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IMPACT OF THERMAL DISCHARGE FROM A JAIGAD COASTAL POWER PLANT ON PHYTOPLANKTON

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ABSTRACT

The impact of thermal effluents from Jaigad coastal power plant located at the Jaigad coast, which is a major fishing village of Ratnagiri district (Maharashtra) along the central Konkan coast of India. Impact of thermal effluent on phytoplankton was studied by field observations. Monthly boat cruises (for 9 months) were carried out to study the effects of temperature on phytoplankton. Phytoplankton and chlorophyll a decreased during the transit of water, while at mixing point the chlorophyll a values recovered significantly. It is concluded that the effect of thermal discharge from the power plant on phytoplankton in the receiving water body is quite localized and phytoplankton distribution and abundance in the coastal waters per se are not affected.

KEY WORDS : Thermal effluent, Phytoplankton, Chlorophyll a.

INTRODUCTION

One of the main uses of water in the power industry is to cool the power producing equipment. Water used for this purpose does cool the equipment, but at the same time, this results in heating up of the cooling water. Water used for power plant cooling is chemically altered for the purposes of extending the useful life of equipment and also to ensure efficient operation (Selvin *et al.* 2010). The discharged warm water from the outfall moves into the sea depending on predominant current features and mixing process. Therefore, it is necessary to study the marine impact of thermal discharge. Since once-through cooling system is the most economical way of condensing the exhaust steam from turbines, there is an increasing tendency for new nuclear and fossil fuel power plants to be located in coastal areas, so as to make use of the availability of the abundant seawater for condenser cooling (Winter and Conner, 1978). Planktonic organisms are drawn along with the cooling water into the plant cooling circuit, where they are subjected to various physical and chemical stress factors. Moreover, organisms in the receiving water body may also be entrained into the effluent plume, even if they do not pass through the plant cooling circuit. Temperature is one of the most important environmental variables, which affects the survival, growth and reproduction of aquatic organisms (Kinne, 1970; Langford, 1990). An increase in temperature of seawater results in an increase in the metabolic rate of the organisms and a reduction of its dissolved oxygen concentration.

Phytoplankton's are a very important constituent of the coastal food chain and, therefore, qualitative and quantitative changes in the phytoplankton population in the receiving water body may have significant implications for the coastal ecosystem. The present study was undertaken in the vicinity of the Jaigad Power Station, Ratnagiri, Maharashtra which uses the coastal waters of the as a heat sink. It was hypothesized that the continuous discharge of condenser effluents may have an impact on the ecology of the coastal marine environment in the vicinity of the plant and a study was organized to understand the influence of the discharge on the phytoplankton population near the discharge zone. Boat cruises were carried out to measure phytoplankton standing crop in the coastal waters.

MATERIALS AND METHODS

The present investigation was carried out along the cost of Jaigad (District Ratnagiri) Maharashtra.

Study site

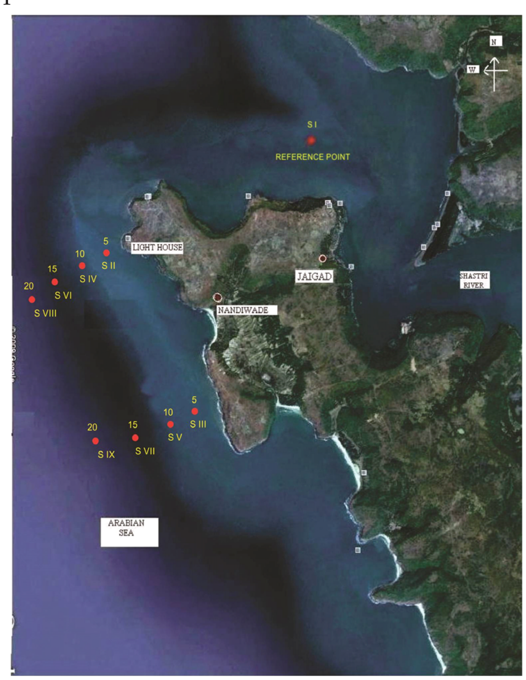
The present study was conducted during May 2014 to August 2015 near Jaigad port (Lat. 170 17' 52.51 N & 730 13' 40.14 E to 17 0 16¡® 45.14 N & 73 0 11' 50.82 E) along the West coast of India. The stations were fixed using global positioning system (GPS). The stations, designed to locate within the 10 km radius of the thermal power plant with due consideration to the outfall site, i.e. waste water discharge point of the plant.

Sampling Design

Monthly sampling was undertaken during September 2014 to May 2015 by using a motorized fishing boat. Water samples from surface and bottom were collected separately during low tide condition. The area of investigation was divided into seven different stations along Jaigad coast. Station 1 (S1) was considered as a representing reference station at Shastri river mouth. Subsequently, other stations were located away from the effluent water discharge point of the thermal power plant, namely S2 and S3 along the 5 fathoms depth contour, S4 and S5 along the 10 fathom depth contour and S6, S7, S8 and S9 along the 15 and 20 fathom depth contour. These stations were set apart with a distance of about 1 km along each counter.

Plankton Collection

The plankton from the different stations of nearshore zone was collected using the 60ì plankton net. Standard plankton net was towed from a motorized boat for 2 minutes at low speed (< 2 knots) at the selected sampling stations and transferred into 300 ml well labelled bottles. Samples were preserved with 5% neutralized formalin solution (APHA, 2012).



Study Are: Jaigad, Ratnagiri, Maharashtra

Plankton analysis

The plankton was identified and recorded employing Sedgwick-Rafter type of cell fitted on microscope (Newell and Newell, 1977). Different CM magnifications (10X, 40X and 100X) were used according to the size of the plankton. Plankton diversities of both phyto and zooplankton were determined and the density expressed as numbers per litre (nos. L^{-1}). The systematic identification of the plankton upto the level of genus was done by adopting the standard keys (Newell and Newell, 1977., Renyolds, 1984 and Nwankwo, 2004).

