

SOME OBSERVATIONS ON *TRICHODESMIUM* BLOOMS

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SUMMARY

Blooms of the blue-green alga, *Trichodesmium erythraeum* Ehrenberg, occur in great profusion in the Laccadives. In April 1968, a bloom was seen over a stretch of several hundred miles when vast sheets of water in the Arabian Sea were covered by the sand-coloured clumps of the algae. While the bloom was largely confined to the upper few metres of water, its intensity varied from place to place. The actual structure of the bloom had no well-defined form except that in some areas it was spread out in large streaks or lanes. In 1969 also a similar bloom occurred in the Laccadives almost during the same period.

The notable features of the environment during the bloom were the depletion of nitrate-N from the sea and a strikingly low population of other phytoplankton and zooplankton. No dead fish or any other animal were seen anywhere in the sea while the bloom was in profusion. The phenomenal growth of *Trichodesmium* during a period when the sea is nitrogen impoverished, and when the propagation of other plant organisms gets limited is probably because of its ability to fix molecular nitrogen.

INTRODUCTION

ALTHOUGH the blue-green algae occur in an exceedingly wide range of habitat, the forms which are commonly found in the sea belong to the family Oscillatoriaceae and Nostocaceae. While the pelagic species largely belong to the genera *Trichodesmium* (placed in *Oscillatoria* by Geitler, 1932), *Oscillatoria*, *Lyngbya*, *Richelia*, *Katagnymene* and *Pelagothrix*, the genus *Nostoc* has also been reported from the tropical Atlantic Ocean, Indian Ocean and the Mediterranean Sea (Bernard and Lecal, 1960). In addition to these, the spores and other developmental stages of several non-planktonic forms are often seen in the plankton. Almost all species of *Trichodesmium* are known to possess gas vacuoles and form characteristic clumps or bundles (Desikachary, 1959).

For most of the year *Trichodesmium* constitutes a minor component of the marine plankton, but in certain seasons it becomes extremely abundant and far exceeds any other plant life in the sea. This phenomenon of forming "blooms" is of a spectacular nature and has been reported in the literature as "red tides". The other groups of organisms which have been found to be associated with similar blooms are the diatoms and dinoflagellates.

Numerous reports in the form of comments and single observations have appeared in the

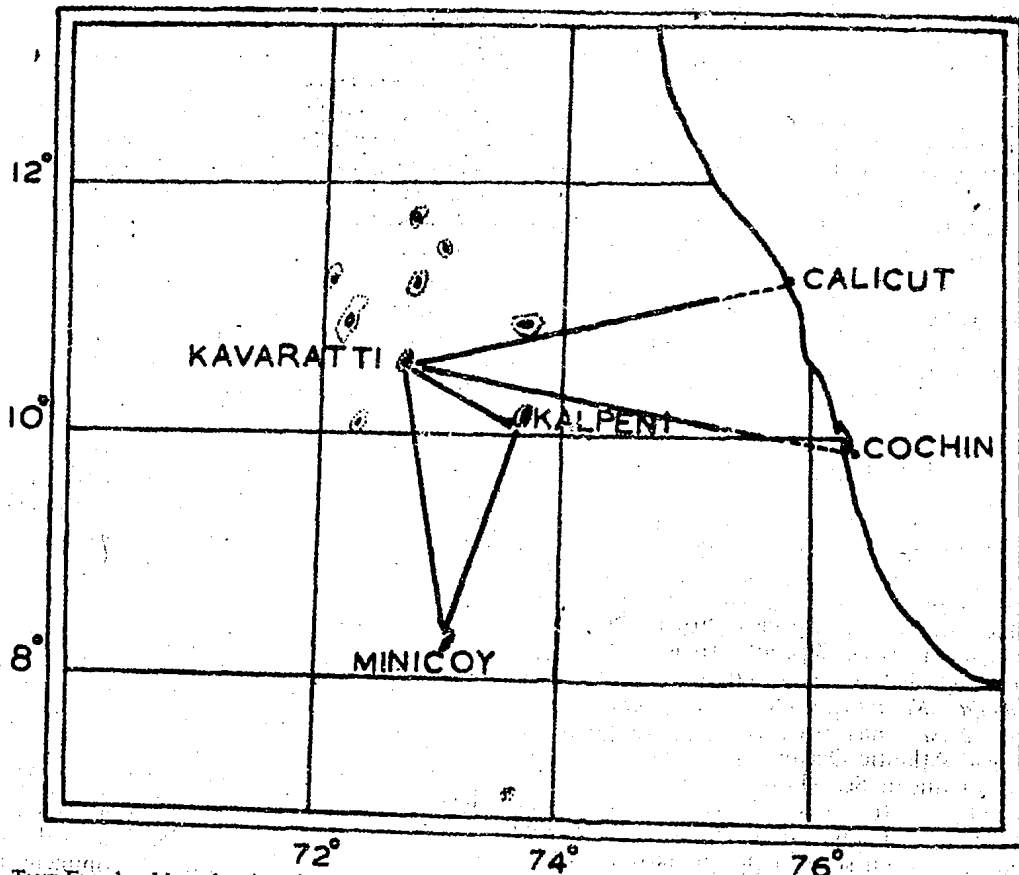
literature on the blooms of *Trichodesmium* from different parts of the world's ocean. Some of these reports have been summarised by Brongersma-Sanders (1948), Bowman and Lancaster (1965) and Wood (1965). The interesting feature, however, which has often puzzled both marine ecologists and oceanographers is the suddenness with which the blooms of *Trichodesmium*, an organism which normally constitutes an insignificant proportion of the total biomass in the sea, appear. Even more intriguing is the disappearance of the bloom, which, according to published reports, has been found to be sudden and dramatic.

