ON THE OCCURRENCE OF "GREENISH-YELLOW WATER" PHENOMENON CAUSED BY THE SWARMING OF *TRICHODESMIUM ERYTHRAEUM* EHRENBURG, IN THE SEA OFF MADRAS AND ITS EFFECT ON THE LOCAL MARINE FAUNA[1]

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The phenomenon of coloration of seawater in various shades, ranging from white through red, brown, yellow or green caused by the swarming of a variety of organisms such as Coccolithophores, Blue-green algae, Cystoflagellates, Dinoflagellates and Protozoans is well known (Hart 1934; Hardy 1956). This phenomenon has been reported from all the major oceans of the World, and is often associated with mass mortality, probably caused by its adverse effect on the marine fauna (Galtsoff 1948; Brongersma-Sanders 1957; Raymont 1963; and Panikkar 1967). In Indian waters, the occurrence of this phenomenon caused by the Cyanophyceaen Alga, *Trichodesmium erythraeum* Ehrenburg, has been reported mainly on the west coast of India, Krusadai Island-Pamban area in the Gulf of Mannar and Minicoy Island (Carter 1858, 1863; Hornell & Nayudu 1923; Chacko 1942; Chidambaram 1942; John & Menon 1942; Chidambaram & Unni 1944; Bhimachar & George 1950; Chidambaram & Kurian 1952; Chacko & Mahadevan 1956; Prakash & Sarma 1964; Prabhu *et al.* 1965; Nagabhushanam 1967; and Sudhakar & Doss 1967).

On the east coast of India bordering the Bay of Bengal, excepting for a reference on the occurrence of a 'bloom' of *Trichodesmium* for eleven days during March 1965, in Porto Novo waters by Ramamurthy & Seshadri (1966), there appears to be no published records on the occurrence of any type of coloration of seawater caused by the blooming of any coloured plant, flagellate or protozoan. Therefore, it was considered worthwhile to report on the occurrence, spatial distribution and the bioconstituents of a greenish-yellow coloration caused by the swarming of the Blue-green alga *Trichodesmium erythraeum* over an extensive region in the nearshore waters off Madras for an extended period of 30 days during March-April, 1976. The opportunity was also utilized to discuss the triggering off (initiation) of the blooming, subsequent development and correlating it with various hydrographical parameters.

During the extensive research cruises of the Research Vessel CHOTA INVESTIGATOR of this Station from August 1974 to date, the swarming of the alga *Trichodesmium erythraeum* was first observed as a feeble greenish-yellow discoloration of the sea on the 20th March, 1976 off Madras. Observations on the hydrological conditions and the bioconstituents of the discoloured areas were made with the aid of reversing water bottles, closing plankton nets, trawls, dredges and an echosounder on

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the R.V. CHOTA INVESTIGATOR during its daily routine cruises for five days in the week. At our request, samples were provided by the mechanized fishing trawlers and 'catamarans' operating in this area, which supplemented the data obtained from R.V. CHOTA INVESTIGATOR.

Data on temperature, pH, salinity, oxygen tension, total phosphorus, inorganic phosphate, nitrate, speed and direction of wind and surface currents and rainfall and air temperature were gathered and compared with the bioconstituents obtained from nets and trawls.

A detailed analysis of the data obtained during the entire period of the bloom revealed that the hydrological conditions, the spatial distribution and the bioconstituents of the greenish-yellow water, enabled the distinguishing of four phases as the swarming intensified, climaxed and then waned, i.e., *Initiative phase,* 20th March to 27th March, 1976; *Ascending phase,* 28th March to 4th April, 1976; *Climacteric phase,* 5th April to 11th April, 1976; *Waning phase,* 12th April to 18th April, 1976. The details of these phases are presented below.

