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Red Tide in the Morobe District of Papua New Guinea[1]

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ABSTRACT: A red tide near Lae in the Morobe District of Papua New Guinea is described. The causative dinoflagellate, *Pyrodinium bahamense* Plate, is known to produce paralytic shellfish poisoning. Its characteristics are extensive orange-brown discolorations of seawater by day, luminescence at night, and mortality to a wide variety of marine life, including dolphins, turtles, fish, and bivalve mollusks. An analysis of plankton samples taken in the area is given. Bivalve shellfish proved highly toxic, but no toxin was detected in dead and live fish from water visibly discolored by red tide. Comparisons are made with observations of a previous red tide in the Central District near Port Moresby.

AN ORANGE-RED DISCOLORATION, evidently a "red tide," in the coastal waters between Lasanga Island and Salamua peninsula in the Morobe District of New Guinea was first observed on 12 November 1972. On 28 November it was reported to be present in a lagoon off Morobe harbor, and on 13 December 1972 it was again present in the sea near Lasanga Island as well as closer to Lae (Figure 1).

Prior to this event, few sightings of red tides in the Morobe District had been recorded. Sightings before the present outbreak are summarized below (Maclean, in press).

April 1971:	Red tide observed near Lae for the third time that year.
May 1971:	Red tide patches seen near Salamua and in inlets near Lasanga Island.
November 1971:	Red tide occurred along the coast between Lae and Morobe; numerous dead fish and turtles washed ashore and eaten by villagers.
October 1972:	Red tide sighted near the coast 60 kilometers east of Lae.

The appearance of a red tide about November is an annual event according to Morobe harbor villagers, who look forward to the associated fish and turtle kills. The meat from the dead animals is cooked and eaten without ill effects.

Elsewhere in New Guinea, three fatal cases of paralytic shellfish poisoning due to blooms of the dinoflagellate *Pyrodinium bahamense* Plate occurred at Walai village on the south coast of mainland Papua near Port Moresby in April 1972 (Worth, Maclean, and Price 1975).

The present investigation was undertaken to ascertain the nature of the November–December 1972 red tide on the Morobe coast, and whether it was a potential health hazard.

The help given by Dr. G. Worth, who carried out the toxicity bioassays, and Mr. B. Burgess, who assisted in the fieldwork, is gratefully acknowledged.

METHODS

A light plane was chartered to overfly the coast in the reportedly affected area on 2 December 1972. At this time red tide was visible only in the inner lagoon off Morobe harbor (Figure 2), where subsequent investigations were carried out.

Water temperatures and samples were taken at several stations in the area (Figure 2). Salinities were later determined by titration for chloride. At each of three stations, one 2-min surface phytoplankton haul was carried out

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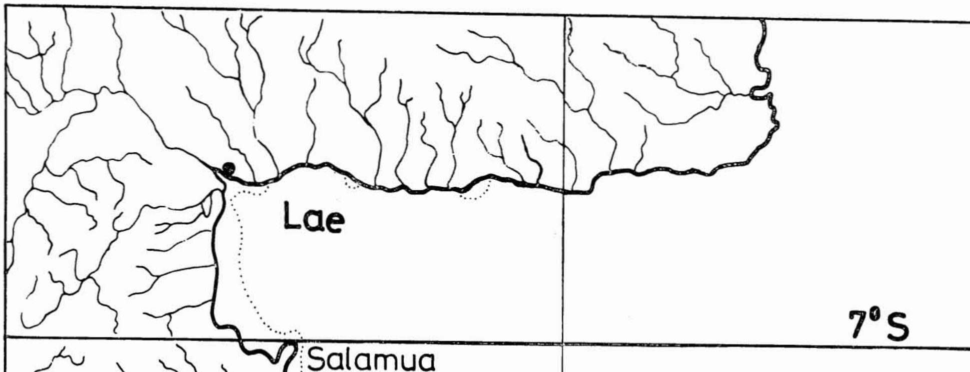

FIGURE 1. Morobe District coast on New Guinea mainland, showing areas mentioned in text.

over an estimated distance of 120 meters, with a 48-micron- , 15-cm-diameter plankton net. Concentrations of planktonic organisms were estimated from hemocytometer counts. A 0.5-meter-diameter, 48-micron net was used to secure larger quantities of red tide for toxicity bioassay.

