

## Some characteristics of a *Trichodesmium* bloom in the Laccadives

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**Abstract**—In April 1968 a bloom of *Trichodesmium erythraeum* occurred in great profusion in the Laccadives and largely occupied the upper few meters of the water. The chief characteristics of the environment during the bloom were the minimum nitrate-N and a sparse population of other phytoplankton and zooplankton. The ability of *Trichodesmium* to fix molecular nitrogen provides an important source of nitrogen enrichment which may make a substantial contribution to the nitrogen budget of tropical seas.

FROM the numerous reports in the literature (see e.g. BRONGERSMA-SANDERS, 1957; BOWMAN and LANCASTER, 1965) it is clear that blooms of the blue-green alga, *Trichodesmium erythraeum* Ehrenberg, are of common occurrence in tropical seas. It has frequently been reported from the Bay of Bengal and the Arabian Sea (CHACKO, 1942; CHIDAMBARAM and MUKUNDAN UNNY, 1942; NAGABHUSHANAM, 1967). In recent years sufficient experimental evidence has been made available to show that *Trichodesmium* can fix atmospheric nitrogen (DUGDALE, MENZEL and RYTHYER, 1961; DUGDALE, GOERING and RYTHYER, 1964; GOERING, DUGDALE and MENZEL, 1966; RAMAMURTHY and KRISHNAMURTHY, 1968). These findings have undoubtedly some very important implications, as in some regions *Trichodesmium* blooms become so intense and widespread that they may make a major contribution to the nitrogen budget of the sea. However, apart from the occurrence of the bloom in different parts of the world and the ability of *Trichodesmium* to fix nitrogen, no quantitative data are available on the bloom itself; nor is there sufficient information on the characteristics of the environment during the time when blooms occur.

In April 1968 during a cruise from Cochin to the Laccadive Islands by a passenger ship *Laccadives*, a bloom of *Trichodesmium erythraeum* was at first noticed over a stretch of more than 100 miles, as far as Kavaratti Island (Fig. 1), where the present author went ashore. Later reports given by the ship's captain and crew, who called at different islands of the Union Territory of Laccadives (Fig. 1), confirmed the occurrence of similar blooms all over the Laccadive Sea. On 20 April while returning to the mainland the bloom continued to occur along the route to Calicut, and as the ship approached closer to the mainland, its intensity decreased, and finally disappeared at about 60 miles† from the shore (Fig. 1).

While the bloom was found along the ship's track (Fig. 1) and fusiform clumps of the algae could easily be seen from shipboard, its intensity varied greatly from place to place. In some areas the clumps appeared to be less numerous, but in others vast sheets of water were virtually covered by the fine sand-coloured clumps of the algae.

At Kavaratti Atoll, thick pads of algae were washed ashore in between tidal marks and over the fringes of the coral reef. Further observations on the nature of the bloom were made in the close vicinity of Kavaratti Island from a small motor boat on 17, 18 and 19 April. The sea was calm on all these days and there was brilliant sunshine and a gentle breeze. Water samples were collected from three different locations in the open sea, outside the coral reef, within an area of about 10 km<sup>2</sup>. A glass jar was used to collect water samples from the surface and a Ruttner sampler at depths. Replicate sub-samples were taken from each sample and the clumps contained in each were counted (12–20 filaments were seen forming clumps). Measurements of the transparency of water were made by a Secchi disc.

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† 1 nautical mile = 1.852 km.

