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Trichodesmium erythraeum (Ehrenberg) bloom along the southwest coast of India (Arabian Sea) and its impact on trace metal concentrations in seawater

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Abstract

The incidence of a large scale *Trichodesmium erythraeum* bloom along the southwest coast of India (Arabian Sea) observed in May 2005 is reported. Around 4802 filaments of *T. erythraeum* ml^{-1} seawater was observed and a colony consisted of 3.6×10^5 cells. The bloom was predominant off Suratkal (12° 59′N and 74° 31′E) with a depth of about 47 m, covering an area of 7 km in length and 2 km width. The concentrations of Zinc, Cadmium, Lead, Copper, Nickel and Cobalt were determined in samples collected from the bloom and non-bloom sites using stripping voltammetry. The observed hydrographical and meteorological parameters were found to be favorable for the bloom. The concentrations of Zinc, Cadmium and Nickel were found to be higher at bloom stations, while the concentrations of Lead, Copper and Cobalt were found to be very low at bloom stations. Elevated concentrations of Cadmium and Cobalt were observed at Valappad mainly due to the decomposition of detrital material produced in the bloom. Statistically significant differences ($P > 0.01$) in metal concentrations between the bloom and non-bloom stations were not observed except for Copper. Metals such as Lead, Copper and Cobalt were removed from the seawater at all places where bloom was observed. Cadmium was found to be slowly released during the decaying process of the bloom.

Keywords: stripping voltammetry; *Trichodesmium*; cyanobacteria; trace metal; coastal water; Arabian Sea

1. Introduction

Cyanobacterial and algal blooms are often extremely ‘patchy’, both temporally and spatially. The patchy spatial distribution of plankton blooms is usually connected to the physical variability of the water body (Kononen and Leppänen, 1997). Patterns of patchiness in the sea are variable and continually shaped by the water movement, which either transports cyanobacterial and algal cells from one place to another or creates conditions for growth enhancement. The frequent appearance of phytoplankton blooms in marine environment has been reported from several parts of the world. The blooming of phytoplankton particularly *Trichodesmium* spp. (cyanobacteria) generally occurs during February to May (pre-monsoon) in the coastal waters adjoining India (Qasim, 1970; Devassy et al., 1979b; Perumal et al., 1999; Jyothibabu et al., 2003; Sarangi et al., 2004). Stable hydrographic conditions and nutrient enrichment of surface waters through upwelling have been known to favour the occurrence of bloom. The non-heterocystous cyanobacterium *Trichodesmium* spp. is ubiquitous in tropical, subtropical, and temperate seas, forming some of the largest phytoplankton aggregations ever observed (3.5×10^5 km^2 in the Arabian Sea, Capone et al., 1997). Cyanobacterium is considered as important primary producers and through nitrogen fixation can provide a source of nitrogen to their environment (Capone et al., 1997). There are five known marine species in the genus *Trichodesmium* spp.: *Trichodesmium erythraeum*, *Trichodesmium hildebrantii*, *Trichodesmium contortum* (Janson et al., 1995), *Trichodesmium tenue* and *Trichodesmium thiebautii* (Carpenter et al.,

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1993). Of these, *T. thiebautii* and *T. erythraeum* are the most common species in tropical waters, the latter being the most prevalent in Indian coastal waters particularly Arabian Sea (Nair et al., 1992; Sarangi et al., 2004).

Phytoplankton affect the trace metal chemistry in natural waters by surface reactions, by taking up the metal directly, and by production of extra cellular organic matter with metal complexing properties (Moffett et al., 1990; Teresa et al., 2002). Coastal areas would have different trace metal concentrations from those in the open ocean because they would be influenced by local sources in surface and bottom waters. Productivity in coastal areas is generally several times higher than in the open ocean due to the influence of coastal upwelling or river run-off. One would expect these trace metals, which have high affinities for the biological activity, would show a characteristic behavior in coastal environments, especially when drastic biological production takes place (i.e. spring phytoplankton bloom). Only a few reports have been published on the behavior of trace metals during phytoplankton bloom (Noriki et al., 1985; Kudo and Matsunaga, 1998). Some work on metal concentrations during phytoplankton bloom has been done in a controlled mesocosm (Wangersky et al., 1989; Slauenwhite and Wangersky, 1991).

