Occurrences of Red Tide in Brunei Darussalam and Methods of Monitoring and Surveillance

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Introduction

Negara Brunei Darussalam is situated in the northwest of Borneo Island and lies between Sarawak to the southwest and Sabah to the northeast. It lies between latitudes 4°N and 5° 05' N and longitudes 114° 04'E and 115° 22'E.

To the northeast of Brunei Darussalam, lies Brunei Bay and Brunei River estuary. These are fringed by mangroves and form the basis of an important prawn and seasonal *Rastrelliger* fishery.

The deep channel entering the bay between Pulau Muara Besar and Tanjong Trusan and the dredged areas in the Muara Port area are relatively deep but generally the water in the inner bay area varies between 2 and 6 m. Fine sands, silts, and muds with a high organic content comprise the sediment. Salinity in the bay varies from 15–28 ppt, but this fluctuates depending on tidal activity and freshwater discharge from rivers.

The coastline fringes the South China Sea and is about 110 km long. The bottom sediments further from the coast consist of mud and sandy mud. Nearer the coast are sand, coral, and rocky patches. A 100-fathom isobath lies offshore and varies in distance from 56 km from the western end and 95 km from the eastern end of the country. Fishing in the South China Sea is largely concentrated close to the shore in open boats. A few fishermen also operate further out to sea using traps and long lines. There are also some trawlers and purse seiners that are engaged in a wider range of offshore activities than those conducted from open boats.

In terms of winds, the northwest monsoon occurs between December and March; the southwest monsoon occurs between July and October. Between these periods, variable winds blow from any direction but usually from southwest through west to north and from north through east to south.

Red Tide Occurrence in 1976

On 11 March 1976, Fisheries Department biologists were conducting unrelated work at sea when they noticed an extensive reddish-brown discolouration 4 nautical miles north-northeast of Muara Port. This was suspected as being a planktonic bloom and samples were collected. Subsequent microscopic examination of the samples showed the presence of heavy concentrations of a marine dinoflagellate that was later identified as *Pyrodinium bahamense* Plate (1906). Although red tide was unknown in Brunei at that time, its potentially toxic nature when concentrated was recognized and the Director of Medical Services was advised of the situation. A statement warning the public not to eat shellfish was broadcast over the radio and television the same evening.

On the same day, five patients sought treatment at Bandar Seri Begawan General Hospital for complaints of numbness and tingling of the lips and tongue, giddiness, bitter taste in the throat, weakness of limbs, fatigue, and tingling and numbness in the fingers and toes. The patients had earlier consumed chub mackerels (*Rastrelliger* sp.) and scads (*Selar* sp.).

News also reached Brunei that four children had died and many more people had been reported ill in Sipitang (on the eastern side of Brunei Bay), Sabah. The children died after consuming a meal of bivalve molluscs (Roy 1977). Although the news was rather sketchy, concern was expressed by the Brunei authorities over the above happenings in Brunei and Sabah. A possible link between the incidents and the appearance of large patches of red tide was suspected.

The usual way for PSP to occur in humans is through consumption of contaminated shellfish. Thus, the complaints outlined above by patients encountered in Brunei after consuming fish seemed a bit odd. This was explained, however, by the fact that in Brunei it is usual to consume part of the gut and internal organs either with the flesh or as a separate dish with rice. *Rastrelliger* sp. is a plankton feeder and could have ingested the toxic dinoflagellates before being caught.

Once the danger was recognized, the Fisheries and Medical Departments undertook action to achieve the following objectives: (1) to inform the public on the nature and possible dangers of red tide, (2) to undertake measures to prevent further poisoning, (3) to identify the organism concerned, (4) to survey and monitor the occurrence, (5) to undertake toxicology tests on various related food items for possible contamination, and (6) to obtain further information on the phenomenon.

It was observed that the blooms were close to the surface. Their intensity was greatest between 08:30 hours and 10:30 hours. The sizes of the blooms varied; an extensive bloom measured was 9.6 km in length and 1.6 km in width (Fig. 1).

The causative organism was originally identified to be a specises of *Gonyaulax*. It was eventually identified by Dr. Karen Steidinger of the Florida Department of Natural Resources, USA, to be *Pyrodinium bahamense* Plate (1906).

Beales (1976) reported that the blooms appeared in phases as follows:

- 11-15 March: The initial dense blooms that originated to the northeast of Pelong Rocks were blown slowly onto the beaches by the prevailing winds.
- 16-19 March: New blooms appeared to the north and northeast of Pelong Rocks. These were either dispersed or blown ashore by 25 March.
- 5-12 April : Further blooms appeared in the area of Pelong Rocks. These slowly dispersed.
- 14-27 April: Visible blooms were observed in the inner part of Brunei Bay, at first covering large areas and later becoming compressed into compact and very dense patches under the influence of the complex water movement in the area.