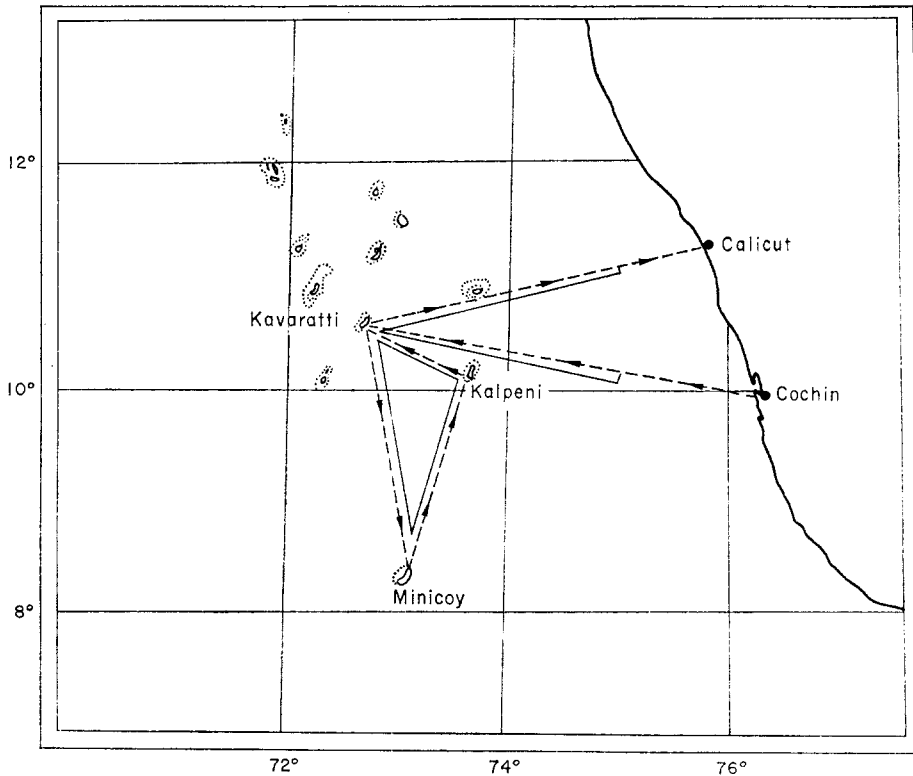


Fig. 1. Outline map showing position of some of the islands of the Laccadive Archipelago. Broken lines with arrows show the ship's track and continuous lines along the track indicate the region of *Trichodesmium* bloom.

Table 1. Concentrations of *Trichodesmium* during its bloom at three different locations near Kavaratti Island (Laccadives) in April 1968.

Sampling depth	Location 1 with Secchi-depth 13 m	Location 2 with Secchi-depth 9 m	Location 3 with Secchi-depth 6 m
	No. of clumps/m <sup>3</sup>	No. of clumps/m <sup>3</sup>	No. of clumps/m <sup>3</sup>
0 m	8540	$27 \times 10^3$	$5 \times 10^5$
5 m	7530	$6 \times 10^3$	$3 \times 10^3$
10 m	5320	550	340

Table 1 shows the concentrations of clumps in relation to transparency of the water. It is clear from the table that in areas like location 1, where the clumps were not very dense and the Secchi disc visibility was up to 13 m, the bloom of the alga was almost uniformly distributed up to 10 m depth, which was the limit of the present observation. But in areas where dense concentration existed, the Secchi disc visibility was reduced further and the bloom largely occupied the upper few meters. No observations were made in regions where the bloom was concentrated in the form of a thick, floating scum except that on scooping the scum by hand the water underneath was found to be perfectly clear, indicating that the bloom was largely confined to the surface only. In areas of dense concentration the bloom emitted a strong chlorine-like smell.

Table 2. Hydrographical features during a *Trichodesmium* bloom in April 1968 near Kavaratti Island (Laccadives)

	Depth (m)	Temp. (°C)	Salinity (‰)	Oxygen (ml./l.)	PO <sub>4</sub> -P μg · at./l.	NO <sub>3</sub> -N μg · at./l.	SiO <sub>3</sub> -Si μg · at./l.
Location 1	0	30·60	34·44	5·54	0·64	0·22	1·67
	5	29·84	34·47	5·25	0·57	Not* detectable	1·35
Location 2	0	30·40	34·62	5·62	1·01	Not* detectable	1·23
	10	30·24	34·52	4·76	0·68	0·14	1·03
Location 3	0	30·52	34·59	5·48	0·52	Not* detectable	1·80
	5	30·30	34·68	4·96	0·67	Not* detectable	1·32
	10	29·74	34·77	4·68	0·45	0·28	1·41

\*Less than 0·1 μg · at./l. The detection limit of the method used (STRICKLAND and PARSONS, 1960) is 0·1–0·2 μg · at./l. The values were not expressed as combined nitrogen (nitrate + nitrite) as the latter was found to be nil.