Detailed investigations on *Trichodesmium* spp. blooms have been carried from the coastal waters of Indian (James, 1972; Choudhury and Panigrahy, 1989; Satpathy and Nair, 1996). There are numerous reports on Arabian Sea and Indian Ocean blooms that suggest that blooms remain largely ungrazed and decompose, resulting in elevated ammonium levels and a succession of diatoms, dinoflagellates, and their grazers (Qasim, 1970; Steven and Glombitza, 1972; Devassy et al., 1979a,b; Borstad, 1982; Devassy, 1987; Nair et al., 1992). *Trichodesmium* spp. take up a number of trace metals from seawater, which is subsequently released as the cells decay (Jones et al., 1982). Reports on variations in trace metal concentrations during *Trichodesmium* spp. bloom are scarce. In this paper we present the changes in the concentrations of dissolved Zinc, Cadmium, Lead, Copper, Nickel and Cobalt during a *Trichodesmium erythraeum* bloom in Arabian Sea adjoining the southwest coast of India.

2. Material and methods

2.1. Site description and sampling

During the cruise of *FORV Sagar Sampada* from 6th to 20th May 2005 (Arabian Sea), extensive greenish-yellow patches of algal bloom were observed at seven places along the west coast of India from Mangalore to Quilon (09° to 13° S latitude) (Fig. 1). A total of five sea water samples were collected for heavy metal analysis as per the details given in Table 1. Three samples were collected from bloom stations (Cochin, Suratkal, 'healthy stage' and Valappad, 'decayed stage') and two from non-bloom stations (Mangalore) for comparison. Water samples were collected from the surface using Niskin samplers from the selected locations. Samples were collected in acid washed polypropylene flasks separately

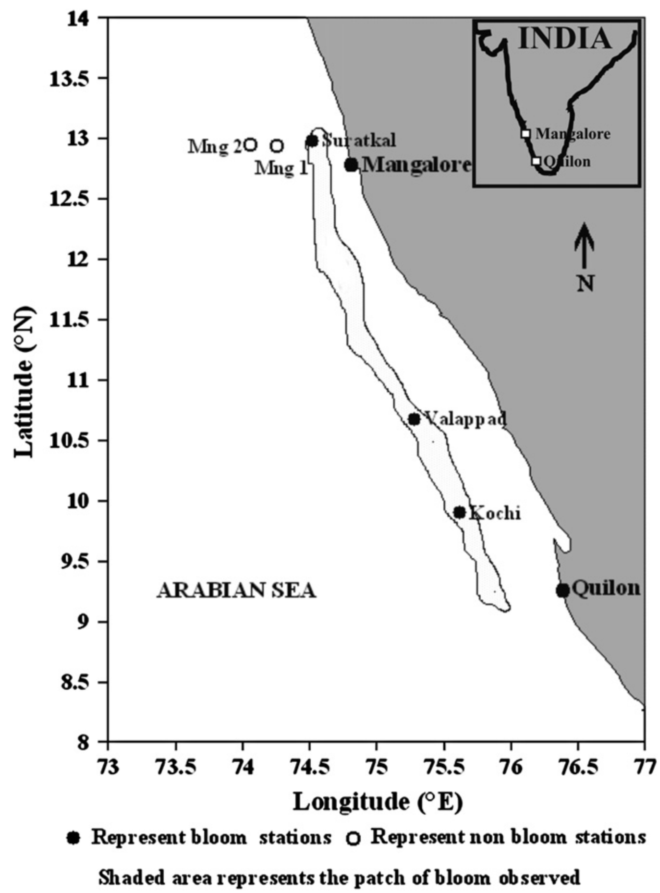

Fig. 1. Map showing the sampling stations. ● Represents bloom stations. ○ Represents non-bloom stations. Dotted areas represent the patch of bloom observed.

