

ON THE MECANISM OF RED TIDE OF TRICHODESMIUM¹ IN RECIFE NORTHEASTERN BRAZIL, WITH SOME CONSIDERATIONS OF THE RELATION TO THE HUMAN DISEASE, "TAMANDARÉ FEVER"

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1. *Trichodesmium* Ehrenber = Skujaella J. de Toni.
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 3. *Trichodesmium erythraeum* = Skujaella erythraea (Ehrenb.) De Toni, J.

INTRODUCTION

It is known that the colour of suspended larger particles, if present in great abundance, can give colour to the sea. In this case, the colour is not determined by the optical properties of the water or by dissolved matter, but by the colours of the suspended inorganic particles, and the water is appropriately called "discoloured".

The discolourations of the water by plankton have been called "red water", "white water", "green water", "pink water" and other names by the natures of those appearance. The terms "red water" and "red tide" have been used inclusively for the red discolourations and for those of other colours.

After the first scientific observations of the discoloured sea water by Scoresby (1820), Charles Darwin (1839) reported the red water of *Trichodesmium* sp. in the waters off Chile during his cruise in 1832. After these reports, the discoloured water had become one of the most interesting problems of the marine biologists. Actually, the red water (often more brown than red), which is quite frequently observed in many areas and after which the Red Sea and Vermilion Sea (Gulf of California) have been named, is well known to be due to abundance of certain algae (in the Red Sea, *Trichodesmium erythraeum*) or dinoflagellates.

However, this field has not yet been fully explored, as the phenomena are usually of erratic occurrence. Then, most of the published reports on the red tides are of the annual occurrences in relation to influences upon fishing.

One of the notable examples in the open sea is "Yakumizu", off the west coast of the northwest district in Japan. During the "Yakumizu", there were no good fisheries, perhaps, by the avoiding movement of fishes, and it has been written with the Japanese symbols of the meaning of disease water. But after it disappeared, there were generally very good fisheries, and therefore it, "Yakumizu" of the same pronunciation, is also written with other Japanese symbols of the meanings of useful or medical water.

The discolouration was brown-green of colour of coffee and was derived from chaetoplankton bloom.

Another famous example is the "baccy juice" ("striking water" of "weedy water") off the north parts of the English Channel in the North Sea, which is constituted of *Phaeocystis* of *Rhizosolenia*. The baccy juice was reported to have exclusive effect through which herring showed avoiding reactions from England to the Dutch coast or encontrarily.

Besides the exclusion effect in the open sea areas, explosive phytoplankton blooms of the red tide in the inlets,

bays of otherwise limited coast may have one of a number of different biological effects, the most conspicuous of which is extensive animal mortality. The first oppression to the animal life may be caused by a transformation of the various environmental factors. Physical obstruction to their branchial respirations by much sticky plankters may be fatal to the attached bivalves (Oda 1935, Nakazawa 1911). Another example of the primary alteration of the chemical character of the water, a case of extraordinary lack of oxygen that make fish breathing difficult during the hours of darkness when photosynthesis is not taking place, and when the metabolism of the large number of phytoplankters is using up the available oxygen, was clearly observed by Nikuni (1953). Thus suffocation may be caused by the oxygen depletion, or it may be caused by the death and decay of large quantities of the phytoplankters. The process of decay of course, will use up the oxygen. Continuation of decay under anaerobic conditions would thereupon result in the production of toxic hydrogen sulphide gas, with death resulting among those animals in the shallow waters which otherwise might have been able to withstand the temporary lack of oxygen (Prescott, 1948).

Most of the reports of the mortality produced by the explosive blooms are specially of dinoflagellates. For example, extensive red tides affecting the Japan coast (Gokasho Bay, Mie) in 1934, resulted in the death of enormous numbers of pearl oysters, against which a protective method (spreading CuSO_4 solution) was proposed by Oda (1935). In 1946-47, the red tide (actually yellow-green) along the west coast of Florida resulted in very heavy mortality of fish.

There is increasing evidence that the blooms of dinoflagellates may produce poisons directly, though the nature of the poison that produced such serious results is unknown, as is the manner in which it was produced. Human respiratory irritation, also concurrent with the mass mortality of fish, have been recorded by Taylor (1917), Lund (1935), Cunter et al. (1947) and Woodcock (1948).

In many cases where excessive blooms of fresh-water phytoplankters cause no animal mortality, they may produce an obnoxious sliming of the water, or unpleasant odors (blue-green algae are specially likely to produce unpleasant odors).

Usually, however, such conditions are only obnoxious and not toxic to such terrestrial animals as might drink the water.

But, there have been authenticated cases of toxicity in such waters as reported, for example by Fritch et al.

(1934), Prescott (1948) and Olson (1951, 52). Olson surveyed all known authenticated cases of algal poisoning of domesticated and wild animals and birds. He showed that not only ingestion of the algae themselves, but also drinking water in which they had been growing is very toxic to such animals as mice.

In northeastern Brazil, the red tide is called "Tingui". The "Tingui" owes its name to the plant of that name, which is a term of the native Tupi, indicating a kind of Timbó. Both plants are used in fresh water to poison fish, which are edible for men without harm.

The city of Recife is situated at 8.° south in latitude, northeastern Brazilian shore, where there are reasonably uniform air temperatures (27 — 29.° C), high humidities (68 - 99%), and almost always onshore breezes (5m/ sec). The casting-net fishermen call the red tide "Tabaco" because of the appearance, and they are aware of its influences upon the fishing. The inhabitants, however, do not know what the red tides are, and sea-bathers have probably not been deterred by the red tides.

At Tamandaré, 120 km south from Recife in the state of Pernambuco, there is a curious disease called "Tingui" (See Fig. 1). A Brazilian physician, Frederico A. Simões Barbosa, who studied the disease in 1943 when the "Tingui" attacked almost all the population and soldiers indiscriminately, suggested the provisory name "Tamandaré fever". According to his report, the disease goes on seriously for three days and is characterised by initial respiratory troubles, heavy asthenia, high fever, muscular, articular and post-orbital pain and sometimes a rash on the thorax and the arms. When he went there, the military area near the beach was like a desert, because hundreds of soldiers had kept to their beds. He stated that it was easy to establish etymology of the term of the disease "Tingui", though he did not actively support the epidemiological relation between appearance of the "Tingui" and the legend of "Tingui". The legend of "Tingui" written by him is as follows; "At certain times of year, in summer, the sea becomes turbid, the air is heavy and the respiration is made difficult. Soon afterwards, dense agglomerates appear on the sea, the cream does go near to the beach, this is the "Tingui". The tide begins to go out and the cream is deposited on the reefs. The mortality of fish is enormous. The residents of Tamandaré know to become ill. The "Tingui" attacks everyman indiscriminately".

During the end of February and the beginning of March in 1961, there was seen discoloured water along the coast of Recife and of Tamandaré. The authors examined samples

collected at the beaches of Recife and Tamandaré, and they were found to be composed of concentrated masses of a single species, **Trichodesmium erythraeum**.

In October 1963, the discoloured water concurrent with unpleasant odor appeared at the sea shore of Recife, where the Oceanographical Institute of the University of Recife is located. The general characteristics of the discoloured water and the distribution of plankton were immediately studied. The results are here reported with some examinations of the mechanism of the discolouration.

In the present work, the microscopic observation of **Trichodesmium** were done mainly by Enide Eskinazi, the discolouration studies were treated by Maryse N. Paranaguá and the distribution of plankton with other synthetic considerations were studied by Shigekatsu Satô, respectively.

The present authors wish to express deepest appreciation to Dr. Lourinaldo Barreto Cavalcanti, who gave chemical data of the sea water samples, and to Dr. Olímpio Carneiro da Silva, who suggested annual occurrence of the red water in this region and furnished the samples collected in 1961. The authors are also indebted to Dr. Petrônio Alves Coelho for his valuable advice, to Mr. Newton Celso Batista de Oliveira, for his photography, to Mr. Paulo Eugênio Martins de Almeida, Fernando Tavares dos Reis and other members of the Institute for their cooperation throughout this study. Thanks are also due to Dr. Frederico A. Simões Barbosa of the Higienical Institute of the University of Recife, who kindly sent his reprint for the authors' use to Dr. Francisco Correia de Oliveira and to Mr. Antonio Valdesio Belo of the Fishery School of Tamandaré, who showed something of the disease and the red tide at Tamandaré. This work was generously supplied through the courtesy and encouragement of Dr. Ramon Nóbrega, the director of the Institute, to whom the authors are much obliged. Finally the authors wish also to express their gratitude to Prof. João Alfredo Gonçalves da Costa Lima, Rector of University of Recife for his kindness to carry out this study.

RESULTS

1. GENERAL OBSERVATIONS

On the 15th. October 1963, the red tide was found on the sea shore in front of the Oceanographical Institute. Onshore breeze brought unpleasant odor like that of ferment-

ted dry grass. Of the 20 persons, who were asked of the odor, 5 persons had sensed nothing and 9 persons of other 15 had noticed the odor like some of putrid algae. It was at 10 o'clock, the sea was calm and the tide was going out. The sand of the beach near the water's edge, which was cleaned up by the heavy rainfall during the night, was coloured in dark-green with strip patterns of films in red-wine-colour here and there. Covering water surface just near the water's edge, light-green cream-like materials were floating. The materials constituted a band of 0.5m in width along the water's edge, beneath which dark-rose water was hidden.

Outside of the light-green band, pink water was spread diminishing its colour about 2 or 3m in width along the shore. More outside, there was seen turbid water. Figuratively speaking, there were seen four bands; dark-green sand surface with strip patterns of red-wine-colour, light-green cream band, pink, water band and turbid water. These bands were distinctly observed specially at the most inner part of the water closed by reef (See Photo 1-2).

In the next morning at full tide, there were no unpleasant odors nor any curious colours. But, when the tide began to be at its low, again the unpleasant odor came with breeze and there were also the same colourfull bands along the beach and shore.