Chlorophyll a

The chlorophyll-a samples of near-shore zone were filtered and collected into 200 ml clean polyethylene bottles.

Chlorophyll-a analysis

The collected water samples were filtered through glass filter paper (pore size 0.42 µm) with a thin bed of magnesium carbonate suspension and chlorophyll-*a* was extracted using 90% acetone. The resulting coloured acetone extract was measured in the UV-Visible spectrophotometer at the wavelengths of 665, 645 and 630nm (APHA 2012).

RESULTS

Chlorophyll-a

At station S1, chlorophyll-a value varied from 1.15 mg m-3 (November) to 8.26 mg m-3 (March). At station S2 and S3, the chlorophyll-a value fluctuated from 0.18 to 2.78 mg m-3 (September-14 and April) and 0.17 to 3.96 mg m-3 (September-14 and March) respectively. At station S4 and S5, concentration of chlorophyll-a ranged from 1.25 to 6.23 mg m-3 (September-14 and March) and 1.32 to 6.25 mg m-3 (September-14 and April) respectively. At station S6, chlorophyll-a content fluctuated from 1.32 to 7.56 mg m-3 in the months of September and February respectively. At the station S7, minimum value of chlorophyll-a was 1.33 mg m-3 (September-14) while the maximum of 7.63 mg m-3 (February) was

Fig. Monthly variations of chlorophyll a (mg m^{-3}) at near-shore stations of Jaigad coast during 2014-15

recorded.

Chlorophyll-a values fluctuated from 1.34 to 7.69 mg m-3 (September-14 and February) and 1.35 to 9.26 mg m-3 (September-14 and February). Chlorophyll-a was found to show increasing trend seaward from S1 and the effluent zone. The ANOVA showed significant difference ($P<0.05$) among the stations and months

Quantitative and qualitative plankton analysis

Phytoplankton abundance

The phytoplankton density at station S1, ranged from 340 to 1655 nos. L^{-1} which was minimum in April while maximum in September. From the month of February, phytoplankton density started to decline gradually upto the month of April followed by slight rise in May again. The phytoplankton density at station S2, ranged from 220 to 1215 nos. L^{-1} which in May-15 and February-15 respectively. In this station phytoplankton increased from the month of November to February and then declined up to May. At the station S3 the phytoplankton density was observed in the range of 240 to 500 nos.L^{-1}. The inclining trend was observed from January-15 to April of phytoplankton abundance at station S3. At the station S4, the phytoplankton density was observed in the range of 1385 to 2865 nos.L^{-1}. The maximum phytoplankton density was recorded in the month of February against the minimum of October. At the station S4, the phytoplankton density was observed in the range of 1385 to 2865 nos.L^{-1}. The maximum phytoplankton density was recorded in the month of February against the minimum of October. At the station S5, the phytoplankton density was in the range of 915 to 1897 nos. $L^{-1.}$ Density at station S6, was in the range of 270 to 1120 nos. L^{-1} which was low in May-15 and maximum in March. Density at station S9, was in the range of 210 to 770 nos. L-1 with low in April-15 contrary to the peak in the month of March. No particular seasonal trend was noted. In general, among the phytoplankton density, S1 station showed higher density as compared with the other stations. Maximum of phytoplankton were recorded away from the effluent mixing zone against the minimum in May-15. From October it inclined upto February and then again declined in March, April and May at S7. Density at station S8, was in the range of 270 to 1120 nos. L-1 which was low in May-15 and maximum in March. There was decrease in density in October then it showed rising trend from December-14 to March-15 and then again lowered in April and May. Density at station S9, was in the range of 210 to 770 nos. L^{-1} with low in April-15 contrary to the peak in the month of March. No particular seasonal trend was noted. In general, among the phytoplankton density, S1 station showed higher density as compared with the other stations. Maximum of phytoplankton were recorded away from the effluent mixing zone.

Phytoplankton diversity

At station S1, diatoms were observed minimum in the month of May-15 (170 nos.L-1) and maximum in September-14 (1330 nos.L-1). Abundance of *Bellorochate sp*, was observed to be dominant and followed by *Skeletonema sp.* and *Pleurosigma sp.* Dinoflagellate contributed by only *Peridinium spp.* were highest in the month of September-14 (270 nos.L-1) but absent in October. Silicoflagellates were entirely absent in all the months except September-14 with low density. Similarly the Blue-green algae *Trichodesmium spp. was* found maximum (136 nos. L^{-1}) in the month of September. January-15 and was not noted in the months of October, November, February and April. Considering the total abundance, diatoms dominated followed by dinoflagellates, blue-green algae and silicoflagellate. At station S2, among diatoms, occurrence of *Coscinodiscus sp.* was reported in the months of September, October and February. *Biddulphia sp*. was found in September and February. *Ditylum sp.* and