for metal analysis and for identification of the bloom. Bloom samples (phytoplankton) collected were preserved in Lugols solution for identification and further counting using Sedgwick-Raftor counting cell. The phytoplankton samples were identified with the help of light Microscope (Olympus BX 50). Seawater samples were filtered through a 0.45 μm cellulose acetate filter and organic matter was digested by adding HNO_3 (Merck-Suprapur) to a final pH of <2 and kept in deep freezer for analysis of major elements (Zn, Cd, Pb, Cu, Ni and Co). Clean procedures were used in order to avoid contamination of water samples. The various meteorological parameters (wind speed, wind direction, air temperature, humidity, pressure and solar radiation) were monitored by an automatic weather station on-board the ship. Salinity and dissolved oxygen were determined from Sea-Bird Electronics

Table 1
Details of stations from where samples were collected for the study

Stations	Latitude (°N)	Longitude (°E)	Date of sampling	Bloom
Mng 1	13° 00	74° 54	10/5/2005	absent
Mng 2	12° 59	73° 53	10/5/2005	absent
Surtakal	12° 59	74° 31	10/5/2005	present
Valappad	10° 41	75° 17	13/5/2005	present
Kochi	09° 54	75° 37	14/5/2005	present

CTD (USA, model: SBE-911 plus) data and the sea surface temperature (SST) was measured using a bucket-thermometer.

2.2. Determination of trace metals by Stripping Voltammetry

Metals were analysed using Stripping Voltammetry in a 757 VA Computrace attached to 765 Dosimat (Metrohm, Switzerland). Total dissolved Zn, Cd, Pb and Cu were estimated by adding 10 ml sample and 1 ml acetate buffer in a Teflon cell, using Differential Pulse Anodic Stripping Voltammetry (DPASV). The concentrations of these metals were simultaneously measured by addition of mixed metal standards (Florence, 1972) using Dosimat. The detection limit for Zn, Cd, Pb and Cu were 500, 50, 50 and 50 ppt respectively. Total dissolved Ni and Co were estimated using Cathodic Stripping Voltammetry (CSV) by adding 10 ml sample, 0.05 dimethyl glycoxime (DMG) and 0.5 ml NH_3 buffer (Meyer and Neeb, 1983) into the Teflon cell and analyzed using respective standards. The detection limit of Ni and Co was 50 ppt. A hanging drop electrode was used as working electrode, and potential were measured versus Potassium chloride (3 mol l^{-1}) reference electrode and an auxiliary platinum electrode for estimation of all the trace metals. The results presented are blank corrected. The accuracy of the analytical procedure was checked using certified reference material BCR − 403 (Community Bureau of Reference). The recovery was 99% for all metal studied, which was estimated by measuring standard spiked samples. All handling was processed in a clean room. To infer the distribution of bloom and its impact on trace metals, hydrographical and meteorological parameters in the study area the data was subjected to statistical analysis to test the Analysis of Variance (ANOVA) using SPSS 7.5 statistical package.

3. Results

3.1. Distribution of Trichodesmium erythraeum

Colonies of the cyanobacterium (2–3 mm size bundles of trichomes) could be seen with the naked eye in the surface water at several stations along the cruise track. During the entire cruise, surface water was blooming with this cyanobacterium, possibly the dominant primary producer during this period. It appeared that *Trichodesmium* spp. was concentrated in the upper 3 meters of the water column (Cochin and Suratkal), and underwater aggregates became abundant towards the latter part of the bloom. Towards the latter part of the cruise (Valappad), the water became visibly thick with the bloom. The surface water attained a brownish color, and the sea conditions were flat calm. It is noteworthy that *Trichodesmium* spp. blooms occur in the warm (summer) nutrient-poor tropical/subtropical ocean only under very calm conditions.

Analysis of the surface plankton collections revealed the presence of *Trichodesmium erythraeum* in the sample. Around 4802 filaments of *T. erythraeum* ml^{-1} seawater was observed. A colony of *T. erythraeum* collected from the bloom stations consisted of 3.6×10^5 cells. This cyanobacterium is strongly pigmented comprising approximately 99% of total cell count and there were many phytoflagellates present in the fixed sample. The *T. erythraeum* found off Valappad showed green pigments and some filaments were even white in colour which suggests that they were in the 'decayed phase' of bloom. The bloom off Cochin and Suratkal showed a brownish to red colour which suggest that the bloom was in the 'healthy phase'. The bloom was predominantly off Suratkal (12° 59′N and 74° 31′E) which has a depth of about 47 m, covering an area of 7 km in length and 2 km width and was seen about 30 km from the shore. The general hydrographic and meteorological conditions as recorded from CTD and AWS a re given in Table 2.