Oysters (*Saccostrea cucullata* [Born]) were obtained from the inner and outer lagoon. A single specimen of *Barbatia paravillosa* Iredale was obtained from the mud near mangroves in the inner lagoon. Three specimens of the fish *Gerres macracanthus* Bleeker were captured alive in the inner lagoon, together with a dead juvenile *Gerres* sp. All specimens were kept frozen until subjected to toxin bioassay. The bioassay procedure was the Association of Official Analytical Chemists mouse bioassay method (anon. 1970: 305).

RESULTS

The Morobe red tide appeared as an orange-brown discoloration of the water clearly different from the milky brown color which is a permanent feature of river mouths in the district. Colored waters in the lagoon situation were elongate-oval to crescent-shaped patches about 30–50 meters in diameter. There were less obvious paler areas around the patches. The inner lagoon is shallow, less than 4 meters

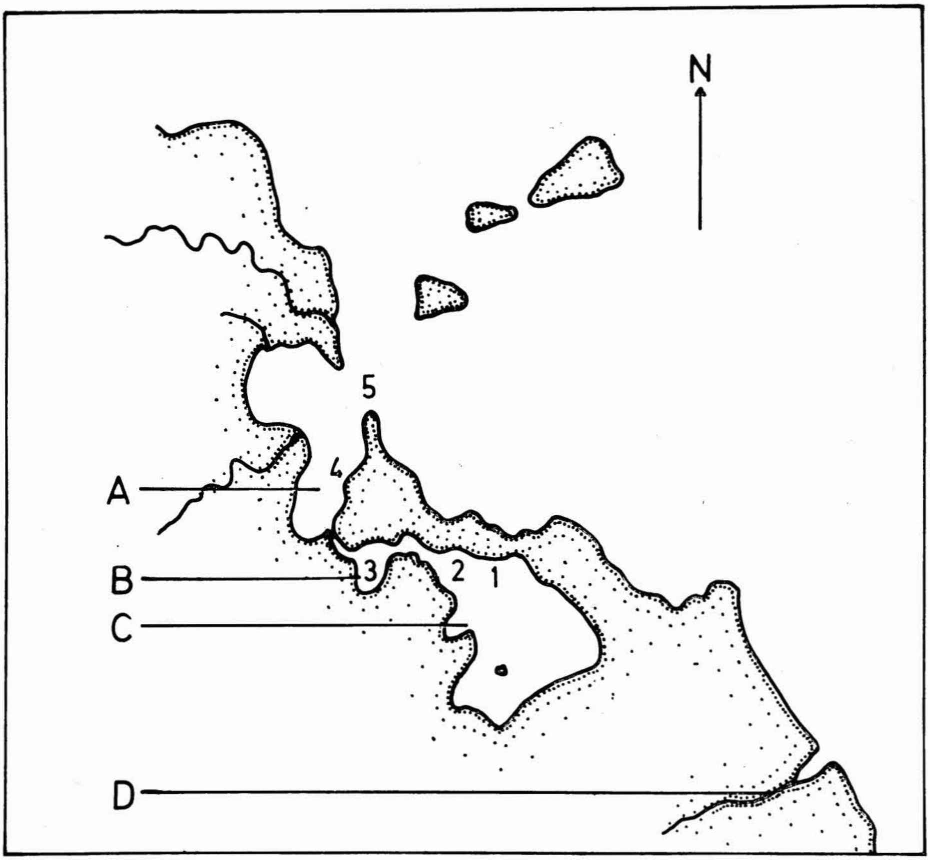

FIGURE 2. Morobe harbor and lagoon, showing the five sampling stations (numerals). *A*, harbor; *B*, outer lagoon; *C*, inner lagoon; *D*, Waria River.

TABLE 1

DATA FROM WATER SAMPLES, MOROBE SAMPLING STATIONS, 2 DECEMBER 1972

ITEM	STATION NUMBER AND SITE				
	1 INNER LAGOON	2 INNER LAGOON	3 OUTER LAGOON	4 HARBOR	5 OUTSIDE HARBOR
Pyrodinium per Liter	3.5×10^6	0.27×10^6	41,000	<5,000*	3,500
Surface Temp., °C	30.5	29.8	30.0	29.7	30.4
Surface Salinity ‰	25.1	24.7	30.5	29.5	33.1

* Sample was lost before a more accurate count had been undertaken.

deep for the most part. The red tide was present on the surface. The bottom of the lagoon is sandy mud and there are coral reefs around part of the perimeter. In the open sea near Lasanga Island, long strips approximately 100 meters wide, and a large crescent patch half a kilometer long and some 200 metres wide were reported on 13 December 1972 (Burgess, personal communication).