On the 17th, the odor changed to a less putrid one and the sea water seemed to become more whitish with increased turbidity.

On the 18th, there were some agglomerates drifting at the water's edge, and nothing more. The fisherman of cast-nets said that the fishing had been very bad during this period.

On the 19th, the fishing became good again, according to the cast-net fisherman.

On the 28th, the red tide appeared again along the coast of Recife.

Observations along the coast were done with a jeep, from the river of Barra das Jangadas to Pina (See Fig. 2), on the next day, 29th October. At. St. A, along the river bank, there were only seen a band of yellow-greenish foam. At. St. B, there came the odor and was seen a foam band also. At. St. C, entrance of the river, there were the odor, the foam band and the dark-green cream at the water's edge. From the entrance of the river to Pina, there were three areas, where the discolourations were observed. It is very interesting that each of the above-mentioned three areas was inner part of the water closed by reefs. At. St. D, there were seen very much agglomeration of yellow-green foam and much dark-green cream materials. At St., F, there



Photo 1-2: Reefs and enclosed waters in front of the Institute. In photo 2 the sampling bottles and the package of cigarretes are put on the dark-green cream on the sand, white foam at the water's edge of the photograph shows light-green cream of *Trichodesmium*. Miss at the left hand and the Miss at the right are collecting the light-green cream and pink water respectively. Recifes e águas fechadas em frente ao Instituto. Na foto 2, as garrafas de amostras e o maço de cigarros estão colocados na nata vermelha escura, sobre a areia; a espuma branca na foto, a nata verde claro de *Trichodesmium*. A srta. à esquerda e a Srta. à direita estão coletando a nata verde claro e a água côr de rosa, respectivamente.

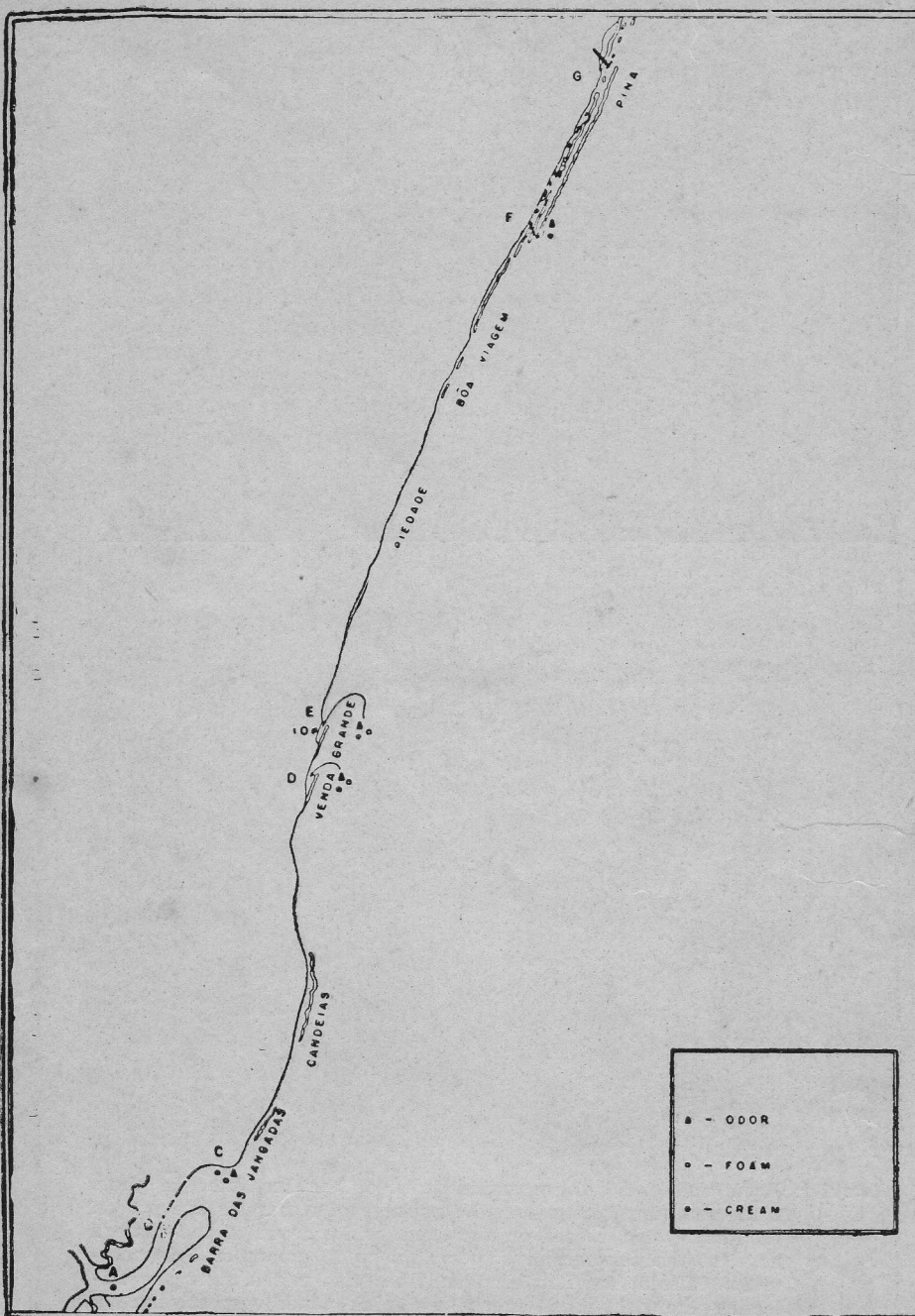


Fig. 2 — Schematic chart of the beach of Recife, showing the occurrences of the odor, foam and cream of *Trichodesmium* on the 29th October 1963.

Mapa esquemático da praia de Piedade mostrando as de odor, espuma e nata de *Trichodesmium* em 29 de outubro de 1961.

were only cream materials. At every station, the odor was detected. However, there were not seen any band of red-wine-colour on the sand and pink water near the beach. Several hundreds meters outside of reefs, there were sometimes seen one or two bands of reddish brown colour, floating parallel to the shore line.

On the 30th, four colour bands were seen near shore in front of the Institute as had been seen on the 15th October. And the water was much more whitish.

On the 31st, the red tide disappeared except for some agglomerates of dark-green cream.

On the 1st November, the very limited part in front of the Institute (St. 1, see Fig. 3) was covered with dark-green cream of its surface changed in red-wine-colour and with pink water, where hot sea water closed on the land by the rocks was coming down to the water's edge along the heated beach sand.

On the 2nd and 3rd, observations were not made.

On the 4th, there was seen nothing along the shore.

General characteristics of the varied discolourations will be summarized as follows.

Type of discolouration		I	II	III
Places	Dates	15-17,30 Oct.	28 - 29 Oct.	1 Nov. — ? (2 or 3 Nov.)
Sea water		whitish	turbid	turbid
Near water's edge		pink water	dark-green cream	turbid
Water's edge		light-green cream	yellow-green foam	dark-green cream with its surface changed in red-wine-colour
On the sand		dar-kgreen with strip patterns of red-wine-colour		

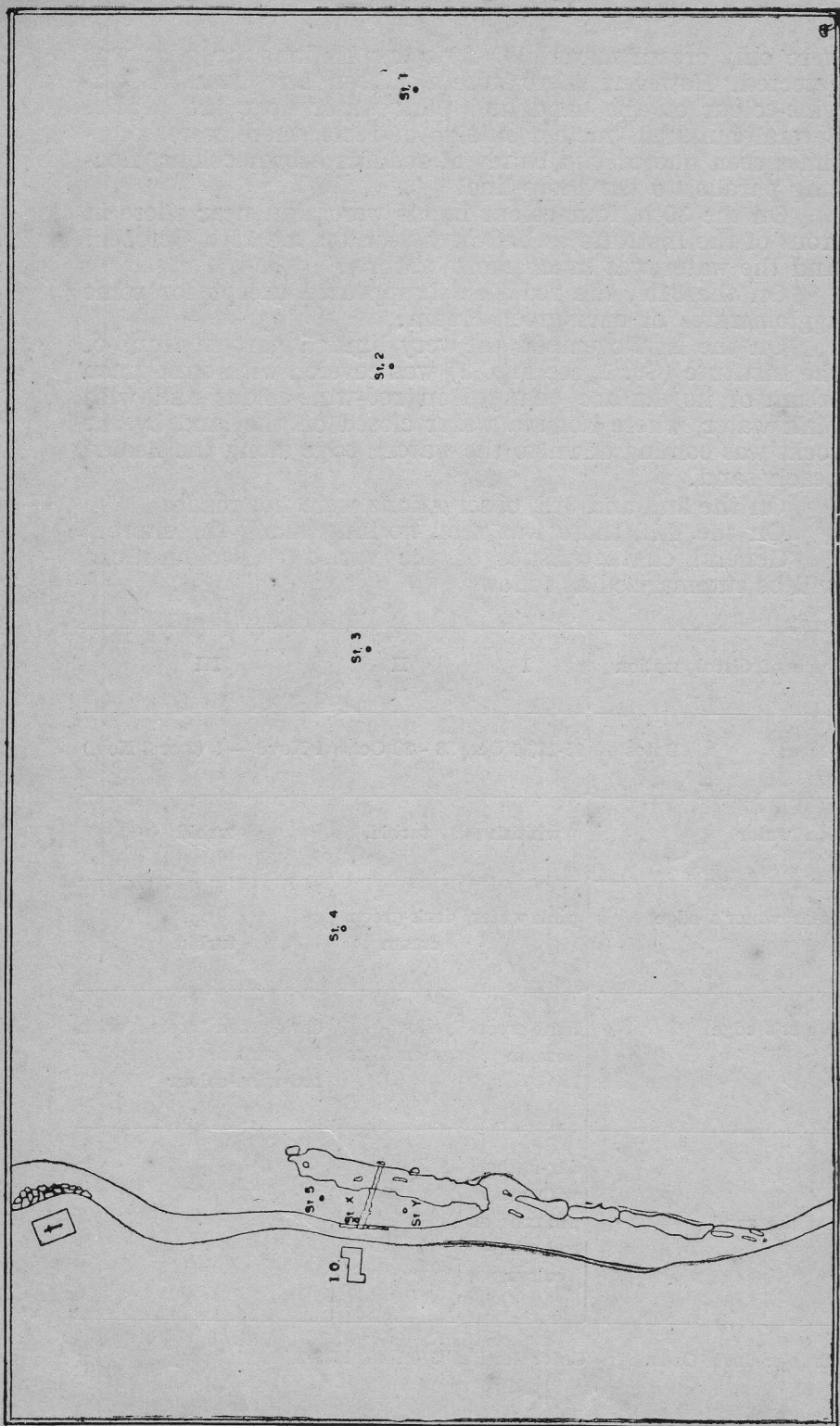


Fig. 3 — Schematic chart of the sampling stations in front of the Institute.