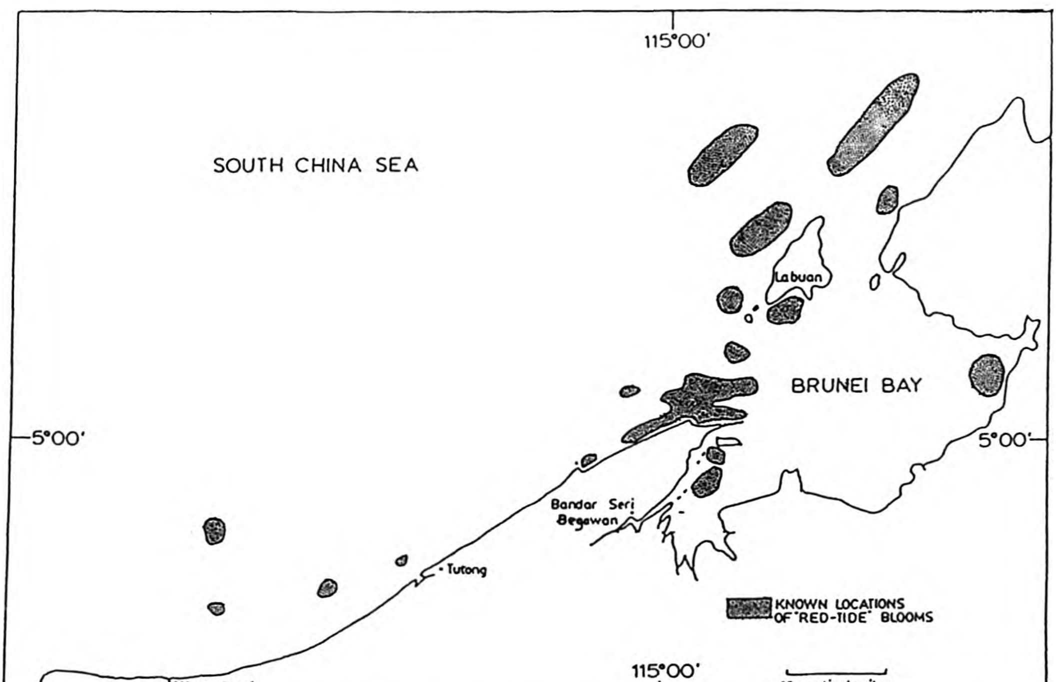

Fig. 1. Known locations of red tides (stippled) in Brunei's coastal waters and adjacent areas, 1976 red-tide occurrence (adapted from Beales 1976).

4- 6 May: Further new blooms to the north of Pelong Rocks occurred on 4 May and small patches were noted coming ashore at Pulau Punyit. These had disappeared by 6 May.

It was reported by oil-rig helicopter pilots that the bloom was very extensive, covering large parts of the water of northwest Borneo. To get an idea of the size of the bloom, it stretched from approximately Kudat in North Sabah to the west end of Brunei, a distance of more than 200 km.

The weather during the period of the occurrence was fine. The days were sunny and the seas calm. A light wind blowing from the north-northeast and becoming stronger in the afternoon was evident.

There was little evidence of large-scale fish kills, although it must be mentioned that a few hundred specimens of *Lethrinus* and *Stolephorus* spp. were found dead along the seashores and in the port area during the early phase of the red tide. At Pelong Rocks, where most of the dense blooms occurred, evidence of damage to the fish or corals during or after the event was lacking. The points of origin of the majority of the blooms were centred around the shallow areas bordering the channel entering Brunei Bay.

The red tide was last detected on 6 May 1976, but toxicology tests were continued on specimens until 21 August 1976, after which it was announced that it was safe to eat molluscs again. Since the first recorded occurrence of red tide in 1976, the Fisheries Department has continued to conduct an annual vigilance during which it advises the public to be on the lookout for red tide.

Red Tide Occurrence in 1980

Following the Fisheries Department's effort to increase public vigilance toward red tide, reports of red tide occurrence were received again on 28 April 1980. The reports that were received from various sources claim that red tide blooms were observed in the Brunei Bay area. These reports were confirmed to be correct when Fisheries Department personnel collected samples at the reported area on the same day. Preliminary examinations of the samples have indicated that the causative organism was similar to the dinoflagellate that caused the red tide in 1976.

A warning was first issued to the public on 29 April 1980 about the presence of the toxic dinoflagellates and the public was warned against consuming molluscs, especially mussels and other bivalves. Owing to this early action, there were no incidents of PSP reported in Brunei during the 1980 red-tide incident.