Table 2 shows some of the hydrographical features at the three locations. It can be seen from the table that while the sea temperature, salinity and oxygen were not subjected to much change and were typical of the upper few meters of tropical ocean water, the nutrient concentrations, particularly inorganic-P and silicate-Si, were fairly high and the nitrate-N strikingly low. In other words the bloom seemed to be accompanied by an almost total depletion of nitrate-N. The range in the values of inorganic-P (0·5–1·0 μg · at./l.) appeared to be rather surprising, particularly when the nitrate-N was so low, but since the observations were made near the atoll, it is suspected that this might have been because of the influence of the coral reef. The rate of <sup>14</sup>C assimilation, as indicated by 5 incubations taken from such areas which apparently seemed to be clear of *Trichodesmium* bloom and where the Secchi depth was 26 m, ranged from 1·70 to 2·20 mgC/m<sup>3</sup>/hr and the chlorophyll *a* values from 0·18–0·23 mg/m<sup>3</sup>, thus indicating that the rate of production of other organisms was very low. This was further ascertained by taking two 30-min phytoplankton hauls at 5 m depth, in relatively clear waters, by an Australian Clarke-Bumpus sampler (TRANter, 1965) provided with a nylon net of 0·05 mm mesh width. The phytoplankton crop as can be seen from Table 3 was mainly composed of *Trichodesmium erythraeum*. Other organisms such as diatoms, dinoflagellates and green algae were sparse with a total count of approximately 650–950 cells/m<sup>3</sup>.

The zooplankton biomass of the area, as indicated by 4 hauls from a nylon net of 0·33 mm mesh width, fitted to the Clarke-Bumpus sampler, ranged from 3·44 to 8·27 mg/m<sup>3</sup> as wet weight. Since

Table 3. Phytoplankton crop during *Trichodesmium* bloom obtained by 30-min hauls at 5 m depth.

Organisms	Sample 1 (counts/m <sup>3</sup> )	Sample 2 (counts/m <sup>3</sup> )
<i>Trichodesmium</i>	2285	882
<i>Lyngbya</i>	27	88
<i>Chlorella</i>	38	—
<i>Chlamydomonas</i>	8	5
<i>Cladophora</i>	16	5
<i>Pearsoniella</i>	5	—
<i>Perdinium</i>	16	—
<i>Coscinodiscus</i>	365	210
<i>Navicula</i>	338	292
<i>Nitzschia</i>	113	54
<i>Fragilaria</i>	11	5
<i>Pleurosigma</i>	11	12
<i>Gyrosigma</i>	5	—

each sample showed considerable diversity in its composition, these were pooled and expressed in terms of the total volume of water filtered (Table 4).

Table 4. Zooplankton composition during *Trichodesmium* bloom obtained by 30-min hauls at 5 m depth.

Organisms	Counts/100 m <sup>3</sup>
Foraminifera	106
Hydroid colony	6
Medusae	15
Siphonophora	12
Polychaeta	15
Bivalve larvae	16
Gastropoda	262
Cirripede larvae	2
Cladocera	8
Amphipoda	32
Copepoda	21220
Decapod larvae	182
Chaetognatha	17
Fish eggs	122
Invertebrate eggs	Many (not counted)

These observations clearly indicate that the bloom of *Trichodesmium* occurs during a time when the sea is nitrogen impoverished and does not sustain much phytoplankton and zooplankton. A general hydrographical survey of the Laccadive waters carried out by JAYARAMAN, RAMAMIRTHAM, SUNDARA RAMAM and NAIR (1960) during the month of April 1959, revealed a thermal stratification at about 75 m depth which was accompanied by a sharp salinity gradient. This situation seems to be true not only of Laccadive waters but has also been reported from all along the west coast of India during the pre-monsoon months (March–April) and seems to persist until the middle of May, when, with the onset of monsoon, the seasonal stratification is broken and conditions in the sea become unstable (see PATIL, RAMAMIRTHAM, VARMA and NAIR, 1964; RAMAMIRTHAM and PATIL, 1965).

