	24.03	24.60	24.32	24.16	24.60	24.38
		± s.d.	0.01	0.03	0.02	0.15	0.10	0.12
12	Apr. 2013	Mean	25.66	25.50	25.58	26.00	26.20	26.10
		± s.d.	0.25	0.20	0.22	0.00	0.10	0.05

Table 4. Variations in the mean salinity (ppt) at Locations - 1 & 2 of Veraval coast

Sr. No.	Months		Mean salinity (PPT)					
			Location - 1			Location - 2		
			Fortnight			Fortnight		
			1st	2nd	Mean	1st	2nd	Mean
1	May 2012	Mean	36.16	36.00	36.08	36.33	36.00	36.17
		± s.d.	0.28	0.50	0.39	0.28	0.00	0.14
2	Jun. 2012	Mean	36.56	38.33	37.45	37.00	36.50	36.75
		± s.d.	0.45	0.28	0.36	0.79	0.50	0.64
3	Jul. 2012	Mean	34.16	34.66	34.41	33.83	34.83	34.33
		± s.d.	0.28	1.25	0.77	1.04	0.76	0.90
4	Aug. 2012	Mean	34.33	35.16	34.75	33.83	35.33	34.58
		± s.d.	0.28	0.28	0.28	0.76	0.28	0.52
5	Sep. 2012	Mean	34.83	35.33	35.08	33.33	35.83	34.58
		± s.d.	0.28	0.28	0.28	0.28	0.28	0.28

6	Oct. 2012	Mean	35.00	35.00	35.00	35.33	35.66	35.50
		± s.d.	0.00	0.00	0.00	0.28	0.28	0.28
7	Nov. 2012	Mean	35.00	35.33	35.17	35.16	35.66	35.41
		± s.d.	0.00	0.28	0.14	0.28	0.76	0.52
8	Dec. 2012	Mean	35.50	35.50	35.50	35.83	35.16	35.50
		± s.d.	0.50	0.50	0.50	0.28	0.28	0.28
9	Jan. 2013	Mean	35.33	35.33	35.33	35.66	35.33	35.50
		± s.d.	0.28	0.28	0.28	0.28	0.57	0.43
10	Feb. 2013	Mean	34.33	35.00	34.67	35.16	34.83	35.00
		± s.d.	1.04	0.00	0.52	0.28	0.28	
11	Mar. 2013	Mean	34.66	34.83	34.75	34.83	34.66	34.75
		± s.d.	0.28	0.28	0.28	0.28	0.28	0.28
12	Apr. 2013	Mean	35.00	35.33	35.17	34.50	35.83	34.67
		± s.d.	0.50	0.28	0.39	0.00	0.28	0.14

Table 5. Variations in the mean pH at Locations 1 & 2 of Veraval coast

Sr. No.	Months		Mean pH					
			Location - 1			Location - 2		
			Fortnight			Fortnight		
			1st	2nd	Mean	1st	2nd	Mean
1	May 2012	Mean	7.92	7.98	7.95	7.95	7.98	7.96
		± s.d.	0.01	0.02	0.02	0.02	0.03	0.02
2	Jun. 2012	Mean	7.87	8.18	8.02	8.02	8.21	8.11
		± s.d.	0.18	0.01	0.09	0.07	0.03	0.05
3	Jul. 2012	Mean	8.17	8.13	8.15	8.13	8.09	8.11
		± s.d.	0.04	0.01	0.02	0.04	0.01	0.03
4	Aug. 2012	Mean	8.12	8.11	8.11	8.14	8.12	8.13
		± s.d.	0.01	0.02	0.02	0.02	0.02	0.02
5	Sep. 2012	Mean	8.09	8.01	8.05	8.14	8.05	8.09
		± s.d.	0.02	0.04	0.03	0.04	0.04	0.04
6	Oct. 2012	Mean	8.24	8.14	8.19	8.26	8.16	8.21
		± s.d.	0.01	0.02	0.01	0.08	0.05	0.06
7	Nov. 2012	Mean	8.28	8.26	8.27	8.27	8.33	8.30
		± s.d.	0.03	0.09	0.06	0.00	0.04	0.02
8	Dec. 2012	Mean	8.13	8.02	8.07	8.22	8.11	8.16
		± s.d.	0.04	0.07	0.05	0.04	0.01	0.02
9	Jan. 2013	Mean	8.18	8.16	8.17	8.28	8.31	8.29
		± s.d.	0.05	0.07	0.06	0.07	0.02	0.04
10	Feb. 2013	Mean	8.04	8.02	8.03	8.02	8.12	8.07
		± s.d.	0.00	0.10	0.05	0.01	0.01	0.01
11	Mar. 2013	Mean	8.02	7.86	7.94	7.98	7.87	7.92
		± s.d.	0.01	0.02	0.01	0.03	0.01	0.02
12	Apr. 2013	Mean	7.87	7.89	7.88	7.88	7.88	7.88
		± s.d.	0.05	0.02	0.03	0.02	0.02	0.02

Table 6. Variations in the mean dissolved oxygen (mg L^{-1}) in marine water at Locations 1 & 2 of Veraval coast

Sr. No.	Months		Mean dissolved oxygen (mg L^{-1})					
			Location - 1			Location - 2		
			Fortnight			Fortnight		
			1st	2nd	Mean	1st	2nd	Mean
1	May 2012	Mean	3.84	4.18	4.01	3.45	3.88	3.66
		± s.d.	0.04	0.11	0.07	0.04	0.20	0.12
2	Jun. 2012	Mean	4.25	4.20	4.22	3.71	3.86	3.78
		± s.d.	0.08	0.04	0.06	0.03	0.07	0.05
3	Jul. 2012	Mean	4.20	4.18	4.19	4.58	4.20	4.39
		± s.d.	0.20	0.23	0.21	0.54	0.04	0.29
4	Aug. 2012	Mean	4.33	4.18	4.25	4.35	4.51	4.43
		± s.d.	0.22	0.21	0.22	0.18	0.05	0.12
5	Sep. 2012	Mean	4.15	4.21	4.18	4.51	4.49	4.50
		± s.d.	0.06	0.08	0.07	0.11	0.17	0.14
6	Oct. 2012	Mean	4.37	4.32	4.34	4.68	4.42	4.55
		± s.d.	0.21	0.10	0.16	0.31	0.13	0.22
7	Nov. 2012	Mean	4.20	4.28	4.24	4.33	4.39	4.36
		± s.d.	0.08	0.12	0.10	0.06	0.16	0.11
8	Dec. 2012	Mean	4.41	5.64	5.02	4.27	5.62	4.94
		± s.d.	0.20	0.13	0.17	0.07	0.26	0.16
9	Jan. 2013	Mean	5.45	5.3	5.40	5.33	5.49	5.41
		± s.d.	0.12	5 019	0.16	0.07	0.16	0.11
10	Feb. 2013	Mean	4.74	4.72	4.73	4.47	4.43	4.44
		± s.d.	0.20	0.15	0.18	0.09	0.05	0.07
11	Mar. 2013	Mean	4.49	4.42	4.46	4.40	4.52	4.45
		± s.d.	0.59	0.10	0.34	0.17	0.10	0.13
12	Apr. 2013	Mean	4.35	4.50	4.42	4.48	4.67	4.57
		± s.d.	0.23	0.30	0.26	0.03	0.23	0.13

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