The answer to this apparent paradox does not seem a simple one and may lie in the study of the environment before the commencement of the bloom, the distribution and physiological behaviour of the organism before, during, and after the bloom, and a detailed study of a single bloom from start to finish.

The problems associated with the blooms of *Trichodesmium erythraeum* Ehrenberg became apparent to the present author when, during an oceanographic cruise from Cochin to the Laccadive Archipelago, he first noticed a bloom. The cruise lasted 6 days from 15-20 April 1968, during which period the ship called at three islands of the Laccadive Archipelago, namely Kavaratti, Kalpeni and Minicoy. Text-Figure 1 shows the route along which the bloom was seen in profusion. On 16th April

the author disembarked at Kavaratti Island where he made further observations on the bloom and returned to Calicut on 20th April where the cruise ended. The information about similar blooms along the route to Kalpeni, Minicoy and Kavaratti Islands (see Text-Fig. 1) was furnished by the ship's captain and crew.

abundance, were selected for observations on the quantitative distribution of the bloom in relation to hydrographical features. From all the three sites water samples were collected in replicates at 0 m, 5 m and 10 m depths by using a plastic bucket at the surface and a Ruttner sampler at depths. The clumps contained in each sample were counted. Trans-



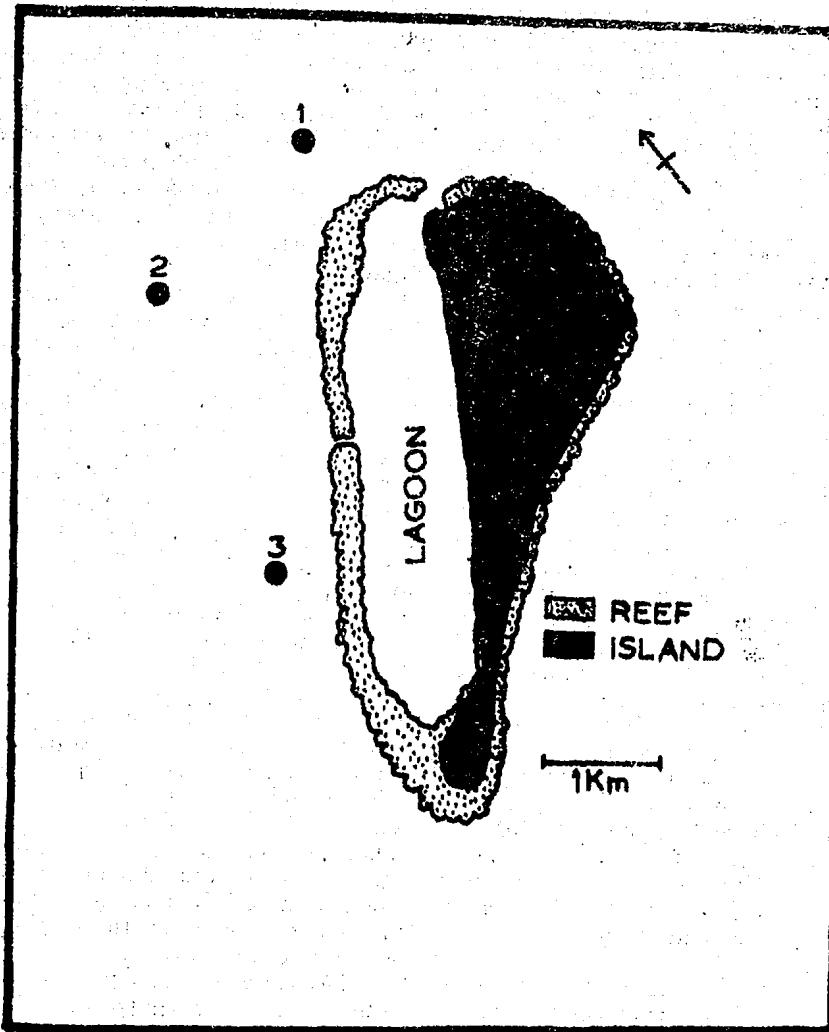
TEXT-FIG. 1. Map showing the Laccadive Archipelago in relation to south-west coast of India. The route along which the bloom of *Trichodesmium* was seen has been shown by thick continuous lines.

Kavaratti is an atoll located along Lat. $10^{\circ}33'N$ and Long. $72^{\circ}36'E$. It has an island with an area of 34.5 sq km and a shallow lagoon about 4,500 m long, 1,200 m wide and with depth averaging 2 m. The latter is surrounded by a ring-shaped coral reef which is about 300 m wide (Text-Fig. 2).