I. **Initiative phase:** 20th March—27th March, 1976:—

Weakly coloured patches of 10-12 metres diameter, on surface, to a depth of one metre and extending from the sea-area off Ennur (at least) in the north to entrance of Madras Harbour in the south, and from shore to the 30 metre isobath. Closing net hauls constituted mainly of *Trichodesmium erythraeum* (200-250 filaments per ml of seawater), along with insignificant numbers of phyto- and zoo-plankton, listed below:

Phytoplankters: Bacillariophyceae	:	*Chaetoceros* sp., *Rhizosolenia* sp., *Navicula* sp., *Nitzschia* sp.
Dinoflagellata	:	*Peridinium* sp., in small numbers.
Zooplankters: Coelenterata		
Scyphomedusae	:	*Cyanea* sp., *Rhizostoma* sp., *Acromitus flagellatus* (Haeckel)
Hydromedusae	:	*Aequora* sp. (*?pensile*)
Ctenophora	:	*Pleurobrachia globosa* (Moser)
Crustacea	:	Mysids, shrimp larvae, prawn larvae, copepods, Cladocera.

Trawl hauls made below these patches yielded very few benthic forms including fish; showing thereby that despite the fact that the high concentrations of *Trichodesmium* occurred only at the surface—one metre depth zone—yet its effect appeared to be felt far below the surface.

Hydrographical data: Temperature (surface) 28.20°C; salinity 33.32°/oo; pH, 8.10; dissolved oxygen, 3.9 ml/1; total phosphorus, 0.7/μ gm at p/1; inorganic phosphate, 0.4/μ gm at p/1; nitrate (NO_2N:mg/1), 0.0019. Current (surface): southerly directed, 2 knots.

Meteorological data: No rainfall over the area. Wind set chiefly from NE towards SW; with light breeze from land to sea in mornings, and sea to land in evenings each day. Air temperature Max.: 34°C, Min.: 22°C. Sky, mostly clear. No fog.

Remarks: No fish or other marine life mortality was observed by us, or reported from

this or surrounding areas, as a result of this bloom. However, there was evidence that fish, prawns, shellfish, and other marine organisms seemed to avoid the bloom area, as the mechanized trawlers and catamarans reported that their catches were falling low in this area.

II. **Ascending phase:** 28th March—4th April, 1976:—

The sea now distinctly greenish-yellow, with grey, gritty matter floating on the surface; faint musty odour over the area. The patches now extended from off Ennur to beyond the New Lighthouse on the Marina, from the surface to near the seabed (in depths less than 5 metres) and from the shore to the 60 metre isobath; each patch measuring 30-50 metres in diameter, with clear water between the patches very narrow. Closing net hauls containing higher concentrations of *Trichodesmium*, and filament counts of bloom samples giving a density of 300-350 filaments per ml of seawater; vertically the bloom was in discrete layers: one layer from surface to 2 metres; another, from 6-7 metres; and (in the 60-metre isobath region) a third layer from 12-15 metre depth-range. Other phyto- and zoo-plankton components, very rare, consisting of:

Phytoplankters: Bacillariophyceae	:	*Chaetoceros* sp., *Rhizosolenia* sp.
Zooplankters: Scyphomedusae	:	*Rhizostoma* sp., *Acromitus flagellatus*.
Crustacea	:	Mysids, copepods.

Trawl hauls made in the area yielded only the two species of medusae mentioned above, and few fish (*Therapon* sp., *Tetradon* sp.).

Hydrographical data: Temperature (surface) 28.20°C, at 60 metre depth 27.65°C; salinity 33.32°/oo; pH, 8.05; dissolved oxygen, 3.2 ml/l; total phosphorus, 11.2/μ gm at p/l; inorganic phosphate, nil; nitrate (NO_2N: mg/l), 0.0002; Current (surface), southerly directed 2-2½ knots.

Meteorological data: No rainfall over the area. Wind set chiefly from NE towards SW; light breeze from land to sea in mornings, and sea to land in evenings, each day. Air temperature Max.: 34°C; Min.: 25°C. Sky, mostly clear. No fog.

Remarks: No fish or other marine life mortality as a result of this bloom was observed, or reported from this area or surrounding areas. Mechanized trawlers and catamarans reported practically no catch from this area. The analysis of the floating grey, gritty matter revealed bundles of thousands of filaments of *Trichodesmium* stuck together.