II. MICROSCOPIC OBSERVATIONS OF **TRICHODESMIUM ERYTHRAEUM**

Various samples were collected on the beach-sand, at the water's edge or in the coastal water. Careful observations were made for existence of dinoflagellates on the samples, fixed by formalin and unfixed. However, dinoflagellates, armored or naked, were very few. Diatoms were also comparatively few. But densely concentrated colonies of **Trichodesmium erythraeum**, a species of blue green algae, were seen in all the samples collected in Recife and at Tamandaré in 1961.

Microscopic observations of the colonies, of the filaments, of the trichomes and of the cells of the species were done of each sample. Characteristics of the different forms observed are given as follows:

(A) Dark-coloured colonies

The form of colony was like a bundle with its margin out irregularly (See Photo 3). Some of the filaments got slightly twisted around one another and then the appearance of the colony resembled **Trichodesmium contortum** (though both species are indetical to each other by some authors). The surface of the colony was generally clean. The colonies were approximately 0.75mm in length, consisting of 20 to 40 filaments.

The filaments were laterally joined or just twisted to one another, and the sheath of filament was delicate but distinctly visible. The trichomes, always with tapered terminal cells, were observed clearly. They consisted of 80 to 200 cells (see Photo 4).

The cells, on the whole, appeared to be of dark brown colour.

Minute observations, however, showed two types of cells with different colours; one consisted of dark-coloured cells and the other of light-coloured cells.

(1) Dark-coloured cells. The cells had some central structures of light-green colour, scattered green pigments and red-brown liquid filling up the cell spaces. The cells always gave distinct wall-view and were measured 11-12u in diameter, 4-6u in height, respectively.



Photo 3: Dark-coloured colonies of *Trichodesmium*.
Colonias de *Trichodesmium* de coloração escura.

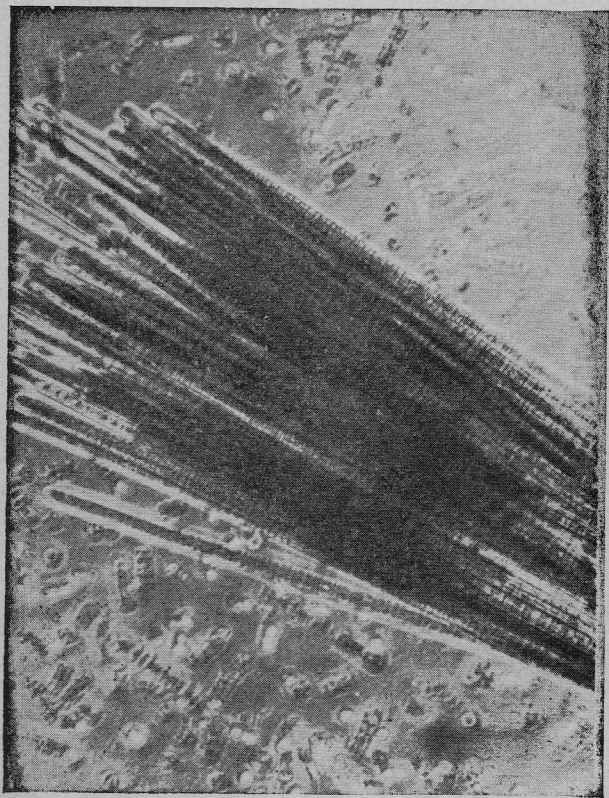


Photo 4: Filaments of the colony.
Filamentos da colônia.

(2) Light-coloured cells: These cells had light-green pigments some of which concentrated in the cell centers. These cells had no red-brown liquid and did not give distinct wall-views. The cells were 10.5 - 11.5 u in diameter, 6-8 u in height. In other words, some cells had elongated forms of single dark-coloured cell and other cells had compound forms of two dark-coloured cells.

The terminal cells and several adjacent ones and sometimes some cells of intermediate parts of the filaments were commonly of light-colour, though most cells of the filaments were of dark-colour (See Photo 5-6).

The samples collected in the red-wine-colour strip patterns, pink water, dark-green cream and turbid whitish water in 1963 belonged to the dark-colored type of colonies. The samples collected at Barra das Jangadas in Recife on the 1st March in 1961 belonged also to this type.

(B) Light-coloured colonies.

The form of colony was completely like a sheet, each margin of which was cut like a conic generally. Its surface was always dirty one.

The filaments were laterally joined to one another as regulary as a bamboo-screem, though the margine were not set straight. The sheath of filament was so delicate as to be almost imperceptible. The trichomes generally lacked of tapered terminal cells.

Most of the cells, especially of the terminal part of the trichomes, consisted of the aforementioned light-coloured cells, which gave the impression of a phase of decomposition (See Photo 7-8-9).

The sample collected in the light-green cream and the yellow-green foam belonged to this type of colonies. The sample collected on the 28th February in 1961 also belonged to this type.

(C) Withered colonies.

The samples collected on the 30th of November in 1963, had different characteristics from the foregoing two types of colonies.

The colonies were commonly green in colour, neither light nor dark, and the filaments were more twisted, having

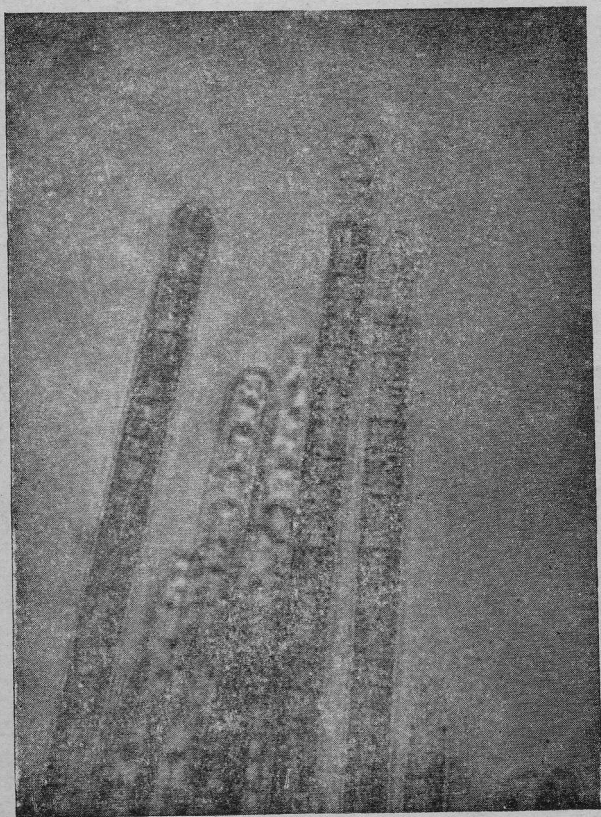


Photo 5: Filaments of the colony, showing two types light and coloured) of cell.
Filamentos da colônia, mostrando dois tipos de células (clara e escura).

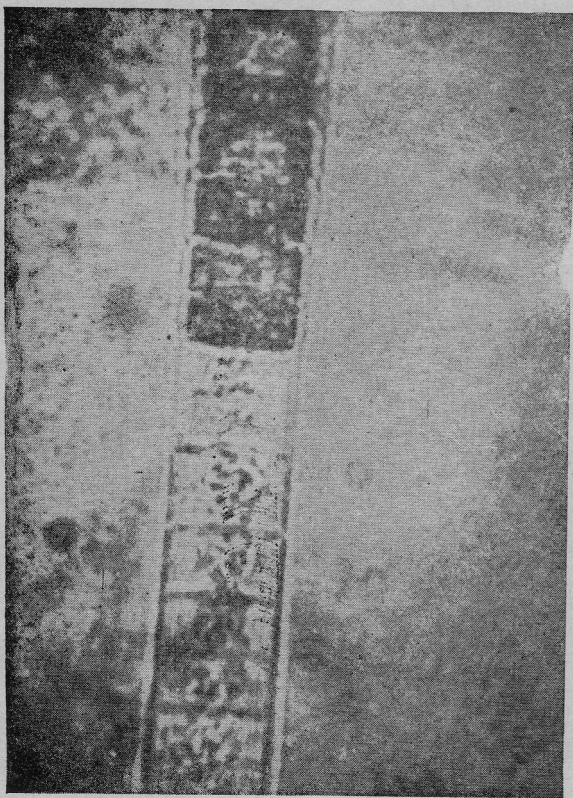


Photo 6: Filaments of the colony, showing two types light and coloured) of cell.
Filamentos da colônia, mostrando dois tipos de células (clara e escura).

the form of more compact bundles than those of the dark-coloured colonies. They had always distinct cell-wall-view and terminal cells.

As a matter of further interest, the cells were somewhat withered, with distinct slits between them, and the filaments had notched walls.

They contained more light-coloured-cells than did the dark-coloured colonies, although the cells were withered (See Photo 10).