PROCEDURE AND METHODS

As shown in Text-Fig. 2, three sites close to Kavaratti Atoll, where the bloom was in

parency of the water at the three sites was noted by a Secchi disc. Measurements of different environmental features included the temperature, salinity, dissolved oxygen and nutrients (phosphate-P, nitrate-N and silicate-Si). In other adjacent areas which appeared to be relatively free from the bloom, C^{14} assimilation and chlorophyll *a* concentrations were also measured. Estimates of phytoplankton crop and zooplankton abundance were made by taking hauls at 5 m depth with an Australian Clarke-Bumpus sampler.



TEXT-FIG. 2. Kavaratti Atoll showing the relative position of island, lagoon and reef. The sites 1, 2 and 3, where observations on *Trichodesmium* bloom were made, have been shown as closed circles.

RESULTS

Form and distribution of bloom.—During the bloom the clumps of *Trichodesmium* are formed of 12–20 filaments. These clumps are large enough to be seen from shipboard and look dark-grey giving an impression of saw-dust sprinkled all over the sea surface. The intensity of the bloom, however, varied considerably from place to place. It frequently occurred in irregular patches, but very often it continued to occupy long stretches of water. The actual structure of the bloom did not

appear to have any well-defined shape, but for the fact that in some areas it formed a series of irregular lanes, several miles long. In the Laccadive area the bloom was found to be unusually dense and at Kavaratti, pads of algae, almost 4–6 cm thick, were driven ashore all along the island by the surf action. At low water, the exposed portions of the coral reef and scattered coral rocks along the shore were covered by the bloom looking as if heaps of sand were piled up. Along the island the bloom must have amounted to several tons of algae.