III. **Climacteric phase:** 5th April to 11th April, 1976:—

The sea still discoloured; no discrete patches observed; entire area uniformly greenish-yellow as viewed from surface; sheets of gritty matter floating on the surface, strong iodoform odour over the area. Concentration of the alga: 400-450 filaments per ml of seawater; the Secchi disc disappeared at 5-metre depth. The sea-area from off Ennur in the north to off Tiruvanmiyur in the south, at least, affected by the bloom. Mechanized trawlers and catamarans reported extension of coloured water from beyond Pulicat in the north to beyond Kalpakkam in the south. Our observations showed that the sea-areas from the shore to the 60-metre isobath was exhibiting the bloom. Closing water bottle samples

revealed that there was heavy concentration -450 filaments per ml of seawater- at the 10-15 metre depth-range in deeper waters, i.e., beyond the 30-metre isobath, and from surface to seabed in lesser depths. Closing net hauls contained *Trichodesmium* filaments almost to the entire exclusion of all other phyto- and zoo-plankters, as evidenced from study of samples taken at various stations and depths in the affected area; thus, the stratification observed earlier in the 'Ascending' phase seemed to have disappeared.

Trawl hauls made in the area yielded only a few large medusae (*Rhizostoma* sp.); no fish were taken. Trawl net fibres coated with gritty slime which when scraped and examined, revealed *Trichodesmium* in large numbers.

Hydrographical data: Temperature (surface) 28.25°C, at 60-metre depth 27.55°C; salinity 33.25°/oo at surface, 33.45°/oo at 60 metre depth; pH, 8.0 at surface; dissolved oxygen 3.1 ml/1; total phosphorus 11.5/μ gm at p/1; inorganic phosphate, nil; nitrate (NO_2N: mg/1), 0.0001; Current (surface), southerly directed, 2-3 knots.

Meteorological data: No rainfall over area. Wind set chiefly from NNE towards WSW; light breeze from land to sea in mornings, and from sea to land in evenings, each day. Air temperature Max.: 34°C; Min.: 25°C. Sky, mostly clear, sometimes with light fleecy clouds. No fog.

Remarks: No mortality of marine life occurred in the area; mechanized trawlers and catamarans reported practically no catch from this and surrounding areas. The sheets of floating grey, gritty matter, when analysed revealed mostly living filaments of *Trichodesmium* in bundles; interspersed were decomposing filaments.

IV. **Waning phase:** 12th April to 18th April, 1976:—

Large patchy sea areas of feebly discoloured seawater, clear stretches in between the patches eroding deeply into the patches. Closing net hauls showed progressive drop in concentration of alga:— 12th April: 400 filaments/ml, 17th April: 200 filaments/ml. On 17th April along with the *Trichodesmium* few copepods, mysids, shrimp larvae, ctenophores and hydromedusae occurred in the samples from most of the area under study. Plankton hauls made on 19th April showed only traces of *Trichodesmium* (20-25 filaments/ml) in the area, and were chiefly made up of copepods, mysids, fish post larvae, ctenophores and hydromedusae.

Trawl and gillnet catches were reported picking up steadily throughout the area from 20th April onwards.

Hydrographical data: Temperature (surface) 28.6°C, at 60-metre depth 27.30°C; salinity (surface) 33.2°/oo, 60 metre depth 33.35°/oo; pH (Surface) 8.10 on 13.4.76, 8.05 on 17.4.76; dissolved oxygen 2.8 ml/1 on 13th, and 2.6 ml/1 on 17th; total phosphor 10.5/μ gm at p/1 on 13th, and 1.4/μ gm at p/1 on 17th; inorganic phosphate, nil on 13th, and 0.3/μ gm at p/1 on 17th; nitrate (NO_2N: mg/1) 0.0015 on 13th, increasing to 0.0019 on 17th April. Current (surface), southerly directed, 2-3 knots.

Meteorological data: No rainfall over area. Wind set chiefly from NE to SW; light breeze from land to sea in mornings, and from sea to land in evenings, each day. Air temperature Max.: 34°C; Min.: 25°C. Sky mostly clear. No fog.

Remarks: No mortality of marine life

occurred in the area; mechanized trawlers and catamarans reported practically no catches from the area upto 18th April, however from 20th April onwards the catches were reported picking up all over the area. The sheets of floating grey, gritty matter on analysis proved to consist chiefly of a mass of dead and putrefying *Trichodesmium* filaments, with very few living filaments interspersed through the mass. The putrefying algal filaments were found to harbour both *gram*-positive and *gram*- negative groups of marine bacteria.