III. DISCOLOURATION EXPERIMENTS

For examining the discolouration mechanism, samples collected in the strip patterns of red-wine-colour, light-green cream, dark-green cream and pink water were tested by the various solvents and temperatures. The samples were put in glass tubes with solvents, mixed and observed:

(A) Solvents.

(1) Fresh water. Just after samples were mixed with fresh water, the solution changed soon to pink and then changed to dark rose after about one hour, with released pigment, probably phycoerythrin, from the cells. Some of the colonies floated up to the surface and others were deposited on the bottom. Finally the surface was occupied by the light-green colonies and the bottom was occupied by the dark-green colonies. The pink water in the coastal water was derived probably in same manner.

(2) Sea-water. With sea-water in tubes, same discolouration occurred as mentioned above, although the colour of the solution was finally more pale.

(3) Brackish water. The brackish water (a mixed solution of sea water and fresh water) showed results intermediate between the two above.

(4) Alcohol. Just after samples were put in the alcohol, the solution changed to green, probably because of chlorophyll and carotinoids, the colonies releasing the colour were changed to purple and deposited on the bottom.

It may be worth noting that the samples collected in the dark-green cream on the 29th of October were delayed in releasing the colour and the solution were pale in colour as compared with the samples collected on the 30th October.



Photo 7: Light-coloured colonies of *Trichodesmium*.
Colonias de células claras de *Trichodesmium*.

(B) Temperatures.

(1) Cooling. When the samples were stored in a refrigerator, the reactions occurred later than when at room-temperatures.

(2) Heating. When heated with water, the samples were changed from original colour to brown and black. But when heated without water, the samples were changed to red-wine-colour. It seems that in floating conditions the red-wine-colour came out from the cells in the same manner at the surface of the agglomerates under strong sunshine.

IV. PLANKTOLOGICAL SURVEYS

The samples were collected by vertical hauls of Kitahara's quantitative net (22.5 cm in mouth diameter made of bolting cloth N.P.; 58). Sub-samples (generally 1/200) were examined and the plankton number per litre was calculated on the assumption that the filtration rates of the net were 100%. Drift of the survey boat by wind and nonuniformity of the horizontal of plankton at same station were not considered.

(A) In the previous year (1962).

The samples were collected by vertical hauls from the depth of 2m in 1962, about one mile off shore in front the Oceanographical Institute (See Fig. 3). Calculated numbers of plankton were shown with the results of the samples collected at same station in 1963 in Fig. 4. Average of zooplankton during July 1962 and January 1963 was 7.6 individuals and that of phytoplankton was 6,427 cells per litre. Standing crops of phytoplankton ranged 55-590 cells per litre, showing poor production in the low latitude, with the exception of October. Through this period very few *Trichodesmium* were observed, and on the 19th of October considerable multiplication of phytoplankton, were observed (27,500 cells per litre), consisting mainly of *Chaetoceros* spp.

(B) In 1963.

(1) On the 4th of October. Zooplankton and phytoplankton number per litre were 13 individuals and 150 cells respectively and there was no *Trichodesmium*. This indicates that there was no significant difference from those of

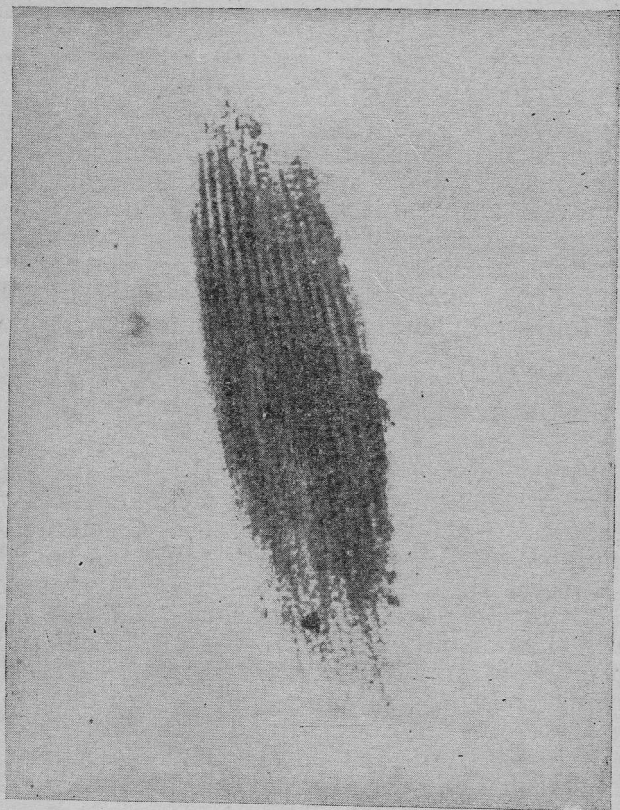


Photo 8: Light-coloured colonies of *Trichodesmium*.
Colonias de células claras de *Trichodesmium*.

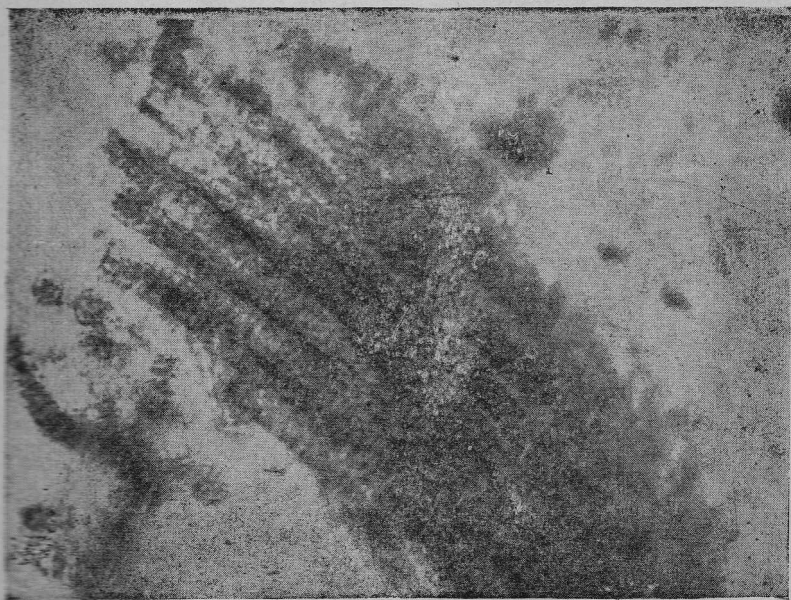


Photo 9: Light-coloured colonies of *Trichodesmium*.
Colonias de células claras de *Trichodesmium*.

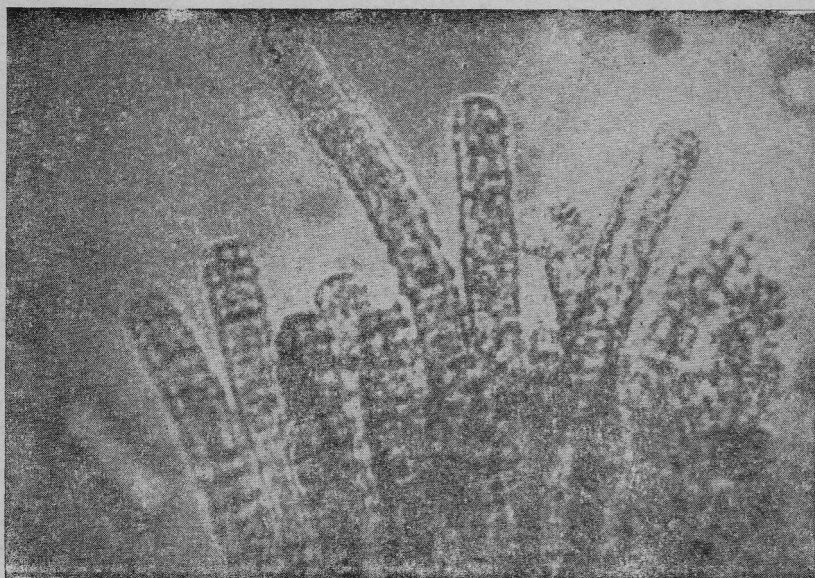


Photo 10: Withered colonies of *Trichodesmium*.
Colônias contraídas de *Trichodesmium*.

the previous year, except that there were not such diatom increases this season, as was seen on the 19th of October in 1962.

(2) On the 18th of October. Just after first disappearance of the discoloured water, plankton samplings were done by vertical hauls from the depths of 2m and 5 or 7m at five stations ranging same distance from each other, the farthest of which. St. 1, (see Fig. 3), is located approximately one mile from the shore. The results are shown in Table 1.

Zooplankton number did not show any significant difference.

	Layer Station	1	2	3	4	5
Zo	0-2m	11	18.5	4.5	2.5	10
	0-5(7)m*	7.5	16.8	8	9	—
	2-5(7)m**	6.2	15.8	10.3	13.3	—
Di	0-2m	67.5	737.5	977.5	350.0	247.5
	0-5(7)m*	197.0	393.0	516.0	97.0	—
	2-5(7)m**	249.0	160.0	202.0	0.0	—
Tr	0-2m	15.0	27.5	0.0	155.0	25.0
	0-5(7)m*	9.3	4.0	6.0	31.0	—
	2-5(7)m**	7.0	0.0	10.0	0.0	—

Tab. 1 — Individual number of zooplankton (Zo), cell number of diatoms (Di) and filament number of **Trichodesmium** (Tr) per litre in hauls on the 18th October 1963.

* St. 1: 0-7m, St. 2-St. 4:05m. St. 5. no sampling.

** Calculated on the basis of the remainders of the above two values.

Número por indivíduo do zooplâncton (Zo) número de células de diatomáceas (Di) e número de filamentos de **Trichodesmium** por litro (Tr), em coletas realizadas a 18 de outubro de 1963.