Due to the intensity of the bloom the transparency of the water was reduced considerably and at sites 1, 2 and 3 the Secchi disc readings were 13 m, 9 m and 6 m respectively. In those areas which appeared to be relatively free from the bloom the Secchi disc visibility was to a depth of 30 m. At site 1 the clumps were well distributed up to 10 m and their counts at 0 m, 5 m and 10 m were approximately 8,000, 7,000 and 5,000 clumps/m³ respectively. At sites 2 and 3, on the other hand, the clumps were many times greater at the surface than at 5 m or 10 m, indicating that the bloom was largely confined to the surface. At site 3, the counts at the surface were approximately 5,00,000 clumps/m³. The form of the bloom and the concentrations of clumps were found to change with time. The observations at site 1 were made on 17 April and at sites 2 and 3 on 18 and 19 April respectively. Thus, it was possible to work one site each day as the next day the conditions of the bloom at the same place were very different. During sampling, however, some difficulty was experienced at first as the clumps adhered to the walls of the sampler rather strongly. This was overcome by adding a dilute solution of formalin and shaking the sampler and the bucket until the clumps became free. After such a treatment, the counting of clumps by taking subsamples was done fairly quickly as the filaments forming clumps get separated. It was, however, not possible to make any observation in areas where the bloom was floating in the form of a thick scum. In such patches the Secchi disc reading would be zero.

These observations indicate that the bloom was largely confined to the upper few metres of water, although in such areas where the bloom was less dense, it occupied a longer column of water.

Environmental features during bloom.—The first few notable features during the entire cruise were the extreme calmness of the sea, a clear sky, a gentle breeze and strong sunshine. The calm enabled the author to approach the three sites at Kavaratti by a small motor boat. At the three sites shown in Text-Fig. 2, the temperature in the upper 10 m of water ranged from 30.6°C–29.7°C, salinity from 34.68‰–34.44‰ and dissolved oxygen from 5.62 ml/l–4.68 ml/l. The other striking features of the environment at the three locations were fairly high concentrations of PO₄-P (range 0.45–1.01 µg-at/l) and SiO₂-Si (range, 1.03–1.80 µg-at/l), from oceanic standards,

and practically no detectable NO₃-N in the upper 10 m of water column.

Several attempts were made at first to obtain plankton samples by a nylon net of 0.05 mm mesh width fitted to the Clarke-Bumpus sampler, but each time the net was completely clogged with *Trichodesmium*. Two successful hauls, however, of 30-min duration at 5 m depth were obtained in relatively clear waters and these showed that the most predominant organism in the plankton was *Trichodesmium*. Other organisms included diatoms, dinoflagellates and algae, but these were very sparse.

Five measurements of C¹⁴ uptake in the water from which *Trichodesmium* clumps were removed by passing the water through a coarse bolting nylon, ranged from 1.70–2.2 mgC/m³hr. The chlorophyll *a* values in water samples completely free from *Trichodesmium* ranged from 0.18–0.23 mg/m³. Both these observations suggest that the rate of production of other organisms in the environment was very low.

The zooplankton biomass based on 4 hauls near the atoll by using a nylon net of 0.33 mm mesh width ranged from 3.44–8.27 mg/m³ as wet weight. The range in values indicates that the zooplankton abundance during the bloom was very low by oceanic standards. On several occasions even this net was badly clogged and the samples obtained had to be rejected. The zooplankton samples largely contained copepods, gastropod veligers, decapod larvae, foraminiferans and fish eggs. A few underwater observations in deeper parts of the lagoon showed that the visibility was considerably reduced within a few metres because of *Trichodesmium* clumps. A sharp decline in the fauna of fish and other animals was also noticed in the lagoon, which is normally well populated when there is no bloom.

Periodicity of bloom.—In April/May 1969, a similar bloom of *Trichodesmium erythraeum* was seen in the Laccadives over a stretch of hundreds of miles. Further information received from the Fisheries Department, Laccadives, seem to confirm that blooms of *Trichodesmium* occur practically every year during March, April and May in the Laccadive Sea. During this period the blooms are very often intermittent and keep appearing and disappearing at one place.