Presumably a prolonged growth of phytoplankton in the stratified photic zone during the pre-monsoon period would seem a main factor reducing the available supply of nitrogen to negligible limits. However, the ability of *Trichodesmium* to bloom in such a situation when growth of the other plant organisms seems to be restricted (see Table 3) recalls the findings of earlier authors (DUGDALE, GOERING and RYTHER, 1964; GOERING, DUGDALE and MENZEL, 1966) of its utilizing molecular nitrogen. These authors by using the <sup>15</sup>N technique have demonstrated that *Trichodesmium* fixes atmospheric nitrogen. RAMAMURTHY and KRISHNAMURTHY (1968) by using axenic cultures of *Trichodesmium* have shown that in nitrogen free media, where the source of nitrogen was only molecular, the rate of nitrogen fixation increased with time (see Table 5). Using the data of these authors an approximation of the rate of nitrogen fixation by *Trichodesmium* at the three locations of the bloom has been made. This is shown in Table 5 from which it can be seen that if the bloom were to stay for a longer period, the amount of nitrogen fixed by *Trichodesmium* would be very substantial. Since no quantitative data were obtained from areas where the bloom formed thick layers at the surface, the nitrogen fixed in such patches would be far greater than at the three locations shown in Table 5. The nitrogen fixed by *Trichodesmium* when released into the system either on death and decay of the organisms or in the form of extracellular products (STEWART, 1963) liberated by the filaments themselves, will provide a new source of nitrogen to the sea.

From the fact that phosphorus depletion does not occur during the bloom (Table 2) and from the findings of RAMAMURTHY and KRISHNAMURTHY (1968) that nitrogen fixation by *Trichodesmium* is greater when the source is only molecular than when it is exposed to two sources of nitrogen—ionic and molecular, it seems that the bloom is not a cause of nitrogen depletion in the sea but probably its effect. While the lack of nitrogen would seem to limit the propagation of other plant organisms, it would possibly accelerate the growth of *Trichodesmium*. The dense concentrations of the bloom occupying the upper few meters is probably an adaptation to utilize the atmospheric nitrogen to a maximum degree.

The bloom seems to occur during a period (April) when solar radiation at Cochin, with 10–12 hr of sunshine each day, may reach approximately 626 gcal/cm<sup>2</sup>/day (QASIM, BHATTATHIRI, and ABIDI

Table 5. Nitrogen fixation in axenic cultures of *Trichodesmium erythraeum* as given by RAMAMURTHY and KRISHNAMURTHY (1968). Using their data (columns 1 and 2) probable nitrogen fixation during the bloom has been computed.

Days	Fixation in nitrogen-free media ( $\mu\text{g N/g}\dagger/\text{day}$ )	Calculated fixation at location 1 with approximately 8000 clumps*/ $\text{m}^3$ ( $\mu\text{g N/g}\dagger/\text{m}^3/\text{day}$ )	Calculated fixation at location 2 with approximately $27 \times 10^3$ clumps*/ $\text{m}^3$ ( $\mu\text{g N/g}\dagger/\text{m}^3/\text{day}$ )	Calculated fixation at location 3 with approximately $5 \times 10^5$ clumps*/ $\text{m}^3$ ( $\mu\text{g N/g}\dagger/\text{m}^3/\text{day}$ )
1-10	0.650	0.023	0.077	1.434
11-20	0.730	0.026	0.087	1.610
21-30	0.780	0.027	0.093	1.720
31-40	0.870	0.031	0.104	1.919
41-50	1.000	0.035	0.119	2.206

\*1 clump = approximately 15 filaments (12-20 filaments form clumps during the bloom).