3.2. Hydrography and trace metal concentrations

Observations on the hydrographic conditions of the surface water at all places where bloom was sighted revealed a seawater temperature of 30.3–30.9 °C and salinity ranging from 34.96 to 35.4. The dissolved oxygen was found to be 2.24 mg l^{-1} at Valappad. The air temperature was found to be around 30.0 °C, the wind speed ranged from 3.7–4.5 m sec^{-1}. Humidity and the pressure were found to be high ranging from 67–77.2% and 1006.8–1009 mbar respectively. Solar radiation which influences the occurrence of bloom was ranging from 76.2–86.3 nWsq cm^{-1} (Table 2).

The Zn concentrations at the bloom stations ranged from 26.92 to 91.99 µg l^{-1}, with a mean of 55.39 µg l^{-1} while at the non-bloom stations it ranged from 10.79 to 64.39 µg l^{-1} with a mean of 28.73 µg l^{-1} (Fig. 2). Highest Zn concentrations of 91.99 µg l^{-1} were observed in the bloom station off Cochin while lowest concentrations of 10.79 µg l^{-1} were observed in the non-bloom station off Mangalore. The Cd concentrations at the bloom stations ranged from 0.31 to 1.16 µg l^{-1} with a mean of 0.65 µg l^{-1} while at non-bloom stations it ranged from 0.32 to 0.58 µg l^{-1} with a mean of 0.48 µg l^{-1} (Fig. 2). Highest Cd concentrations of 1.16 µg l^{-1} were observed in the bloom station off Valappad and the lowest concentrations of 0.31 µg l^{-1} was also observed at bloom stations off Cochin (Fig. 2). The Pb concentrations at the bloom stations was found to be below detection limit

Table 2
General hydrographical and meteorological condition at bloom stations

Parameters	Suratkal	Valappad	Cochin
SST	30.3 °C	30.7 °C	30.68 °C
Salinity	35.4	35.27	34.96
Wind speed	4.5 m sec^{-1}	4.5 m sec^{-1}	3.7 m sec^{-1}
Wind direction	9.6°	291.3°	316.3°
Air temperature	30.1 °C	30.0 °C	30.0 °C
Humidity	67.0%	77.2%	72.5%
Pressure	1009.0 m bar	1006.8 m bar	1007.9 m bar
Solar radiation	76.2 nWsq cm^{-1}	86.3 76.2 nWsq cm^{-1}	79.3 76.2 nWsq cm^{-1}