Concentrated plankton samples of the red

TABLE 2

ANALYSIS OF PLANKTON HAULS AT THE THREE SAMPLING STATIONS IN MOROBE HARBOR AND LAGOON, 2 DECEMBER 1972

ITEM	PLANKTON NUMBERS/LITER: INNER LAGOON (STATION 1)	OUTER LAGOON (STATION 3)	HARBOR (STATION 4)
*Pyrodinium bahamense**	49,670	13,500	20
Peridinium steinii (?)	110	30	10
Chaetoceros spp.	0	310	770
Bacteriastrum sp.	0	70	230
Nitzschia sp.	80	80	100
Thalassiothrix sp.	0	30	0
Unidentified Diatom	230	20	0
Trichodesmium sp.	0	0	130
Crustacea	30	150	60
Other	140	440	220
Total/Liter	50,260	14,360	1,540
Plankton minus *Pyrodinium*	590	1,130	1,520
No. Organisms Counted	3,349	1,638	326

* Other dinoflagellates observed in the plankton samples from Morobe harbor included *Gonyaulax polygramma*, *Ceratium furca*, *C. fusus*, *Prorocentrum micans*, and *Peridinium cerasus* (?). Only *Pyrodinium bahamense* and *Peridinium steinii* (?) appeared in the lagoon samples. Dinoflagellate identifications were kindly made by Dr. J. Dodge, University of London.

TABLE 3

BIOASSAY RESULTS ON SAMPLES FROM MOROBE, 2 DECEMBER 1972

SPECIES	WEIGHT OF TISSUE EXTRACTED (GRAMS)	SITE	NUMBER OF MICE	AVERAGE WEIGHT OF MICE (GRAMS)	NUMBER OF DEATHS	MEAN DEATH TIME
Shellfish						
Barbatia paravillosa	3.6	inner lagoon	6	22.5	6	1 min, 30 sec
Saccostrea cucullata (Born)	30.0	inner lagoon	6	13.8	6	3 min, 30 sec
Saccostrea cucullata (Born)	50.0	outer lagoon	6	10.6	6	2 min, 15 sec
Fish						
Gerres macracanthus (live)						
Body	57.9	inner lagoon	6	32.6	nil	—
Intestine	1.9	inner lagoon	2	22.4	nil	—
Gerres sp. (dead)						
Body	2.2	inner lagoon	2	24.8	nil	—
Intestine	0.3	inner lagoon	2	19.3	nil	—
Pyrodinium bahamense	*	inner lagoon	6	20.5	6	1 min, 15 sec

* One milliliter of supernatant from plankton haul concentrate was administered to each mouse.

tide were chocolate brown and sandy in texture. They caused no irritation to the skin or respiratory tracts of the three persons handling the concentrates. Respiratory irritation is a feature of gas from the Florida red tide, *Gymnodinium breve* (Torpey and Ingle 1966).

The organism responsible for the Morobe blooms was the armored dinoflagellate, *Pyrodinium bahamense*, also responsible for the Walai fatalities earlier in 1972 (Worth, Maclean, and Price 1975).

During sampling operations, it was noticed that plankton hauls emitted a smell reminiscent of oysters. Within 30 minutes of removal from the lagoon all samples had this smell, which became pungent and offensive within an hour.

The red tide on the Morobe coast exhibited strong luminescence at night when disturbed. This species is a cause of luminescence in the Bahamas, Persian Gulf, and Puerto Rico (Wall and Dale 1969).

Two 1-liter samples from visibly discolored water in the inner lagoon contained 3.5 million and 0.27 million *Pyrodinium*, respectively. A sample from the outer lagoon contained 41,000 per liter and, in the harbor, there were fewer than 5,000 per liter (Table 1).