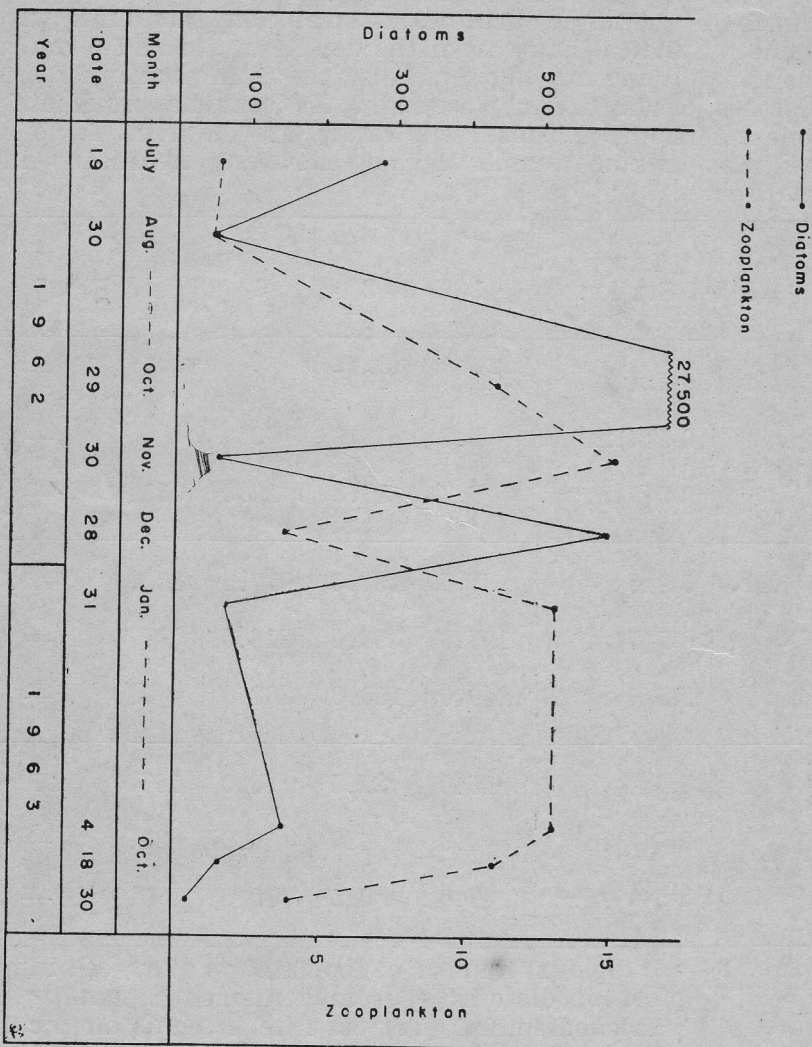


Fig. 4 — Variation of the individual number of zooplankton and cell number of diatoms per litre at St. 1.

Variação individual do número de zooplankton e número de células de diatomáceas por litro na Est. 1.

Diatoms also were in ordinary amounts, however, at St. 2 and St. 3 there were considerable increase.

Os **Trichodesmium**, considerable number of the filaments were in the upper layer (0-2m), and the horizontal distribution was not uniform. The largest number was at St. 4, which had 155 filaments per litre. As compared to that in the upper layers, distribution in all layers (0-5 or 7m) might be considered as fairly uniform. The distribution in all layers (0-5 or 7m) seemed to be inversely proportional to that in the upper layers. But this relationship might be a false one because of locally over-abundant occurrence in the upper layers.

(3) On the 30th of October. The results are shown in Tables 2-3.

Trichodesmium increased at all the stations and there was an extraordinary increase at St. 5, nearest to the shore. At St. 2 and St. 3, where there was increase of diatom on the 18th of October, there was little increase of **Trichodesmium** on the 30th. The increase was only in the upper layers.

Cell numbers per filament were counted and are shown in Table 3. On the whole, cell numbers per filament decreased with the distance from the shore, and those in the upper layers seemed to be fewer than in the lower layers. Calculated total cell numbers per litre at each station are shown in Table. 3. Cell numbers at St. 5, inside of the reef, where the sample was collected in the whitish water just outside of the pink water, was 2,580,000, showing remarkable multiplication of **Trichodesmium**.

Approximate ratios of light-coloured, cells to all cells were counted and shown in Table. 3. At St. 1 and St. 5, the ratios were large, that is most of the cells were discoloured. At St. 2, 3, and 4, most of the cells were dark-coloured in all layers.

(4) On the 31st of October. After the tide began to go out, the water inside of reef was retained in a pool by the rock, at the conter (St. Y, see Fig. 3) of which 3 samples of 100 cc water were collected at 8:30 and 10:30 s.m. Average number of the filaments in the collected samples were 2 at 8:30 and 3 at 10:30 approximately.

Although the tide went out and left some agglomerates on the beach, the concentration of the filaments increased during two hours.

V. HYDROGRAPHIC BEARINGS

(A) In the previous years.

Seasonal variation of meteorological conditions in front of the Institute and Barra das Jangadas were reported by Okuda and Nóbrega (1960). The results (from June 1955 to July 1960) are cited in Fig. 5. In the figure, water tem-

	Layer Station	1	2	3	4	5
Zo	0-2m	4	1.5	5.5	21	1.5
	0-5 (7) m*	2	0.5	1.5	8	—
	2-5 (7) m**	1.4	0.2	1.2	0.0	—
Di	0-2m	22.5	582.5	335	425	—
	0-5 (7) m*	175	108	410	235	—
	2-5 (7) m**	256	0	460	110	—
Tr	0-2m	570	15	12.5	492.5	23.885
	0-5 (7) m*	67.1	9	8	124	—
	2-5 (7) m**	0	5	1.3	0	—

Tab. 2 — Individual number of zooplankton (Zo), cell number of diatoms (Di) and filament number of **Trichodesmium** (Tr) per litre in hauls on the 30th October.

*, **: See Tab. 1.

Número por indivíduo de zooplankton, número de células de diatomáceas e número de filamentos de **Trichodesmium**, por litro, em coletas realizadas a 30 de outubro de 1963.

*, **: Ver Tab. 1.

	Layer Station	1	2	3	4	5
Of	0-2m	86	72	91	107	108
	0-5 (7) m*	75	98	129	188	—
C t	0-2m	48,400	1,080	1,140	52,700	2,580,000
	0-5 (7) m*	503	882	1,032	23,400	—
	2-5 (7) m**	0	490	168	0	—
Pl	0-2m	54.2	0.0	13,7	17,5	50.3
	0-5 (7) m*	61.9	2.1	3,9	8.1	

Tab. 3 — Cell number per filament (Cf), calculated total cell number (Ct) and percentages of light-coloured cells (Pl) of **Trichodesmium** in hauls on the 30th October 1963.

Número de células por filamentos (Cf) número total de células calculada (Ct) e percentagem de células claras (Pf) de **Trichodesmium**, em coletas realizadas a 30 de outubro de 1963.

*, ** — Ver. Tab. 1.

peratures 500m from the shore in front of the Institute ranged from 25.5 to 28°C, with the maximum in December and the minimum in July (in 1960). And in the dry season (August-February) water temperatures were higher than in the rainy season (March-July).

Examples of the horizontal and vertical distribution of the hydrographical factors of the coastal waters in front of the Institute are cited in Table 4 from Okuda (unpublished). In the table, St. I is situated at same location as St. 1 of the present paper. The surface temperatures, ranged from 25.8-27.7°C and the salinities were 35.12-35.44‰, decreasing

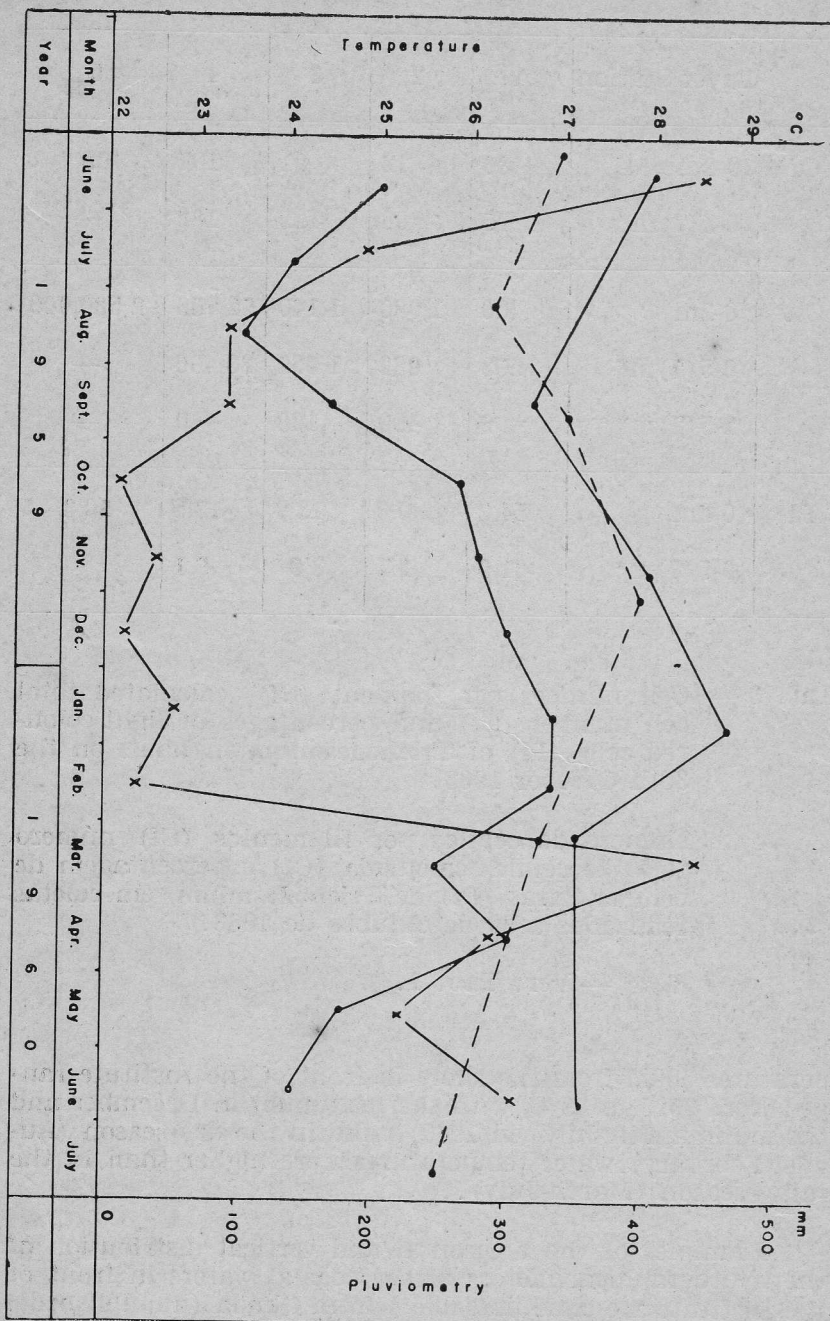


Fig. 5 — Seasonal variations of meteorological conditions from Okuda and Nóbrega (1960).

o—o, air temperature. o—o, water temperature 500m off shore in front of the Institute, o—o, water temperature at Barra das Jangadas x—x pluviometry.