Skeletonema sp. were recorded periodically in different months. Diatom were maximum (905 nos.L-1) in the month of February contrary to the minimum in May-15. Dinoflagellate were maximum (200 nos.L-1) and minimum (110 nos.L-1) in the month of September-14 and October and May-15 respectively. Among dinoflagellate, *Peridinium spp.* was found periodically in all the months with peak in September-14. Silicoflagellate were found at station S2, minimum (90 nos.L-1) in the month of October and April and maximum (150 nos.L-1) in the month of February. They were absent in May. At station S3, diatoms were maximum in the month of September-14 (315 nos.L-1) and minimum in May-15 (70 nos.L^{-1}). Among diatom, *Coscinodiscus sp.* was dominant followed by *Leptocylindricus sp and Globigerina sp.* Dinoflagellate dominated in May (260 nos.L^{-1}) and it was minimum (20 nos.L^{-1}) in the month of November. Among dinoflagellate, *Ceratium sp.* was observed more common. Silicoflagellate were maximum (125 nos.L^{-1}) in September-14 and minimum (60 nos.L^{-1}) was in October. At station S4, diatoms were maximum in the month of February (2650 nos.L-1) and minimum in October (1345 nos.L-1). Among the diatom, *Coscinodiscus sp.* was most dominant, followed by *Biddulphia sp., Leptocylindricus sp., Asterionella japonica, Bacillaria sp., and Thalassionema sp.* to a small extent. Dinoflagellates were at peak in December (210 nos.L^{-1}) against the minimum (25 nos.L-1) in May-15. Among dinoflagellate *Peridinium sp.* was predominantly observed and followed by *Isochrysis sp.* Blue-green algae (*Trichodesmium sp.*) were present in all the months but in low numbers.

At station S5, the diatoms were maximum in the month of March (1877 nos.L^{-1}) and minimum in October (810 nos.L^{-1}). Among diatom, *Coscinodiscus sp.* was dominant followed by *Navicula sp., Skeletonema sp.,* and *Chaetoceros sp.,* Dinoflagellate dominated in the month of September-14 (220 nos.L^{-1}). Among dinoflagellate, *Peridinium sp.* was maximum followed by *Gymnodinium sp.* Silicoflagellates (*Dictoycha sp.*) were present only from the months of October-2014 to February-15 and totally absent in the months of September, March, April and May. The Blue green algae were absent at this station in the entire period. At station S6, diatoms were maximum in the month of December (1335 no.l^{-1}) and minimum in May (590 nos.L^{-1}). Among diatoms, *Coscinodiscus sp.* was dominant followed by *Fragillaria sp., Leptocylindricus sp., Navicula spp., Nitzschia spp., Pleurosigma sp.,Globigerina sp., Skeletonema sp.,* and *Chaetoceros sp.* in different months. Dinoflagellate was at maximum in the month of November (190 nos. L^{-1}). Among dinoflagellate the dominant sp. was *Ceratium sp.* (November). Silicoflagellate (*Dictoycha sp.*) were present only in the month of seperatly November and February to a small extent. At station S7 diatoms were at peak in February (1095 nos. L^{-1}) and minimum in May (405 nos.L^{-1}). The *Coscinodiscus sp.* was most abundant in all months followed by *Rhizosolenia sp*. Dinoflagellates were maximum in the month of February (240 nos.L^{-1}) while minimum in the month of April (10 nos.L^{-1}). *Peridinum sp.* along with *Ceratium sp.* was abundant. Silicoflagellates were present in month of October and January only while the blue green algae were totally absent. At station S8, the diatom group was maximum in the month of March (560 nos.L^{-1}) on the contrary it was minimum in May-15 (190 nos.L^{-1}). Among diatom, Coscinodiscus sp. was dominant followed by Fragilaria sp. Dinoflagellate were minimum (70 nos.L^{-1}) in May-15 and maximum (560 nos. L^{-1}) in February and March. Among dinoflagellate, Prorocentrum sp. was predominant followed by Peridinium sp. Silicoflagellate (Dictoycha sp.) were in small numbers from the month of September-2014 to December-15. The blue green algae were not found.

Zooplankton abundance

Density of zooplankton in S1 station ranged between 125 and 440 nos.L^{-1} in October-14 and February-15 respectively. Subsequently the density showed declining trend upto May-15.

At stations S2 and S3, the density of zooplankton varied between 130 and 325 nos.L^{-1} and 45 and 230 nos.L^{-1}, which were minimum in May-15, October and maximum in February. From the month of October, zooplankton density showed increase till February. From the month of March, zooplankton density started to decline at station S2 and S3.

Zooplankton diversity

At station S1, copepods were maximum in the month of February (255 nos.L-1) and minimum in the month of November and May (100 nos.L-1). Among copepods, calanoid was observed to be dominant. The dinoflagellates, (Noctiluca) was absent in the months of September-14 and October but was maximum in the month of November. Tintinnids were maximum in the month of February (55 nos.L-1) but totally absent in the month of

October. Among tintinnids, Flavella sp. was the only species present. There was no any specific trend in monthly zooplankton variations. (Fig. 53.0)

At S2 station, copepods were maximum in the month of February (255 nos.L-1) while minimum in May (115 nos.L-1). Among copepods, calanoid forms were predominant followed by cyclopoids. There was no any specific trend in monthly zooplankton variations.

At station S3, among the copepods were at maximum in the month of February (175 nos.L-1) and minimum (25 nos.L-1) in October. Calanoid was the major contributor. The dinoflagellate (Noctiluca) was observed at low density in the months of December and January. Tintinnids were maximum in September (70 nos. L-1). Flavella sp. being the only contributor. (Fig. 55.0)

At S4 station, the copepods were maximum in the month of September-14 (240 nos.L-1) with minimum in May. Among copepods, calanoid was principal form. The dinoflagellate (Noctiluca) was noted in the months of November, December and February with low abundance. Tintinnids were maximum (70 nos.L-1) in the month of February (65 nos.L-1) and minimum in October. Among tintinnids, Tintinopsis sp. the only form was recorded (Fig 56.0).