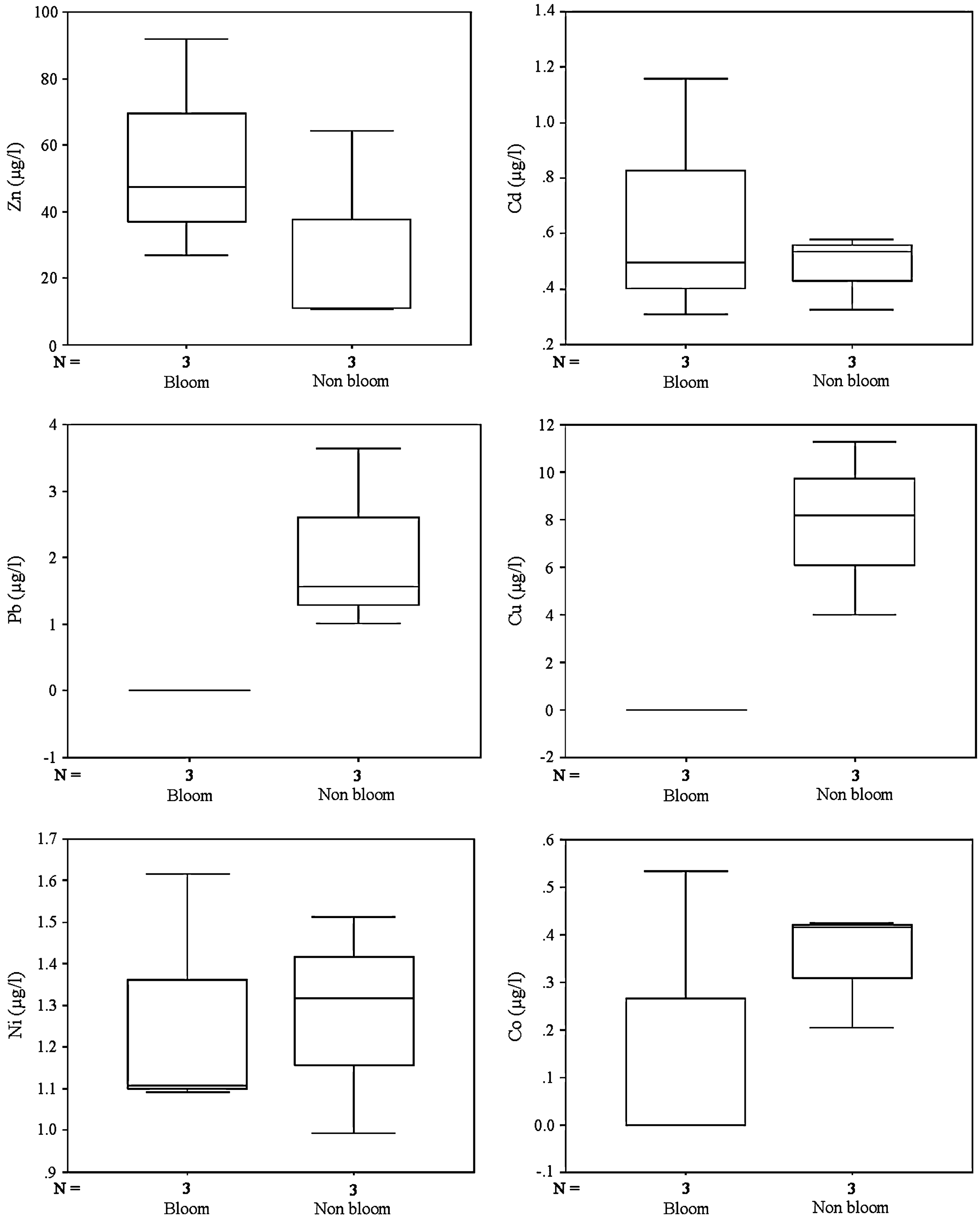

Fig. 2. Trace metal concentrations at the bloom and non-bloom stations represented by Box- and Whisker plot based on the median, quartiles and extreme values. (The box represents the interquartile range, the whiskers are lines that extend from the box to the highest and lowest values and the line across the box indicates the median).

(BDL), while at non-bloom stations it ranged from 1.01 to 3.64 μg l^{-1} with a mean of 2.07 μg l^{-1} (Fig. 2). The Cu concentrations at the bloom stations was found to be below detection limit (BDL), while at non-bloom stations it ranged from 4.02 to 11.26 μg l^{-1} with a mean of 7.82 μg l^{-1} (Fig. 2). The Ni concentrations at the bloom stations ranged from 1.09 to 1.62 μg l^{-1} at the surface with a mean of 1.27 μg l^{-1} while at non-bloom stations it ranged from 0.99 to 1.51 μg l^{-1} with a mean of 1.28 μg l^{-1}. Highest Ni concentrations of 1.62 μg l^{-1} was observed in the bloom station off Cochin while the lowest value of 0.99 μg l^{-1} was observed in the non-bloom station off Mangalore (Fig. 2). The Co concentrations at the bloom stations range from BDL to 0.53 μg l^{-1} at the surface, while at non-bloom stations it ranged from 0.20

to 0.43 $\mu g\ l^{-1}$ with a mean of 0.35 $\mu g\ l^{-1}$. Highest Co concentrations of 0.53 $\mu g\ l^{-1}$ was observed in the bloom station off Valappad while the lowest value of 0.20 $\mu g\ l^{-1}$ was observed in the non-bloom station off Mangalore (Fig. 2). No statistically significant differences ($P > 0.01$) were observed in metal concentrations between the bloom and non-bloom stations except for Cu where it showed a significant difference ($P < 0.01$).