General remarks

A comparison of the hydrographical data obtained during the different dates reveal that there is no significant difference in the temperature, pH, salinity and surface currents; and the meteorological data, i.e., speed and direction of wind, rainfall and air temperature, similarly did not show much variation. Data on dissolved oxygen, total phosphorus, inorganic phosphate and nitrate concentrations exhibit interesting correlation with the different phases of the *Trichodesmium* bloom. These are discussed:

Dissolved oxygen: Data on dissolved oxygen values show that there is a depletion of oxygen with the increase of the bloom, and the lowest oxygen values occur during the waning phase of the bloom. Similar low oxygen values obtained by previous workers during the peak and waning phases of mono-specific blooms causing coloured water phenomena have been attributed to (i) the upwelling of oxygen-depleted water in these zones (*vide* Panikkar 1967); and (ii) the mass decay of 'red plankton' which was aggravated by the release of decay products (Grindley & Taylor 1962). In the Madras inshore waters, where upwelling is not known to take place, the first explanation may not be suitable. Therefore, the depletion of the oxygen during the peak period of the bloom in Madras inshore waters can be attributed to the increased oxygen demand of the rapidly reproducing asexual, non-motile spores and homogenes of the alga. The lowest oxygen values occurring during the waning phase of the bloom is probably due to the bloom formation being followed by an upsurge of marine bacteria, which thrive in the putrefying algal bloom. This ultimately results in the breakdown of the algal mass and in an aggravated deficiency condition of the oxygen content in the seawater. The putrefying algal filaments harbouring *gram*-positive and *gram*-negative groups of marine bacteria during the waning phase of the bloom (*vide supra*), lend support to this view.

Total phosphorus—inorganic phosphate: A comparison of the total phosphorus—inorganic phosphate data with the development of the bloom shows that (i) at the beginning of the bloom, the inorganic phosphate in the seawater declined while the total phosphorus increased gradually; (ii) at the peak of the bloom, the inorganic phosphate was reduced to Zero Value and the total phosphorus increased to the maximum; and (iii) as the bloom waned, the total phosphorus also declined considerably and the inorganic phosphate reappeared. These results support the view that the intensification of the bloom involves the utilization of inorganic phosphate and its conversion to the organic form (Ramamurthy & Seshadri 1966). The reappearance of inorganic phosphate during the waning period of the bloom would suggest that this is one of the parameters regulating the development of the bloom.

Nitrates: Nitrate values were found to decrease with the strengthening of the bloom, reaching low values at the climacterization of the bloom; increasing to normal concentrations

with the disapperarnce of the bloom. These results suggest that during *Trichodesmium* blooming nitrate concentration was depleted to trace values, which is attributable to the utilization of the nitrates during the swarming period. Similar depletion of nitrate to almost zero value with diatom-outburst has been observed by earlier workers, and it has been suggested to regulate the diatom-outburst [Raymond 1963, quoting Harvey (1923), off the New South Wales coast].

Possibly, further work will confirm that the waning of the bloom commences when the inorganic phosphate and nitrate values of the sea-area fall to almost zero value.

However, it must be remembered that the nitrate concentration in the coastal waters of a tropical environment like that of Madras is generally very low and the fluctuations of maximum and minimum values as a result of *Trichodesmium* bloom are correspondingly minimal. Further, the results of culture experiments on nitrogen fixation by *Trichodesmium erythraeum* conducted by Ramamurthy & Krishnamurthy (1968) indicating that this alga can fix free nitrogen in addition to utilizing combind nitrogen, would suggest that when nitrate concentration of seawater falls to zero value the organisms at the interface zone tend to fix atmospheric nitrogen. This may explain the occurrence of vast floating sheets of *Trichodesmium* observed during the present study during the ascendment, climacterization and waning phases of the bloom.