At station S5, copepods were maximum in the month of February (320 nos.L-1) against the

Table 1. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_1

Parameters	Water temp	Chlorophyll-a	Phyto-plankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	-0.370	1		
Phytoplankton	-0.432	0.707**	1	
Zoo-plankton	-0.187	-0.312	0.414	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 2. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_2

Parameters	Water temp	Chlorophyll-a	Phyto-plankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	-0.293	1		
Phyto-plankton	-0.154	-0.136	1	
Zoo-plankton	-0.740**	-0.306	0.-740**	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 3. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_3

Parameters	Water temp	Chlorophyll-a	Phyto-plankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	-0.147	1		
Phyto-plankton	-0.655*	-0.258	1	
Zoo-plankton	-0.724**	0.365	-0.792**	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 4. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_4

Parameters	Water temp	Chlorophyll-a	Phytoplankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	0.093	1		
Phyto-plankton	-0.493	0.276	1	
Zoo-plankton	-0.122	-0.072	0.018	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

minimum in the month of May (60 nos.L-1). Among copepods, calanoid was observed maximum in the month of January. Dinoflagellates were totally absent. Tintinnids represented by Tintinopsis sp. were maximum in the month of February (85 nos.L-1). There was no any specific trend in monthly zooplankton density. (Fig.57.0)

Copepods were maximum in the month of February (500 nos.L-1) and the minimum (190 nos.L-1) was in October at station S6. The cyclopoids was observed maximum in different months. Dinoflagellates (Noctiluca) was observed at low density in all the month except October. Tintinnids were maximum in the month of March (200 nos.L-1). Among Tintinnids, maximum Flavella sp. were predominant followed by Tintinopsis sp. (Fig 58.0)

At station S7, copepods were maximum in the month of May (390 nos.L-1). The calanoids were observed to be major contributor in the month of February (350 nos.L^{-1}). Dinoflagellate (Noctiluca) was present in all the months in low abundance with maximum in the month of September-14. Tintinnids were maximum in February (55 nos.L-1) and minimum in the month of October. Among tintinnids, Flavella sp. was the chief contributor. There was no any specific trend in monthly zooplankton variation.

At station S8, copepods were maximum (240

Table 5. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_5

Parameters	Water temp	Chlorophyll-a	Phytoplankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	0.625*	1		
Phytoplankton	-0.369	0.678*	1	
Zoo-plankton	-0.283	0.198	0.427	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 6. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_6

Parameters	Water temp	Chlorophyll-a	Phyto-plankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	0.194	1		
Phytoplankton	-0.896	0.146	1	
Zoo-plankton	-0.483	0.592*	0.591*	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 7. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_7

Parameters	Water temp	Chlorophyll-a	Phytoplankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	-0.249	1		
Phyto-plankton	-0.755**	0.388	1	
Zoo-plankton	0.088	0.686*	0.315	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

Table 8. Correlation matrix among the physico-chemical parameters and plankton density of Jaigad coast at station S_8

Parameters	Water temp	Chlorophyll-a	Phytoplankton	Zoo-plankton
Water temp	1			
Chlorophyll-a	-0.170	1		
Phytoplankton	0.220	0.320	1	
Zoo-Plankton	-0.600*	0.717**	0.644*	1

**Correlation is significant at 0.01 level
*Correlation is significant at 0.05 level

nos.L-1) in the month of February and minimum (120 nos.L-1) was noted in May-15 and the cyclopoid was predominant. Dinoflagellate were present in all the months but maximum (60 nos.L-1) in the month of March and the minimum (10 nos.L-1) in October. Tintinnids were maximum in the month of February (125 nos.L^{-1}) contrary to the minimum in October (20 nos.L^{-1}). Among Tintinnids, Flavella sp. was the most abundant.

In general, maximum of zooplankton were recorded in the month of September-14 and February-15 from S1 to S3 and fluctuating density was observed in other months.

DISCUSSION

Plankton

Phytoplankton

Temperature being an important ecological variable, affects almost every aspect of aquatic life, thermal discharge from power plants has the potential to cause significant perturbations to the coastal marine environment (Schubel and Marcy., 1978). The effects may vary from increase in the metabolic rate of organisms to displacement or even mortality of sensitive organisms, depending on the temperature of the released water and the duration for which the organisms are exposed to the elevated temperature. Phytoplankton is a good indicator of water quality. The relatively high abundance of chlorophyta is an indicative of productive water since they are at the base of the coastal marine food chain. The possible impact of the thermal discharge on them needs to be understood in detail.

Quantitative analysis of Phytoplankton

The lowest and highest counts are observed in May-15 and September-14 respectively and comparatively high numbers of genera were observed during September-14, January, February and March. The study has revealed monthly variation in phytoplankton clearly. The results indicate that the effect of thermal discharges on phytoplankton is marginal and confined to a relatively small area. The higher density of phytoplankton could also be due to higher salinity and surface water temperature, besides availability of nutrients. Density of plankton showed decreasing trend from the month of March to May-15 however density of plankton increased with distance from the effluent mixing zone. It showed lower ranges at 5 fathom depth contour (S_2 and S_3) as compared to other depth contour (S_4 to S_9). Probably thermal power plant effluent is affecting the plankton density near the effluent discharge zone. Phytoplankton in the discharged area is affected by two main factors first is general increase in nutrient concentration and second is increase of temperature (Llus and Keskitalo, 2008). High phytoplankton production during post-monsoon could be attributed to upwelling that brings the nutrient-rich deeper water to the surface, which is a regular phenomenon (La Fond, 1957; Murty and Varadachari, 1968). On the other hand, phytoplankton production in coastal waters of Kalpakkam was mainly dependent on nitrogen and silicate (Muthulakshmi *et al.*, 2013).Phosphate which is considered to be of marine origin does not play any significant role in phytoplankton production at this location, whereas nitrogen and silicate together form the limiting factors. No impact of thermal discharge was noted in the present study.