4. Discussion

Along the west coast of India, the phytoplankton bloom is usually observed during the southwest monsoon season starting from May to September (Subrahmanyam, 1973). Blooms are most conspicuous in calm conditions, with trichomes forming dense mats or rafts on the surface of the ocean. Calm conditions at sea and water temperatures <21 °C assist the formation of bloom (Marumo and Asaoka, 1974; Carpenter and Price, 1976; Carpenter and Romans, 1991; Suvapepun, 1992). Most marine cyanobacteria exist in temperatures ranging from −5 °C to 35 °C, exhibiting temperature optima somewhere in the range of 25–35 °C (Fogg et al., 1973). Generally, cyanobacteria require higher temperature optima for growth than other phytoplankton and the temperature has been considered the most important factor contributing to cyanobacterial dominance (Suvapepun, 1992; Sellner, 1997). Usually low dissolved oxygen values are observed in seawater near the bloom when it is in the decayed stage (Choudhury and Panigrahy, 1989; Suvapepant, 1995).

A thick bloom of *Trichodesmium erythraeum* was observed throughout the cruise track in the present study. Bloom formation and the accumulation of a scum on the water surface, is a result of a change in weather conditions (e.g. Walsby, 1994). Buoyancy regulation by cyanobacteria plays a key role in this phenomenon. Once a large dominant cyanobacterial population has developed in a water body, the continuous turbulence, mixing of the water body and the decrease in light penetration cause cyanobacteria to increase their buoyancy. As soon as the wind abates, cyanobacteria float rapidly towards the surface due to their ‘over-buoyancy’ (Sellner, 1997). The surface accumulations are quickly dispersed over the water column by wind-induced mixing at wind speeds over 6–8 $m\ s^{-1}$ (Kahru et al., 1993). If the wind energy is not strong enough to redisperse the cells into the water column, cyanobacteria accumulate on the water surface as observed in the present study (Table 2). As *Trichodesmium* spp. tolerates higher irradiances (Table 2), their filaments will concentrate and can survive near the surface during calm and sunny periods.

Blooms are associated with significant enrichments in a number of dissolved and particulate trace metals as in the case of Zn and Ni found off Cochin and Suratkal during this study. Concentrations of Zn varied little between ‘healthy’ and ‘decayed’ samples thus suggesting negligible biological uptake or release. Laboratory culture experiment has shown that Cyanobacteria did not require Zn for growth, however they do appear to have an absolute requirement for Co (Sunda and Huntsman, 1995). Cadmium concentrations were generally higher in seawater samples from Valappad (decayed phase) compared to Cochin and Suratkal (healthy phase). This suggests that physical conditions can influence Cd transformations. From this study it has been well-demonstrated that the chemical speciation of Cu and Zn significantly affects the bioavailability of these metals to phytoplankton compared to other work done (Sunda and Guillard, 1976; Anderson et al., 1978). Concentrations of Zn, Cd, and Ni were generally high at bloom stations when compared with non-bloom stations. Generally, the apparent removal of Pb and Cu from all the three bloom stations was observed (Fig. 2) and Co from Cochin and Suratkal where the bloom was in healthy phase, a case of accumulation of metals. Earlier workers have observed discoloration of water, production of offensive smell and mortality of fishes and other organisms in the coastal water due to *Trichodesmium* spp. bloom (Chacko, 1942; Chidambaram and Unny, 1944). There was however no report of fish mortality during this observation.

Current data on variations in trace metal concentrations from bloom and non-bloom sites underline the influence of trace metals in *Trichodesmium erythraeum* bloom. The cyanobacteria have relatively high temperature optima thus, if the temperature conditions are not favourable then even high nutrient concentrations in the upwelling areas cannot facilitate the cyanobacterial growth. In general, *Trichodesmium* spp. blooms are a natural part of marine ecology and are not harmful to the ecosystem. A continuous monitoring of physico-chemical parameters of coastal water in the study area on a long term basis would help in understanding the cause of bloom and the influence of trace metal concentration on bloom formation.

5. Conclusion

Trichodesmium erythraeum bloom is common in tropical waters and along the Southwest coast of India. The *Trichodesmium* spp. is largely confined to the surface and occurs in varying intensity almost every year from February to May along west coast of India. Concentrations of Zn, Cd and Ni showed higher values at places were the bloom was observed. Metals such as Pb, Cu and Co were removed from the seawater at all places where bloom was observed. Cadmium was found to be slowly released during the decaying process of the bloom.

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