Mullet were said by villagers to have been killed during the present red tide, although there were none in evidence at the time of sampling. The only dead specimen in the lagoon was a small (8 cm) fish, *Gerres* sp. As well, a dog was said to have died as a result of eating one of the dead mullet. Villagers, on the other hand, cooked and ate the fish without ill effect. Oyster banks on mangroves in the inner lagoon consisted of 90-percent dead shells. The upper valves of these oysters were still attached, slightly agape; they had not been opened by villagers for food, and it is concluded that the red tide was responsible for the mortality, whether by poisoning or suffocation. By contrast, oysters on mangroves in the outer lagoon were all alive. The outer lagoon is in fact a passage between the inner lagoon and the harbor; the current through it is strong, which would not appear conducive to bloom formation. Small turbinid gastropods living in the intertidal zone in the inner lagoon appeared healthy and *Barbatia paravillosa* was recovered alive from the mud.

Plankton counts per liter of seawater for the three plankton stations are shown in Table 2. The data are based on the estimated hauling distance of 120 meters, but are uncorrected for net efficiency and are therefore somewhat low. For example, the inner lagoon stations were visibly discolored by *Pyrodinium*. Water samples contained a very dense population (0.27 and 3.5 million *Pyrodinium* per liter), whereas the estimate from plankton hauling there was about 50,000 per liter.

Table 2 shows an overall depression in numbers of other organisms with increasing concentration of *Pyrodinium*. Two phytoplankters, *Peridinium steinii* (?) and a small unidentified diatom, show the opposite trend, but the situation is complicated by the differences in salinity among the three stations.

The inner lagoon was quite brackish (salinity 25‰) with salinity increasing toward the harbor. Water temperatures ranged from 29.7° to 30.5° C. Data by station are given in Table 1.

Results of bioassays are shown in Table 3. These results do not permit estimation of the concentration of toxin in terms of mouse units due to a lack of mice. (Ten mice within certain size are required in each test for proper calculation of toxin strength.) In analyses of shellfish tested after the Walai fatalities, Worth, Maclean, and Price (1975) treated as highly toxic material that resulted in mean death times of mice of less than 7 minutes, since specimens from the death-causing meals had this level of toxicity.

The bivalves sampled in the inner and outer lagoon at Morobe, then, may be termed highly toxic. The supernatant of a plankton haul through the red tide also produced rapid mouse deaths. Fish sampled contained no toxicity.

DISCUSSION

Several features of the bloom are comparable with those reported from elsewhere; others are reported for the first time.

The distribution of *Pyrodinium bahamense* has been restricted to tropical and subtropical latitudes of the Caribbean Sea, eastern Pacific Ocean, Red Sea, Persian Gulf, and North Atlantic Ocean (Wall and Dale 1969). Therefore, its presence in both the north and south coasts of mainland New Guinea represents an expansion of range to the western tropical Pacific Ocean.

Observations made on the Port Moresby-Walai blooms in May 1972 are summarized in the appendix for comparison. Water temperatures were lower in the latter blooms than in the Morobe outbreak; blooms, therefore, may be tolerant of a wider range of temperatures than so far experienced (26.2°–30.5° C). Wall and Dale (1969) suggested that temperatures of 25° C and over favor profuse growth.

Pyrodinium blooms may also be viable in a range of salinities. While the Morobe outbreak was in a brackish (24.7 ‰) situation at the time of sampling, such blooms were previously and subsequently observed in the nearby sea in presumably higher salinities. During sampling, the sea just outside Morobe harbor (station 5) had a salinity of 33.1‰ and contained 3,500 *Pyrodinium* per liter.

In general, armored dinoflagellates are said to be estuarine or coastal, whereas naked forms are found more in the open sea (Rounsefell and Nelson 1966). Thus, blooms of the naked dinoflagellate *Gymnodinium breve* in Florida usually occur in waters over 30.5‰ salinity (Rounsefell and Nelson 1966); armored *Gonyaulax tamarensis* in eastern Canada has an optimum salinity range of 15–23‰ (Prakash, Medcof, and Tennant 1971).

However, *P. bahamense* is said to grow most profusely in high salinities, around 35.7‰ (Wall and Dale 1969). The blooms in brackish water at Morobe suggest that *Pyrodinium* can grow profusely in waters of a wide range of salinities if other environmental factors are favorable.