Variação estacional das condições meteorológicas por Okuda e Nóbrega (1960).

Station	Depth	29 Sept. 1959		12 Jan. 1960	
		Temp.	Sal.	Temp.	Sal.
I	0m	27.7	35.12	28.0	36.18
	1	27.1	35.61	28.0	36.18
	2.5	26.8	35.68	28.0	37.57
	4.5	26.7	35.70	28.0	36.73
II	0m	27.1	35.41	28.1	39.69
	1	26.7	35.46	28.1	39.96
	2.5	26.6	35.55	28.1	39.69
	5.0	26.4	36.31	28.1	39.72
	7.5	26.5	36.33	28.1	39.87
	9.0	26.3	36.40	28.1	39.69
	0m	26.8	35.44	—	—
	1	26.8	35.43	—	—
	2.5	26.6	35.59	—	—
	5.0	26.4	36.20	—	—
	7.5	26.3	36.42	—	—
	10.0	26.2	36.31		
	12.5	26.1	36.37		
	15.0	26.2	36.42	No sampling	

Tab. 4 — Hydrographic conditions of the sea water in front of the Institute in Sept. 1959, and. Jan. 1960, from Okuda (unpublished).

St: I. one mile, St. II: two miles, St. III: three miles off shore.

Temp: Temperature °C, Sal.: Salinity ‰.

Condições hidrográficas da água do mar, em frente ao Instituto, em setembro de 1959 a janeiro de 1960, por Okuda (não publicado).

Estação — I: uma milha, Est. II: duas milhas. Est. III: — três milhas da costa. Temp. Temperatura, °C. Sal.: Salinidade ‰.

their values with the distance from the shore in September. And in January, temperatures were high and uniform at all layers, and salinities were also high with the vertical variation decreased. It seems that the stability of water diminished by the vertical mixtures from approaching oceanic current during September and January.

Seasonal variation of hydrographic factors just near the shore, where the water samples were collected at the depth of human thigh, are cited in Table 5, from Cavalcanti

Month	Temp.	Sal.
Març. 1962	29.35	36.01
Apr.	28.82	35.71
May	27.65	35.29
June	26.36	33.04
July	26.14	32.50
Aug.	25.91	34.10
Sept.	26.71	33.65
Oct.	28.28	35.07
Nov.	28.41	36.33
Dec.	28.74	36.62
Jan. 1963	29.74	36.25

Tab. 5 — Monthly averages of temperature ($^{\circ}\text{C}$) and salinities (‰) of the sea water collected at the depth of human thigh in front of the Institute, from Cavalcanti (unpublished).

Médias mensais de temperatura ($^{\circ}\text{C}$) e salinidade (‰) da água do mar, coletada na profundidade de 1 (um) metro (sem auxílio de barco), em frente ao Instituto, por Cavalcanti. (não publicado).

(unpublished). In the table, the average water temperatures ranged from 25.91-29.74°C and average salinities 32.50-36.62‰ respectively, showing lower temperatures and salinities than those of the above-mentioned data. Maximum monthly average temperature occurred in January and maximum monthly average salinity was in December.

(B) In 1963.

(1) On the 15th of October. On the first day of the first appearance of the red tide, the samples for salinity measurement were collected in the pink water inside of the

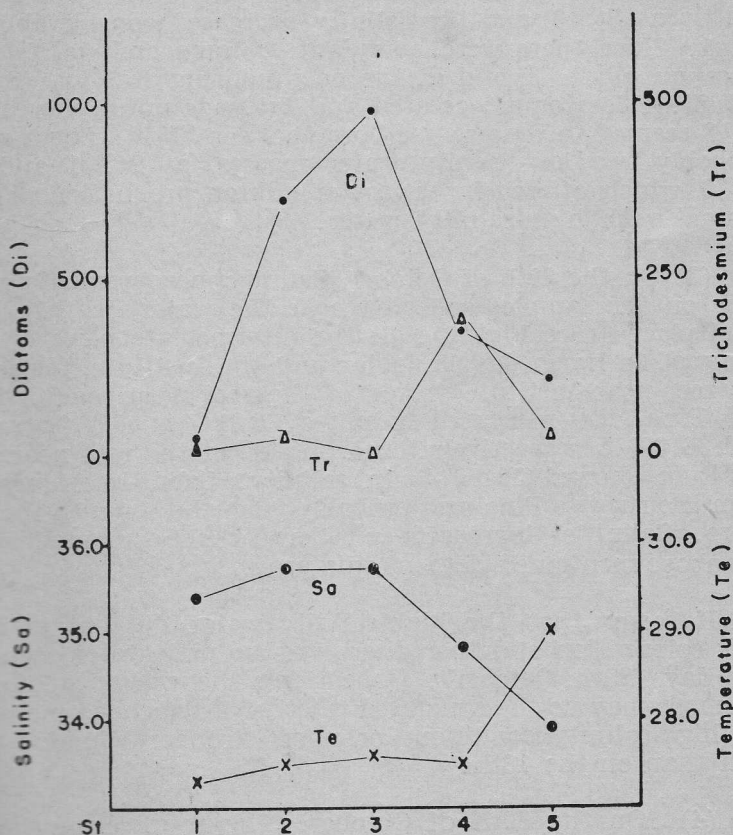


Fig. 6 — Horizontal distributions of the sea-surface salinity (‰), temperature (°C), diatoms (cell number per litre) and *Trichodesmium* filament number per litre) in hauls on the 18 th October 1963. Distribuição horizontal da salinidade na superfície do mar (‰); Temperature (°C); Diatomáceas (número de células p/litro); e *Trichodesmium* (número de filamentos p/litro), em coletas realizadas a 18 de outubro de 1963.

reef and in the whitish water outside of the reef. The salinities were 31.33‰ and 35.84‰ , respectively. It seems that the pink colour was extracted from the cells by the low-salinity water as indicated in the discolouration experiments (III, A, 1).

(2) On the 18th of October. The results of the hydrographic measurements of the surface water on the 18th October are shown in Fig. 6. The characteristic feature were very low salinity and high temperature at St. 5, as compared with the results in the previous years. The temperature decreased and the salinities increased gradually with the distance from the shore, although the temperature increased a little at St. 3, and the salinity decreased considerably at St. 1. Since there were abundant diatoms and no *Trichodesmium* at St. 3, and at the neighbouring stations (St. 2 and St. 4) diatoms decreased and *Trichodesmium* increased, St. 3 seemed to represent a borderline condition. There were probably two low-salinity water masses, at St. 1 and at St. 5, which offered large phytoplankton production at the contact with high-salinity water.

(3) On the 29th of October, Salinity measurements were done on the samples collected near the water's edge at several places (See Fig. 2). At the intermediate place of the entrance to Barra das Jangadas and the Institute, inside of the reef near Institute, inside of the reef near the Institute and Pina, the measured salinities 36.31‰ , 36.56‰ and 36.80‰ respectively. And outside of the reef near the Institute showed 36.80‰ in salinity. Salinities increased from the river to Pina and probably from the shore to the off shore. Salinities increased considerably as compared with the above-mentioned data of this year.

It seems that the high-salinity water did not extract pink colouration and then there was no pink water seen on this day (29th October). Concerning the existence of the foams it may not be concluded whether it depended more on the high-salinity conditions or upon stronger wind on the 29th than on the 18th.

(4) On the 30th of October. The results are shown in Fig. 7.