Tiwari and Nair (1998) recorded maximum phytoplankton in the months of September-14-October, while secondary peak was in the month of April along Maharashtra coast. Devassy and Bhargava (1978) also observed phytoplankton to dominate in pre-monsoon and post-monsoon seasons in the Mondovi and Zuari estuary of Goa. Poornima *et al.* (2005) observed that phytoplankton comprised (numerically) 94% of diatoms, 3% of green algae and 3% dinoflagellates in the vicinity of MAPS, located at Kalpakkam on the east coast of India,. They stated that during most of the months, cruise stations close to the mixing point did not show any difference in chlorophyll *a* concentration or phytoplankton cell count, as compared to the other stations in the sea. However, on a few occasions (April, September and January), stations close to the mixing point showed a decrease in phytoplankton and chlorophyll *a*. They concluded that phytoplankton passing through the power plant cooling water system experience combined mechanical, chemical and thermal stresses, which vary in duration and magnitude, depending on the flow rate and thermal exposure regimes.

Qualitative analysis of phytoplankton

In the present study, four groups of phytoplankton were recorded namely: Bacillariophyceae (Yellow-green algae/diatoms), Dinophyceae (Dinoflagellate), Chrysophyceae (Silicoflagellate) and Cyanophyceae (Blue-green algae). In the Jaigad coastal water, totally 26 genera of phytoplankton were identified from nine stations including twenty from diatoms, four from dinoflagellates one each from silicoflagellate and blue-green algae group.

At station S_1, diatoms were observed minimum in the month of October and maximum in September-14. *Coscinodiscus sp.* revealed the maxima in the months of September-14 and January during post-monsoon season, while the secondary maxima were observed in the month of February and March. *Skeletonema sp.* was observed to be next dominant. Blue green algae was maximum in the month of January-15 and entirely absent in the months of October, February, April and May-15. Dinoflagellates were highest in the month of January and absent in October.

At 5 fathom depth contour *Biddulphia sp., Coscinodiscus sp., Ditylum sp., Skeletonema sp.* and *Nitzschia sp.* were found in September-14 and February among diatoms, while *Ditylum sp.* and *Skeletonema sp.* were recorded periodically in all the months. Among dinoflagellates, *Peridinium spp.* was found periodically in all the months.

The 10 fathom contour showed the dominance of *Coscinodiscus sp.,* followed by *Biddulphia sp., Asterionella japonica, Leptocylindricus sp., Bacillaria sp., and Thalassionema sp.,* while dinoflagellates dominated in December. Among dinoflagellates, *Peridinium sp*. was observed maximum followed by *Prorocentrum sp*. and *Isochrysis sp*. Blue green algae were totally absent.

At 15 fathom diatoms were maximum in the month of December, February and minimum in May-15. Among diatoms, *Coscinodiscus sp.* was dominant, followed by *Leptocylindricus sp., Navicula spp., Nitzschia spp., Pleurosigma sp., Globigerina sp., Skeletonema sp., Chaetoceros sp., and Thalassionema sp.* Dinoflagellates were maximum in the month of November contrary to the minimum in December. Among dinoflagellates, *Peridinium sp*. was observed maximum followed by *Ceratium sp*. Silicoflagellates (*Dictoycha sp*.) were present in the month of November and February only.

At 20 fathom, diatom was maximum in the month of March and minimum in May-15. Among diatoms, *Coscinodiscus sp.* dominated the population followed by *Ditylum sp., Rhizosolenia sp., Melosira sp., Skeletonema sp. and Leptocylindricus sp*. Among dinoflagellates, *Prorocentrum sp*., was observed maximum followed by *Peridinium sp*. Silicoflagellates (*Dictoycha sp*.) were present from the month of September-14 to December-15. Dinoflagellates were maximum in the month of March and absent in the month of September-14, December and April. Among dinoflagellates, the bulk was of *Peridinium sp.* .

Poornima *et al.* (2005) observed that phytoplankton comprised (numerically) 94% of diatoms, 3% of green algae and 3% dinoflagellates in the vicinity of MAPS, located at Kalpakkam on the east coast of India. They found that *Chaetoceros* decreased as temperature increased from 28 to 40°C (28°C is the optimum temperature for its growth) along Kalpakam coast. Monthly distribution of phytoplankton at Kalpakkam showed the maximum during September-14, coinciding with the transition period. Although there is a measurable reduction in phytoplankton distribution, at outfall point, the changes in chlorophyll *a* were no longer discernible for a short distance beyond the mixing point, where the thermal discharge mixes with the sea. The results of their study further confirm that the temperature regimes experience inside the condenser or in the thermal plume are unlikely to affect the growth rate of the diatoms in a significant manner. They also stated that during most of the months, stations close to the mixing point do not show any difference in concentration or phytoplankton distribution, as compared with the other stations in the sea. High numbers of the genera, *Asterionella*, *Skeletonema*, *Thalassionema*, *Thalassiothrix* and *Trichodesmium* were noticed during all seasons except pre-monsoon season in all three stations, indicating their thermophilic nature. Diatoms dominated the phytoplankton and there was no indication of any dominance by cyanobacteria or other algal species, due to thermal discharge. The occurrence of phytoplankton was the lowest during monsoon months, when the water column is remarkably stratified to a large extent because of heavy rainfall, high turbidity caused by runoff, reduced salinity, decreased temperature and pH, overcast sky and cool conditions. Phytoplankton counts were high during pre-monsoon (June–September) as reported by Marichamy *et al*. (1985). High phytoplankton abundance in summer could be attributed to more stable hydrographical conditions prevailing during that period (Rajasekar *et al.*, 2005).