DISCUSSION

Hydrographical features and bloom.—The observations at Kavaratti indicate that blooms

of *Trichodesmium* occur during a period when there is enough phosphorus and silicon in the sea but when there is practically no nitrate nitrogen. According to Jayaraman *et al.* (1960) stable hydrographic conditions prevail in the Laccadive area during the premonsoon period (April), which are associated with a thermocline at about 75 m depth. Similar conditions seem to exist all along the western coast of India and continue to remain so until the premonsoon thermocline breaks down with the commencement of monsoon towards the middle of May (Patil *et al.*, 1964; Ramamirtham and Patil, 1965). From these observations it could follow that since mixing is prevented because of stratification, the upper photic zone would become nutrient impoverished as a result of continued growth of phytoplankton. Probably nitrogen depletion occurs later than the other nutrients and this would restrict the growth of other phytoplankton organisms and would probably favour the growth of *Trichodesmium* because of its reported ability to fix atmospheric nitrogen (see last section).

Mortality of animals and bloom.—Several earlier authors have reported the mortality of fish and other animals associated with the blooms of *Trichodesmium* (see Brongersma-Sanders, 1957). In the coastal waters of Palk Bay (Bay of Bengal) a large number of dead animals was seen following blooms of *Trichodesmium* (Chacko, 1942; Chidambaram and Mukundan Unny, 1944). This was probably caused by the decay and putrefaction of the algae in rockpools and other sheltered areas.

Throughout the course of the present observations, the author failed to find dead fish or any other animal either in the sea or around Kavaratti Atoll. Even along the beaches of the atoll where thick layers of bloom had accumulated, no dead animals were seen. It is therefore doubtful whether mortality can occur because of the toxic effects of the bloom. The author swam freely in such areas where the bloom was in profusion, and where it was emitting a strong chlorine-like smell, without any ill-effect or skin irritation, although very often *Trichodesmium* clumps had stuck to the body for prolonged periods.

Nitrogen fixation by *Trichodesmium*.—The ability of *Trichodesmium* to fix nitrogen from the atmosphere has been investigated in recent years. Dugdale *et al.* (1961) for the first time

suspected the possibility of nitrogen fixation in *Trichodesmium*. This was further investigated by using the N^{15} technique (Dugdale *et al.*, 1964) and positive evidence of nitrogen fixation in *Trichodesmium* was obtained. In the tropical Atlantic Ocean, Goering *et al.* (1966) estimated the *in situ* rates of nitrogen fixation, ammonia uptake and nitrate uptake in *Trichodesmium* and showed significant amounts of nitrogen fixation. In all these experiments, since the material of *Trichodesmium* used was from the natural environment, and therefore contained associated microbes, it did not prove conclusively that the fixation of nitrogen was from *Trichodesmium* alone. In a more recent communication, Ramamurthy and Krishnamurthy (1968) presented evidence based on observations of growth for nitrogen fixation in clone cultures of *Trichodesmium* which they claimed to be bacteria-free.

These evidences, when taken collectively, appear to be impressive indeed, but still a direct proof of the nitrogen-fixing ability of *Trichodesmium* using bacteria-free cultures and a more sensitive technique is lacking (Fogg, personal communication). Nitrogen fixation in the blue-green algae seems specific to those groups which possess heterocysts (Stewart, 1966; Fay *et al.*, 1968). *Trichodesmium* species lack heterocysts and although in a recent communication a non-heterocystous, coccoid blue-green alga, *Gloeocapsa* sp. has been reported to fix nitrogen (Wyatt and Silvey, 1969), a clear-cut proof on *Trichodesmium* is urgently needed. Evidence that potential nitrogen-fixing microbes occur in association with the blue-green algae appears to be strong (Fogg, personal communication). It is therefore important that bacteria-free cultures of *Trichodesmium* and unequivocal methods of detecting nitrogen fixation are used in future tests.

Blooms of *Trichodesmium* in the Arabian Sea seem to be a regular and annual feature and under these situations if *Trichodesmium* were to fix molecular nitrogen, it would make a substantial contribution to the nitrogen budget of the sea.

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