†1 g wet weight of *Trichodesmium* = approximately  $3.4 \times 10^6$  filaments in cultures, which do not aggregate into clumps (RAMAMURTHY, private communication).

1968); and since Kavaratti Island is located almost along the same latitude, similar light conditions would probably be applicable to that area also. A close correspondence, therefore, between the occurrence of massive blooms and high seasonal illumination indicates that even when the under-water illumination is considerably reduced as a result of the profusion of the bloom, the solar radiation cannot become a limiting factor as with increasing population, the bloom moves closer to the surface (Table 1). In another blue-green alga, *Anabaena* it has been shown that the overall fixation of nitrogen is directly dependent upon the light conditions and that bright light increases the nitrogen fixation substantially because it occurs in conjunction with photosynthesis (DUGDALE and DUGDALE, 1962).

Many reports have appeared in the literature regarding *Trichodesmium* as food of marine fishes. DEVANESAN (1942) and CHACKO (1942) pointed out that *Trichodesmium* in a certain season formed an important component of the food of a variety of fishes. The former suggested that the fishery for sardine and mackerel, to some extent, is dependent upon the occurrence of this blue-green alga. JOHN and MENON (1942), on the other hand, reported that dense concentrations of *Trichodesmium* appearing at intervals, from December to April, in the coastal waters of the Arabian Sea have an inhibitory influence not only on plankton-feeding fishes but also on certain planktonic organisms. CHIDAMBARAM (1942) while supporting the views expressed by Devanesan is of the opinion that the inhibitory influence was more related to its occasional profusion than to its unpalatable qualities and that the fish tended to avoid the organism because of its sheer density. CHACKO (1942) and CHIDAMBARAM and MUKUNDAN UNNY (1944), however, reported two instances of mortality of fish and other marine animals in the coastal waters of the Palk Bay (Bay of Bengal) during May, which was caused by the bloom of *Trichodesmium*. This they thought to be due to decay and putrefaction of the algae. NAGABHUSHANAM (1967) noticed a massive bloom of *Trichodesmium* around Minicoy Island from early May to late June and reported that tuna shoals avoided the bloom. No dead fish or any other animal were seen by the author during the bloom, either in the sea or around the island and coral reef.

The precise duration of the bloom which was seen between 15-20 April 1968 is not known. However, a message received from the Fisheries Department, Laccadives, in response to instructions given to them at the time of observation, indicates that it lasted till 4th or 5th May, when the weather became cloudy and the bloom suddenly disappeared. Mr. George Varghese, Fisheries Officer, Laccadives, later informed the author that the bloom of *Trichodesmium* occurs practically every year in the Laccadives, very often intermittently, from March to May; and since March, April and May are the best fishing months, it seems to have no adverse effect on the tuna fisheries of the islands. In his records there are several instances of fish mortality appearing during the months of September and October in the Laccadive waters, but not during the period March-May. In his opinion fishing goes on fairly intensively during the bloom period. He has, however, no information whether the fishes are actually caught in such patches where the bloom is in profusion.

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*Note added in proof*

During the International Symposium on the "Taxonomy and Biology of Blue-green Algae" held at Madras from 8–13 January 1970, the problem of nitrogen fixation in the blue-green algae was discussed in detail. From the papers of Prof. G. E. Fogg, Prof. W. D. P. Stewart and others it was concluded that the evidence on nitrogen fixation in the blue-green algae is rather specific to those groups which possess heterocysts. *Trichodesmium* lacks heterocyst, and therefore, despite the evidences that have been obtained so far on the ability of *Trichodesmium* to fix nitrogen, a further proof using bacteria-free cultures is necessary, in view of the potential nitrogen-fixing microbes generally occurring in association with the blue-green algae.