Salinities were generally uniform but temperatures were higher at all the stations, than on the 18th. Somewhat higher salinities were noted at St. 1 and at St. 5, where excessive multiplications of *Trichodesmium* were seen. Es-

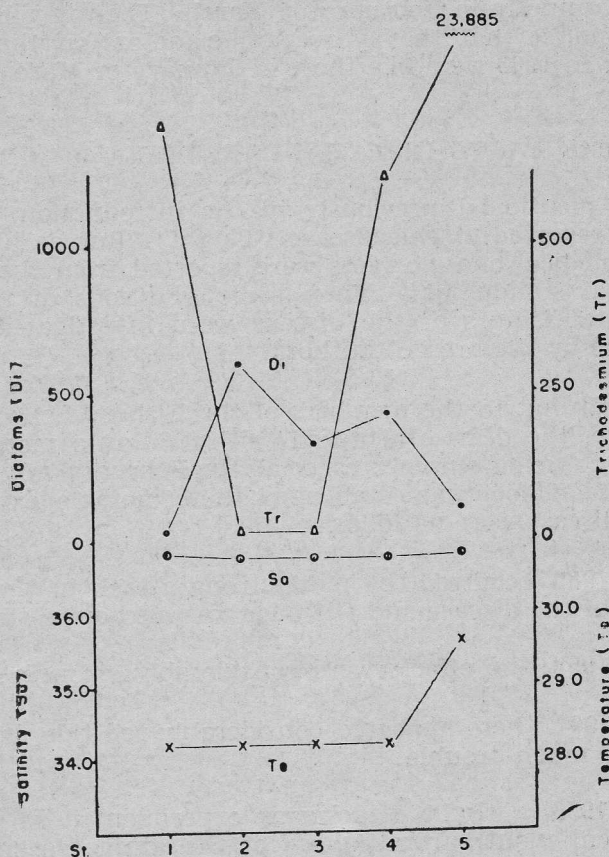


Fig. 1 — Horizontal distributions of the sea-surface salinity ($^{\circ}/_{00}$), temperature ($^{\circ}\text{C}$), diatoms (cell number per litre) and *Trichodesmium* (filament number per litre) in hauls on the 30th October 1963.

Distribuição horizontal de salinidade na superfície do mar ($^{\circ}/_{00}$); Temperatura ($^{\circ}\text{C}$) Diatomáceas (número de células por litro); e *Trichodesmium* (número de filamentos por litro), em coletas realizadas a 30 de outubro de 1963.

pecially at St. 5. inside the reef where the temperature was 29.6°C , explosive bloom was observed.

As compared with the results at St. 1 (Table 5), the results at St. I showed higher salinity and temperature, specifically, higher than maximum salinity and only slightly lower than maximum temperature in 1959-60. In 1959, 1960, these high values were observed in January or March. As mentioned later, the red tides of ***Trichodesmium*** were ob-

served annually in February or March. Then it will be worthy of notice that the hydrographic factors on the 30th of October in 1963 were like those of January or March in 1960.

VI SOME FACTS IN TAMANDARÉ BAY

As mentioned previously in the introduction, Barbosa (1943) reported of the disease "Tingui". But as his report was a medical one, no facts were reported from the oceanographical standpoint. Then some questions of the environmental factors of the disease were investigated at Tamandaré by the present authors.

According to the members of the Fishery School of Tamandaré, the disease attacked all habitants more or less annually during summer especialy in February and March. After the School was established there, notable experiences of the disease were as follows.

In 1955, occurred the most strong attack in their experiences of the disease and the odor was also quite strong.

In 1958, the effects were considerably stronger.

In 1961, there appeared considerably red tide, but it did not give much trouble.

In 1963, a slight attack was experimented in October, a different month from those of the annual occurrences, when the red tide was observed in the coastal water off Recife.

The disease was clearly related with the red tide. When the red tide appeared the red-wine-colour and the unpleasant odor spread on the bay which opened to the ocean at full tide but had only a small baymouth enclosed by coral reef at ebb tide. Everyone who lived or visited near the beach at that time was attacked by the disease without exception if he respirationed the foul air. But when the red tide disappeared, almost all persons recovered from the heavy troubles after three days. And if the patient bathed with fresh water, he would recover shortly afterwards. Actually physicians do not give any medicine but advise fresh-water bathing for the patients. And if rain came over the shore, the odor disappeared and did not give troubles of any consequence.

Someone expressed his impression that the red tide ca-

me from the ocean and killed fish in the bay. Some fisherman, who were working off-shore, were said to be able to forecast the red tide appearance near-shore. This might be possible although it has not been proved. The high mortality of fish was not authenticated and not probable also, according to the director of the School, because there are scanty fish and only few cast-net fishermen in the bay at all times.

DISCUSSION

I. THE EXPLOSIVE MULTIPLICATION OF **TRICHODESMIUM ERYTHRAEUM**

It is generally known that phytoplankton production in the tropical sea is quite poor, for example, the annual average of diatom standing crops in Palao Is. was 160 cells per litre (Motoda, 1941). Standing crops of diatoms in the coastal water of Recife are likewise very little. Average cell number (except October: 212 per litre) is very small and the maximum of the year (in October, 37,500) is also not very large, as compared with annual average in Friday Harbour of U.S.A. (62,200), Aomori Bay of Japan (24,000) and Plymouth of England (14,000) (Cupp, 1937).

However, the capacity of **Trichodesmium** to multiply rapidly within short periods is enormous. The maximum number of cells collected with the plankton net was 2,580,000 per litre, and at the water's edge the number (although uncoun- ted in this instance) was proportionally much larger. Because the **Trichodesmium** has relatively large cells and forms colonies, the mass quantity will be enormous, even compared to that of **Skeletonema**, 24,800,00, reported by Satô et al 1960 or of **Gymnodinium** (60,324,000 reported by Gunter et al 1948). In the example of the maximum collection, mentioned above in the present paper, there were only 247 cells of ther phytoplankters per litre, which indicates almost purely monospecific population growth, as compared with the other above-mentioned examples, wherein other phytoplankters (with **Skeletonema**) were 7,620,000 and (with **Gymnodinium**) numbers 616,000.

The monospecific population growth and the disease "Tingui" might easily remind of some antibiotics such as reported by Rice (1954) and Tsujita (1956), which inhibited the production of other phytoplankters, but the problem will be discussed later.

II. CAUSAL FACTORS OF MULTIPLICATION

Tsujita (1956) presented some physical conditions for the occurrence of red waters as follows:

1. Discrete mass of physiologically suitable water, with consequent development of the discontinuity layer.
2. Unusual enrichment of the coastal waters by drainage from the land.
3. Bright sunshine immediately after rains.

First appearance of **Trichodesmium** (during 15-17th October 1963) may be related to those conditions. In this season, coastal water may be enriched as indicated the considerable increase of diatoms (See IV, B, 2). Sunshine is almost always strong at this coast. After a rain during the night, water shut off by reef might be heated discretely, which was probably suitable for the **Trichodesmium** production. The increased production was limited to areas inside of reefs, and outside of reefs it was not very large. Considerable increase was noted at the nearby stations of St. 3, where (at. St. 3) the salinity was rather higher and considerable diatoms were seen. It seems that high-salinity condition is more suitable for the **Trichodesmium** production.

Second appearance of **Trichodesmium** (on the 28-30th) also shows that discrete waters inside of reefs are most suitable to the production (See I).

However, the multiplication was seen more or less throughout the coastal water, and more abundantly at the stations with higher salinities (See V, B, 4). The maximum of the temperatures and salinities were 29.6°C and 36.82‰ respectively.

The physical conditions seemed favorable for high production of **Trichodesmium**, as it occurs here seasonally, might be compared with those in the Red Sea where the water is constantly reddish by **Trichodesmium**. Salinity in the Red Sea reaches values between 40 and 41‰ and the temperature is very high mostly exceeding 30°C. This would seem to clearly indicate that the causal factors favoring multiplication of **Trichodesmium** are high-temperature and high-salinity, especially when it has been found that multiplication here is increased under such conditions.

Along the northeastern coast of Brazil, generally during December and March, such high-salinities and high-temperatures may have occurred to produce the red tide, but in 1963 they occurred very early in October.

Inside of reefs, the waters are discrete and localize the multiplication by being heated more to get suitable higher temperatures. When the multiplication occurs on the surface of the sea throughout the numerous favorable areas along the coast, and when the agglomerates are concentrated by onshore wind and tidal currents, the production may be accelerated and be enormous in enclosed bays such as the Tamandaré Bay shut by reefs. And at full tide, the agglomerates sometimes float out over the low reefs, and they form discoloured bands, receiving tropical strong sunshine and multiplying their cells in the bands of higher respectivity to the temperature-energy, than that of the neighbouring off-shore water.

According to Ueno (1959), the influence of temperature to diatom production increases in the temperatures more than 25°C, and therefore a little increase of temperature results in a large decrease of total diatoms. Then in the higher temperatures written in the present paper, inhibitory substances produced by **Trichodesmium** are not essential for understanding of the decrease of diatoms.

The duration of the red tide of **Trichodesmium** was approximately three days each time. In this case, it may be considered that the species probably produces antibiotic substance to restrain the population growth of itself, as in case of chlorellin produced by **Chlorella** (Pratt et al. 1944).

III. VARIED DISCOLOURATIONS

In the present paper, varied discolourations of **Trichodesmium** are stated; pink water or "pale reddish tint" off the coast of Chile (Darwin, 1839), reddish brown bands of reddish bands in the Red Sea, whitish and turbid water such as that off Japan reported by Tsujita (1956), etc. It is known of the colouration of blue-green algae that the variations of the relative quantities of chlorophyll, carotinoids phyco-cyanin and phycoerythrin combined sometimes with pigmented sheaths around the cells, and with light refracted by pseudovacuoles, cause many of them to be other colours, such as red, bright green, yellow, brown, purple and even black. At time, and in some localities a great abundance of such coloured forms in the plankton may cause the water in which they are going to take on a coloured cast. (Davis 1959). However, it is noteworthy that the reddish pigment, probably phycoerythrin, is extruded from the cells in brackish water, or at the surfaces of the agglomerates by heat, as reported previously, showing different discolouration from that of the

cell itself in the water, although cells change their original colour also.

The mechanism might influence not only the colouration but also the forms of the cell, filament and colony. The existence of withered cell collection one mile off the coast seems to show that the mechanism is not a process of common decomposition. The mechanism may suggest an extraordinary process of production because the ratios of light-coloured cells to all cells increased at the station with abundant **Trichodesmium**.

But that is left for future study without conclusion here, also whether some light-coloured cells are compound forms of two dark-coloured cells.