According to Onyema *et al*. (2003) in the Lagos lagoon, diatoms among the phytoplankton and copepods among the zooplankton dominated the plankton spectrum. They stated that zooplankton diversity and abundance was higher in the dry months possibly due to increases in salinity and hydrological stability (Onyema *et al*, 2007). A similar situation was noted during the present study in some stations.

Chang *et al*. (1996) observed the seasonal variation of seawater temperature and phytoplankton biomass in coastal seawater adjacent to Taiwan Keelung. The water temperature at their study site varied between 17 and 30°C. Plankton abundance was low in the winter and started to increase when surface water became warmer than 25°C. Their result also confirmed that seawater temperature was an important factor in controlling the phytoplankton biomass in northern Taiwan. This is in agreement with the present study.

Perumal *et al.* (2009) reported that the *Skeletonema elongatum* was the most dominant form during pre-monsoon period in the southeast coast of India. Pednekar *et al.* (2011) recorded high abundance of *Skeletonema coastatum* during monsoon and post-monsoon season in the estuaries of Goa along the southwest coast of India. The diatom, *Skeletonema sp*. was dominantly recorded throughout the year in Dharma estuary, Bay of Bengal, India (Palleyi *et al.*, 2011). *Skeletonema coastatum* mainly dominated the plankton population in the summer in the Mahanadi estuary (Naik *et al.,* 2009). Devassy and Bhargava (1978) observed *Skeletonema sp*. dominantly in the post-monsoon season at lower streams of the Mandovi estuary. In the present study, *Skeletonema sp was* found maximum in February and minimum in May-15.

Chaetoceros sp. was observed in the post-monsoon season in the Zuari estuary (Patil *et al.*, 2004). Gowda *et al.* (2002) recorded *Chaetoceros curvisetus* as dominant species in the pre-monsoon and post-monsoon seasons in Mangalore, southwest coast of India. *Chaetoceros sp*. was recorded throughout the year in Nate and Ranpar, Ratnagiri, southwest coast of India (Dhumal and Sabale, 2014). Pednekar *et al.* (2011) recorded *C. nitidus* as the most frequently observed species and occurred throughout the year but at low concentrations during the pre-monsoon and post-monsoon season in Goa coastal waters. Abundance of *Chaetoceros sp*. was observed at mid- and upper-reaches of Shastri estuary whereas in the Kajvi estuary *Chaetoceros sp*. was observed at the mouth region throughout the year (Achuthankutty *et al.,* 1981) along the Konkan coast, India. Devassy and Bhargava (1978) observed *Chaetoceros sp.* dominantly in the post-monsoon season at upper streams of the Mandovi estuary. In the present study, *Chaetoceros sp*. was recorded only once in post-monsoon and sporadically in pre-monsoon season.

Tiwari and Nair (1998) recorded *Coscinodiscus sp.* throughout the study period in the Dharamtar creek in Mumbai. *Coscinodiscus sp.* was observed in the post-monsoon season by Patil *et al.* (2004) in the Zuari estuary. Gowda *et al.* (2002) recorded *Coscinodiscus marginatus* dominantly in the pre-monsoon and post-monsoon seasons in Mangalore, southwest coast of India. Perumal *et al.* (2009) reported that the *C. centalis* was predominant during pre-monsoon season in the southeast coast of India. Devassy and Bhargava (1978) observed *Coscinodiscus sp*. dominantly in the post-monsoon season at lower streams of the Mondovi estuary. Abundance of *Coscinodiscus sp*. was observed at all stations of mid and upper reaches of Shastri estuary, whereas in the Kajvi estuary it occurred at the mouth region throughout the year along the Konkan coast, west coast of India (Achuthankutty *et al.,* 1981). In the present study, *Coscinodiscus sp.* showed the maxima in the month of September-14 and January during post-monsoon season, while the secondary maxima was observed in the month of February and March.

Gowda *et al.* (2002) recorded *Thalassionema* dominantly in thepre- and post-monsoon season in Mangalore, along the southwest coast of India. *Thalassionema sp*. was recorded throughout the year in Gavkhadi, Ratnagiri, southwest coast of India (Dhumal and Sabale, 2014). In monsoon period, peak of *Thalassionema* sp. was reported along Kerala coast of India (Gopinathan, 1975). Perumal *et al.* (2009) reported that the *Thalassionema nitzschiodes* during pre-monsoon period in the Tamilnadu coast of India. In the present study, *Thalassionema sp.* was observed sporadically.

Abundance of *Nitzschia sp*. was observed throughout the year except in the month of August and April (Untawale and Parulekar, 1976) in the estuarine mangrove of Goa. Abundance of *Nitzschia sp*. was observed at all stations of mid and upper reaches of Shastri estuary (Jaigad), whereas in the Kajvi estuary *Nitzschia sp*. occurred at the mouth region throughout the study year (Achuthankutty *et al.,* 1981) along Konkan coast, India. In the present study, *Nitzschia sp*. was observed from the month of September-14 to March-15.

Navicula sp. occurred throughout the year except in the month of August (Untawale and Parulekar, 1976) in the estuarine mangrove of Goa. *Navicula sp*. was recorded very frequently by Tiwari and Nair (1998) along Mumbai coast, India. The same species was recorded throughout the year in Gavkhadi, Ratnagiri, southwest coast of India (Dhumal and Sabale, 2014). Abundance of *Navicula sp*. observed at all stations specially in the mid and upper reaches of Shastri estuary, whereas in the Kajvi (Ratnagiri) estuary these occurred at the mouth region throughout the year along Konkan coast, India (Achuthankutty *et al.,* 1981). Devassy and Bhargava (1978) observed *Navicula sp*. dominantly in the post-monsoon season at upper streams of the Mondovi and Zuari estuary. In the present study, *Navicula sp*. dominantly recorded in both seasons.