The densities of visible blooms of *Pyrodinium* in Morobe lagoon (0.27–3.5 million/liter) were not excessive. Buchanan (1968), for instance, noted concentrations of up to 10 million per liter in Oyster Bay, Jamaica. *Pyrodinium* has not been reported to cause shellfish toxicity there.

There is no history of shellfish poisoning on the Morobe coast, and this is surprising in view of the high toxicity of shellfish during red tides. However, shellfish are minor dietary items among the villagers, and it is possible that the occasional illness is not recognized as shellfish poisoning. By contrast, villagers in the Trobriands have a history of poisonings and generally avoid bivalves during the red tide season there. Nevertheless, there have been some deaths (Maclean, in press).

After *Pyrodinium* had been identified at Morobe, broadcasts on the local radio station were arranged to warn residents of the potential danger of eating bivalve shellfish during and up to 3 months after the red tides. District health officers were also advised of the problem and symptoms. The period of abstinence from bivalves after the red tide "season" appears necessary in view of the earlier finding (Worth, Maclean, and Price 1975) that some bivalves, in particular oysters, retain toxicity for some time after *Pyrodinium* concentration has dropped to an insignificant level (less than one per liter according to estimates from net hauls).

APPENDIX

OBSERVATIONS ON RED TIDE, PORT MORESBY TO WALAI, MAY 1972

Visual

An aerial survey of the coast between Port Moresby and Walai was made by helicopter on 17 May 1972 when extensive orange discoloration of the sea or red tides were observed over a distance of about 40 kilometers. The discolorations were generally in the form of streaks running parallel to the coast, from a hundred meters to over a kilometer in length and 10 to 50 meters in width, and tending to diffuse gradually along the edges. Water samples and temperatures were taken at various stations by Nansen bottle lowered from the survey helicopter (see below, *Concentration*). Later, diving showed that the discoloration was confined to the upper two meters of the water column.

A second observation flight was made on 25 May 1972. The red tide had disappeared from the area, but had appeared in Port Moresby harbor. By the next aerial survey on 6 June, the red tide had vanished from the whole area.

Subsequently, observation flights between Port Moresby and Walai village were made fortnightly. Up to 27 December 1972, there were no further sightings of red tide.

Concentration

Following are counts per liter of *Pyrodinium* and water temperatures at various stations in the Port Moresby-Walai area, 17 May 1972:

STATION	SITE	*Pyrodinium*/LITER	TEMPERATURE (°C)
1.	Off Pari beach, 5 km southeast of Port Moresby	negative	26.2
2.	Bootless Bay, 10 km southeast of Port Moresby, near a red tide patch	37,000	26.2
3.	Bootless Bay, in red tide patch	596,000	26.2
4.	Bootless Bay, in red tide patch	619,000	26.2
5.	Off Walai village, 80 km southeast of Port Moresby, on fringing reef	2,000	27.7
6.	Off Walai village outside fringing reef	negative	26.9

LITERATURE CITED

ANON. 1970. Official methods of analysis of the Association of Official Analytical Chemists. 11th ed.

BUCHANAN, R. J. 1968. Studies at Oyster Bay in Jamaica, West Indies. IV. Observations on the morphology and asexual cycle of *Pyrodinium bahamense* Plate. J. Phycol. 4: 272–277.

MACLEAN, J. L. In press. Red tides and paralytic shellfish poisoning in Papua New Guinea. Papua New Guin. agric. J.

PRAKASH, A., J. C. MEDCOF, and A. D. TENNANT. 1971. Paralytic shellfish poisoning in eastern Canada. Bull. Fish. Res. Bd. Can. 177.

ROUNSEFELL, G. A., and W. R. NELSON. 1966. Red-tide research summarized to 1964 including an annotated bibliography. Spec. Scient. Rep. U.S. Fish Wildl. Serv. 535.

TORPEY, J., and R. M. INGLE. 1966. The red tide. Educ. Ser. Fla. Bd. Conserv. 1 (revised).

WORTH, G. K., J. L. MACLEAN, and M. J. PRICE. 1975. Paralytic shellfish poisoning in Papua New Guinea, 1972. Pacif. Sci. 29: 000–000.

WALL, D., and B. DALE. 1969. The "hystrichosphaerid" resting spore of the dinoflagellate *Pyrodinium bahamense*, Plate, 1906. J. Phycol. 5: 140–149.