It is evident from the above observations that changes in dissolved oxygen, total phosphorus, inorganic phosphate and nitrate concentrations of the seawater are affected during the different phases of the bloom, and these in turn appear to regulate the algal out-burst. However, the precise mechanism which influences the triggering-off (initiation) of the bloom is not clear. The causative factors contributing to the initiation of such heavy and sudden algal blooms have been attributed to (i) sudden dilution of salinity in coastal waters by addition of freshwater as drain-off from land during heavy rains; (ii) the addition of large quantities of nutrients either by upwelled oxygen-depleted water or by land-drainage; and (iii) the possibility in sudden increase of certain external metabolites or growth factors due to the presence and interaction of micro-organisms and phyto- and zoo-plankton constituents promoting an increase in cell-division (collated from references listed—see Raymont 1963, for details of external metabolites or growth-factors). During the present observations there was no dilution of salinity; additions of large quantities of nutrients by upwelling and/or land-drainage will have to be excluded, since there was no rainfall over the area during the entire period of observations and for some months previous to it, and no large rivers open into this zone; further, upwelling of water masses have not so far been established for this area; there was no difference in the limited land-drainage in the entire zone preceding or during the bloom period. Thus the possibility of increased nutrients by either of these two mechanisms, namely, upwelling or land-drainage, is excluded. It is, therefore, probable that increase in certain external metabolites or growth factors, caused by the presence and interaction of micro-organisms and other phyto- and zoo-plankters, has resulted in the promotion of the rate of cell-division of *Trichodesmium* contributing to the initiation of this vast mono-specific bloom.

Ill-effects of this bloom on marine life: Mass mortality of marine animals has often been associated with the occurrence of coloured water by the swarming of coloured plants,

flagellates and Protozoans from all the major oceans of the world (Brongersma-Sanders 1957; Grindley & Taylor 1962). Previous reports of such mass mortality of marine fauna have also been correlated to the occurrence of heavy *Trichodesmium* blooms from the west coast of India, Krusadai Island and Pamban areas (Chacko 1942; Sudhakar & Doss 1967). Other records in the same region and from Minicoy Island (Arabian Sea) and from Porto Novo (East coast) have recorded the absence of free-moving marine fauna in the 'blooming' areas, although no mass mortality was observed (Prabhu *et al.* 1965; Nagabhushanam 1967; Ramamurthy & Seshadri 1966). This mass mortality reported by earlier workers has been attributed to the planktonic blooms producing potent toxins and/or of direct influence of oxygen depleted water (Prakash & Sarma 1964; Panikkar 1967). During the present study, no fish or other marine life mortality as a result of this bloom was observed or reported from this area or from surrounding areas. There was evidence that free-moving marine organisms avoided the bloom areas as the mechanized trawlers and catamarans also reported that there was practically no catch from this and surrounding areas. It is therefore inferred that the free-moving marine organisms—mainly gill-breathers—avoided this area due to (i) *Trichodesmium* filaments choking or damaging their gills and (ii) depletion of oxygen values as a result of increased oxygen demand of the reproducing algae. It is probable that when these blooms develop gradually, the marine animals are able to avoid such infested zones well in time. Mass mortality probably occurs during heavy and sudden blooming, when the animals are unable to escape from the infested zone. It may also be mentioned that some of the animals in the food-chain may feed on this bloom algae during the initiation phase, and though they may not be directly affected they may act as accumulators of the toxic or poisonous substances produced by the algae; when the bigger animals eat these, it proves fatal and mass mortality may have occurred due to the poisoning effect.

It is clear from the observation described here, and an analysis of the factors suggested as influencing the initiation, development and waning of the algal bloom, that (i) certain external metabolites due to the presence and interaction of micro-organisms, particularly bacteria, play an important part in the initiation of the bloom; (ii) the waning of the bloom commences when the inorganic phosphate and nitrate values of the sea fall to almost zero value, and the oxygen tension is lowered to minimal value; and (iii) the marine organisms avoid the affected area due to choking or damaging of their gills and depletion of oxygen values. Further investigations on the factors influencing the occurrence and spatial distribution of coloration of seawater and their bioconstituents especially the micro-organisms releasing metabolites are required, so that some method of controlling such blooms may be devised with a view to prevent losses to the fisheries of the affected region.

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