Gopinathan (1975) observed *Pleurosigma normani, P. directum* and *P. elongatum* to be dominant during monsoon period along the southwest coast estuary, Kerala. *Pleurosigma sp*. was recorded ordinarily throughout the year in the Dharamtar creek in Mumbai by Tiwari *et al.* (2002). The same species occurred throughout year in the estuarine mangrove of Goa (Untawale and Parulekar, 1976). *Pleurosigma sp*. dominantly recorded throughout the year in Dharma estuary coast, India (Palleyi *et al*., 2011). *Pleurosigma sp*. was recorded throughout the year in Ratnagiri coast of India (Dhumal and Sabale, 2014). Abundance of *Pleurosigma sp.* was observed during pre-monsoon by Naik *et al.* (2009) in Mahanadi estuary along northeast coast of India. In the present study, *Pleurosigma sp.* was found in both pre-monsoon and post-monsoon season.

Fragilaria sp. was dominant in the late post-monsoon and throughout the pre-monsoon (Untawale and Parulekar, 1976) in the estuarine mangrove of Goa. Pednekar *et al.* (2011) recorded *Fragilaria oceanica* in less quantity in all seasons in estuaries of Goa coast. In the present study, *Fragilaria sp*. was recorded sporadically in the post-monsoon season, but common in pre-monsoon.

Pednekar *et al.* (2011) recorded *Rhizosolenia stolterforthii* during pre-monsoon season in the estuaries of Goa. *Rhizosolenia sp*. was also recorded throughout the year in Nate, Ratnagiri, southwest coast of India (Dhumal and Sabale, 2014). Achuthankutty *et al.* (1981) recorded abundance of *Rhizosolenia sp*. at mid and upper reaches of Shastri estuary, whereas in the Kajvi estuary the species occurred at the mouth region throughout the year along the Konkan coast, India. Tiwari *et al.* (1998) recorded higher percentage of *Rhizosolenia sp*. throughout the year in the Dharamtar creek in Mumbai. In present study, *Rhizosolenia sp*. was observed only in post-monsoon seasons.

Madhav and Kondalaro (2004) along the Andaman and Nicobar coast observed the *Ditylum sp.* dominant in the monsoon season. Sachithanandam *et al.* (2013) observed *Ditylum sp* during monsoon season along the Andaman and Nicobar islands. *Ditylum sp.* was observed during pre-monsoon period in the Tamilnadu, coast of India (Perumal *et al.*, 2009). Naik *et al*. (2009) recorded *Ditylum brightwelli* during the pre-monsoon and post-monsoon seasons in Mahanadi estuary, West Bengal. In the present study, *Ditylum sp.* was observed in the post-monsoon season mainly.

Among the dinoflagellate, *Peridinium sp*. was recorded in high density in all the stations. *Peridinium sp.* was dominantly recorded in the pre-monsoon period as compared to post-monsoon season (Naik *et al.*, 2009) in the Bengal. *Peridinium sp*. was recorded highest in the pre-monsoon and lowest in the monsoon season (George *et al.*, 2012) in the Tapi estuary along Gujarat coast. Devassy and Bhargava (1978) observed *Peridinium sp*. dominantly in the pre-monsoon season at upper streams of the Mondovi estuary, southwest coast of India. Abundance of *Peridinium sp*. had uneven distribution in both Kajvi estuary and Shastri estuary but their abundance was more in the Kajvi estuary throughout the year along Konkan coast, India (Achuthankutty *et al.,* 1981). In the present study, *Peridinium sp.* was found in both seasons.

Abundance of *Prorocentrum sp*. had uneven distribution in both Kajvi estuary and Shastri estuary but their abundance was more in the Kajvi estuary throughout the study year (Achuthankutty *et al.,* 1981) along Konkan coast, India. Devassy and Bhargava (1978) observed *Prorocentrum sp*. dominantly in the pre-monsoon season at upper streams of the Mondovi estuary, Goa. In the present study, *Prorocentrum sp.* was found at S_3, S_4, S_6 and S_9 stations.

The phytoplankton characteristic of the Bay of Bengal was largely dominated by diatoms in all seasons, contributing up to 80% of total abundance with low phytoplankton abundance during summer when there was high water temperature confirming the abundance of diatoms was inversely related to temperature (Turner *et al.,* 2009). High phytoplankton density was found in February when salinity was low and reactive silicate and inorganic phosphates were moderate. Density was low during May-15 when increased SST, salinity and low nutrients availability were observed.

In the present study, *Coscinodiscus* sp. was distributed in all stations in May-15, whereas

Skeletonema, Asterionella japonica,Leptocylindricus sp., Navicula sp., and *Ditylum sp.*, were abundant in September-14 and January to March. Both Chlorophyll *a* and phytoplankton cell counts showed a reduction from the reference point to the outfall, indicating loss of plankton density. The seasonal abundance of *Coscinodiscus sp* revealed that there was not much impact of thermal power plant effluent.

A positive significant correlation was observed between Chlorophyll *a* and phytoplankton. Phytoplankton was negatively correlated with temperature at 5 fathom depth contour and with zooplankton from 15 to 20 fathom depth contour.

Zooplankton

Zooplankton plays a central role in the coastal marine food web. At the same time, the structure and function of species composition are highly susceptible to induced environmental changes, especially eutrophication. It is suggested that replacement of zooplankton species composition by eutrophication results in changes in the food chain structure and acceleration of biogenic materials from embayment to outer ocean. In the context of anthropogenic impact, thermal discharge of power plants in coastal waters and climatic change, faunal shifts in biodiversity and biogeography have been topics of interest.