IV. THE RED TIDE OF **TRICHODESMIUM** AND "TAMANDARÉ FEVER"

Woodcock. (1948) reported of the human respiratory irritation associated with high concentrations of plankton (**Gymnodinium** sp). He found on the sea that the presence of an irritant in the free air over the red water seemed to be correlated with increased wind and with the presence of breaking waves and foam. According to his report, simple experiments show that respiratory irritation is always associated with the presence of small drops of "red water" in the air. Drops from effervescing heated "red water" were more irritating than drops from effervescing water at room temperature, and these latter drops seemed more irritating than spray drops produced by the hand atomizer.

Though the odor of **Trichodesmium** is not irritating but only an unpleasant one, the mechanism of the occurrence seems to resemble that of **Gymnodinium** as regards to the formation of foam and to the increase by heated condition. Since the unpleasant odor disappeared and the disease did not attack on rainy days in Tamandaré Bay, and since the patients are recovered by fresh-water-bathing, the cause of the disease may be fragments or contents of the cell of **Trichodesmium**, which were contained within "the sea-water nuclei or aerosols" and were sent in the over the beach such as reported in the case of **Gymnodinium**. At any rate, it is a matter of interest that red tide of **Trichodesmium** gives serious troubles to the human, as compared with only respiratory irritation by that of **Gymnodinium**.

Besides of the occurrences in Tamandaré Bay, the disease may have occurred at other places along the northeastern coast. But the occurrence, if present, unless annually

or strongly, may not attract any public attention, since the nature of the disease, at the initial stage, is similar to a common cold. For the disease, named locally as "Tingui", Barbosa (1944) provisorily suggested the endemic name "Tá-mandaré fever", but the disease is characterized in this paper as "**Trichodesmium** fever", because of the biological or planktonological relationship brought out by the present authors.

SUMMARY AND CONCLUSIONS

1. The red tide of **Trichodesmium erythraeum**, a species of blue-green algae, appeared three times during October and November in 1963 in the coastal waters of Recife, northeastern Brazil. The samples were examined and presented along with the results of planktological and hydrographical surveys in the previous years.
2. From the beach sand, to the outer reef, varied discolourations were observed, namely of turbid, whitish, pink, light-green, dark-green, yellow-green, and red-wine-colour.
3. Three types of the colonies were found to consist differing proportions of dark-coloured cells and light-coloured cells.
4. Pink water and red-wine-colour were derived from the reddish pigment of the cells in water, with solvent of brackish water and at the surface of agglomerates affected by heat, respectively. The mechanism seems to present varied discolourations different from those of the cells themselves in the water.
5. In the previous year, the average number of diatom standing crops was poor, with its maximum in October. In 1963, diatoms increased only slightly in October and decreased shortly after the first appearance on the red tide of **Trichodesmium**.
6. The multiplication of **Trichodesmium** was very abundant showing its maximum 2,580,000 cells per litre on the results of net-hauled samples.
7. In the previous year maximum temperature and salinity were observed during December and March. In

1963, same high temperature and salinity were observed in October.

8. The explosive productions of **Trichodesmium** were observed specially in the waters enclosed by reefs. The species may multiply abundantly in the high-temperature and high-salinity conditions which are not suitable for diatom production.
9. The red tide may have resulted in poor catch of cast-net fishermen near shore, but is cannot actually be proved.
10. The human disease, which is locally named "Tingui" and the suggested provisorily endemic name "Tamandaré fever" by Barbosa (1944), is herein characterized as "**Trichodesmium** fever", chiefly because, the disease may be derived from "the water nuclei or aerosols" containing fragments or contents of **Trichodesmium** such as in the case of **Gymnodinium** reported by Woodcock (1948). The disease has been observed almost annually, generally in February or March, only in Tamandaré Bay but it may have occurred throughout the northeastern coast of Brazil without attracting any public attention.

RESUMO

1. O **Trichodesmium** que ocasionou a maré vermelha é uma espécie de alga verde azulada (Cyanoficea) que apareceu 3 vezes no período de outubro a novembro de 1963 nas águas costeiras do Recife, nordeste do Brasil. Para as amostras destas águas contendo **Trichodesmium** foram feitos os estudos planctológicos e hidrológicos.
2. Desde a areia da praia até a linha dos recifes, foi observada uma grande variedade de côres a saber: lodoso, esbranquiçado, rosa, verde-claro, verde-escuro, verde-amarelado e vinho.
3. Foram observados três tipos de colônias constituídas de células escuras e células claras.
4. A variação de côres apresentada pelo mecanismo de desprendimento de pigmento é maior do que aquela apresentada pelas células nas suas várias colorações.

5. De acôrdo com observações feitas em 1962, o número de diatomácea alcançou o seu máximo em Outubro. Em 1963 houve um pequeno aumento, em outubro, mas diminuiu pouco depois dos primeiros aparecimentos da maré vermelha de **Trichodesmium**.
6. O resultado das coletas demonstrou que a multiplicação de **Trichodesmium** alcançou um máximo de 2.580.000 cels/litro.
7. No ano anterior a temperatura e a salinidade máxima foi observada em Dezembro estendendo-se até Março de 1963. Neste ano, o máximo foi em Outubro.
8. A produção máxima de **Trichodesmium** foi observada especialmente nas águas cercadas pelos recifes. As espécies multiplicavam-se abundantemente em alta temperatura e salinidade, condições estas que não são convenientes para produção de diatomácea.
9. De acôrdo com as informações colhidas dos pescadores, a pesca no período em que ocorre a água vermelha é pobre; todavia, não temos os dados suficientes para confirmar.
10. A doença humana que no local é conhecida com o nome de "Tingui" foi denominada por Barbosa (1944) de "Febre de Tamandaré". Devido as suas características, esta doença pode ser chamada de "Febre de Trichodesmium" porque ela deriva "the water-nuclei or arrosols" contendo fragmentos de **Trichodesmium**, semelhantes aqueles de **Gymnodinium** descritos por Woodcock (1948). Até agora a doença foi observada anualmente em fevereiro ou março somente na Bahia de Tamandaré. Mas, presume-se que ela tenha ocorrido em toda a costa nordeste do Brasil sem todavia ter sido notada.

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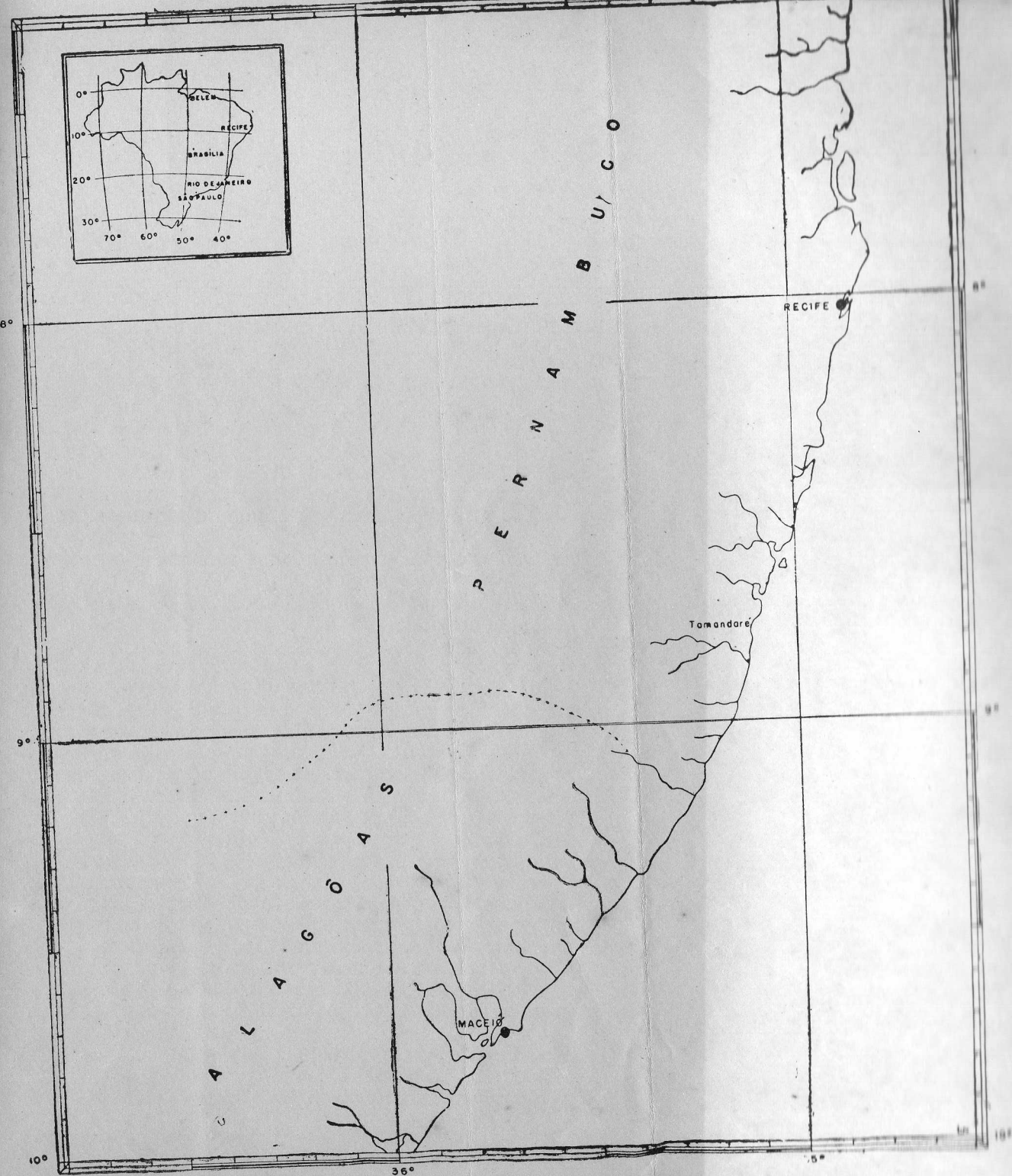


Fig. 1 — Map of northeastern coast of Brazil.
 Mapa da região Nordeste da costa do Brasil.