Quantitative analysis of Zooplankton

In all the stations, zooplankton density showed increase from November, followed by gradual decline in March and remaining constant till May-15. In the present study, maximum density of zooplankton was recorded in the early pre-monsoon (February) and minimum in the summer season (May-15). Perumal *et al.* (2009) observed that the minimum population density of zooplankton during the pre-monsoon season along Tamil Nadu coast might be due to the high temperature and high salinity, while the maximum population density was recorded during post-monsoon season. Janakiraman *et al.* (2013) observed maximum number of species (20) during post-monsoon and the lowest (9) during monsoon and summer seasons along the southeast coast of India.

Qualitative analysis of zooplankton

At reference station (S_1), copepods were maximum in the month of February and minimum in the month of November and May-15. Among copepods, calanoidwas observed to be dominant. Dinoflagellates (*Noctiluca*) was minimum in the month of May-15 and maximum in the month of November. Tintinnids were maximum in the month of February and totally absent in the month of October. Among tintinnids, *Flavella sp*. was maximum. There was no any specific trend in monthly zooplankton variations.

At 5 fathom depth contour, copepods were maximum in the month of February. Among copepods, calanoid was observed maximum. Dinoflagellates (*Noctiluca*) were observed in the month of December and January. Tintinnids were maximum in the months of September-14 but *Flavella sp*. was recorded in all the months.

At 10 fathom depth contour, copepods were maximum in the month of September-14 and February while minimum was in May-15. Among copepods, calanoid was observed to be maximum in the month of March. Dinoflagellates (Noctiluca) was observed in the month of November, December and February. Tintinnids were maximum in the month of March, with the occourance of *Tintinopsis sp*. and *Flavella sp*. Among zooplankton, copepods were maximum in the month of February. Among copepods, calanoid was observed maximum in the month of February. Tintinnids were maximum in the month of March. Among tintinnids, *Tintinopsis sp*. and *Flavella sp*. were recorded at 15 fathom depth contour.

At 20 fathom depth contour, calanoid were maximum in the month of September-14 and February, while cyclopoid was observed maximum in the month of February and minimum was recorded in the month of May-15. Dinoflagellates were present in all the months, maximum in the month of March and minimum in the month of October. Tintinnids were maximum in the month of February and minimum in the months of October. Among tintinnids, *Tintinopsis sp*. and *Flavella sp*. were recorded.

Tintinnopsis proves a wide range of salinity tolerance and the recorded high post monsoon density which might be due to the influence of neritic waters. It is significant to note that they mostly occur during post monsoon. Perumal *et al.* (2009) recorded high abundance of copepods followed by other groups in the month of November and May-15 with rising trend of salinity along Tamilnadu coast. *Calanus sp.* of copepod showed two distinct peaks, one during November and the other during February (Pillai, 1970) in Cochin along the west coast of India. Goswami (1983) recorded *Calanus sp.* of copepod dominantly throughout the year in the Zuari estuary along the southwest coast of India. Janakiraman *et al.* (2013) observed *Calanus sp. of* copepod dominantly along the Chennai coast. *Calanus sp.* was recorded in three seasons along southwest coast of India.

Among tintinnids, genus *Tintinnopsis sp.* and *Flavella sp.* were the most abundant throughout the year, along the southeast coast of India (Perumal *et al.*, 2009). Tintinnids were also recorded in maximum numbers in all the station in the Dahanu creek, Maharashtra (Kadam and Tiwari, 2012). *Tintinnopsis sp. and Paraflavella sp.* were dominant in the pre-monsoon and post-monsoon period in Parangipettai along the southeast coast of India (Godhantaraman, 2002). In the present study, *Tintinnopsis sp*. showed a peak in post-monsoon for all stations except reference point. *Noctiluca sp.* was observed during pre-monsoon period in the Tamilnadu coast of India (Perumal *et al.*, 2009).

In the present study, qualitative analysis indicates that calanoid copepods absolutely dominated the copepod abundance throughout the year. Abundance of various zooplanktons in the coastal areas fluctuates in accordance with salinity regime. Among the various groups, copepod forms a predominant group being abundant throughout the study period at all stations. Similar type of copepod abundance also was recorded by Santhanam and Perumal (2002) in Paragipettai, southeast coast of India. Among zooplankton, copepods account for 60–80% of net-zooplankton biomass and represent the major group of secondary producers, which play a key role in the cycling of nutrients and energy in marine ecosystem by forming a link between primary and tertiary production. The abundance of zooplankton in the coastal waters is influenced by three factors: water movements, fish predation and heating by the power station. Zooplankton density during post monsoon might be due to the relatively stable environmental condition that prevails during this season, and the presence of large amount of neritic element from adjacent coastal area could have also contributed to the maximum density of zooplankton. Further, salinity is the key factor influencing the distribution and abundance of zooplankton (Padmavati and Goswami, 1996).

CONCLUSION

In the present investigation, positive significant correlation was noticed between zooplankton and pH, DO, silicate and phosphate. The inorganic phosphate to the upper layers may occur by chemical composition of simple excretory products, bacterial decomposition of organic debris and organic compound is the predominant regeneration process. The rate of regeneration depends upon the temperature and the amount of plankton (Nair and Thampy, 1980) which contains decaying phytoplankton and zooplankton material there is a rapid liberation of inorganic phosphate. A positive significant correlation was observed between zooplankton and extinction coefficient at S_1, when light penetration occurred in high intensity, the photosynthetic activity get enhanced in terms of formation algae subsequently the phytoplankton production leads to increase in zooplankton production (Nair and Thampy, 1980).

The results, therefore, indicate that the effect of thermal discharges on plankton is marginal and confined to a relatively small area, while the coastal waters per se are not adversely affected.

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