Plankton samples were again sent to Dr. Karen Steidinger of the Florida Department of Natural Resources for identification. The causative organism was again positively identified as *Pyrodinium bahamense* var. *compressa.*

During this occurrence, the following actions were taken to ensure that the public was protected from the dangers of the red tide: (1) continuous surveillance and monitoring of the presence of the organism responsible, (2) toxicology tests on various seafood items for possible contamination, and (3) inform the public of the dangers involved.

The 1980 blooms were less visible on the surface, being most densely concentrated around 10 m depth (Fig. 2). Observations made on 1 May showed that large quantitites of toxic dinoflagellates were present. Blooms were still reported around mid-May and daily plankton sampling showed considerable amounts of *Pyrodinium bahamense* var. *compressa* had also appeared within the confines of Muara Port and the Brunei River estuary.

There was a distinct decline in the presence of the organism around the week of 20 May in the waters off Muara and the Brunei River estuary. Reports were also received that blooms had been observed off Seria in the western end of the state. These reports, however, could not be confirmed.

On 19 June, a large bloom about 6-15 nautical miles wide and with a streaking pattern was sighted in the northern part of Brunei Bay. By 7 July, there was a decline in the abundance of toxic dinoflagellates in plankton samples and in September the Fisheries Department reduced the routine daily sampling to once a week.

Routine plankton samples collected in November and December indicated that toxic *Pyrodinium bahamense* var. *compressa* was absent in the stations sampled, whereas samples collected in January and February 1981 again contained the causative organism around Pelong Rocks. Plankton samples collected in March 1981 still showed low concentrations of *P. bahamense* var. *compressa.* This trend of the occasional and sparse presence of toxic *Pyrodinium bahamense* var. *compressa* continued until July 1981, after which the toxic dinoflagellate was absent.

Methods of Monitoring

Plankton Sampling

Plankton sampling by boat was the most widely used method of monitoring the presence of red-tide organisms. For this reason, stations were

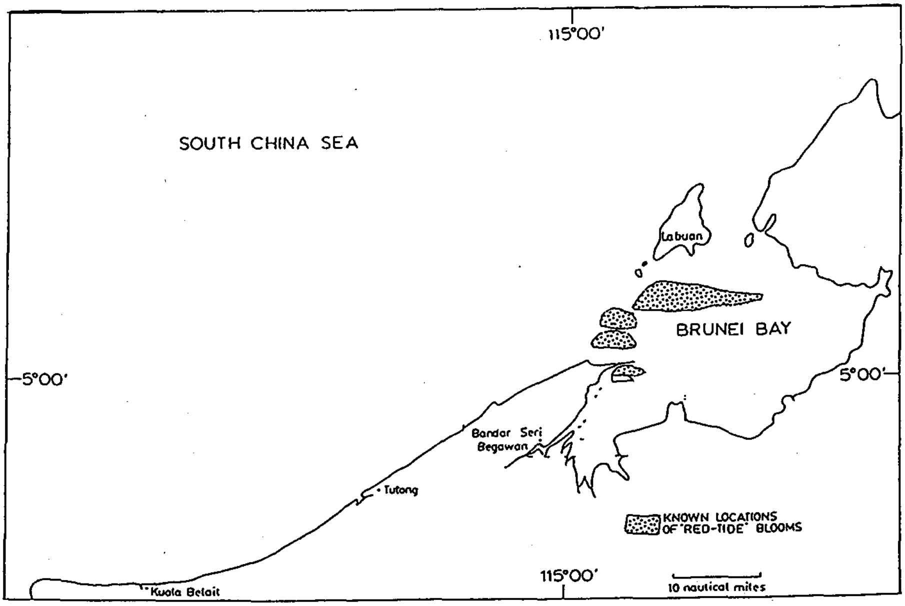

Fig. 2. Known locations of red-tides (stippled) in Brunei's coastal waters and adjacent areas, 1980 red-tide occurrence.

established at representative locations and samples were taken at these stations for comparative assessments. Quantative sampling was not possible using the equipment available. For horizontal sampling, a net was towed just below the water surface at a speed of about 3 knots for about 3-5 min. Vertical sampling was carried out at a depth of 15 m. The samples were preserved in 5% formalin and examined in a laboratory.

Because it was not possible to undertake quantitative sampling, subjective terms of "dense" or "diffuse" were utilized in cases of visible blooms and "present" or "absent" in cases where blooms were not readily visible.

Aerial Surveillance

Aerial surveillance was used extensively during both the 1976 and 1980 red-tide occurrences. At this time, state armed forces helicopters were made available for surveillance purposes, especially during the critical initial and latter phases of the occurrences. In addition to the armed forces helicopters, near-shore waters were surveyed using helicopters belonging to Brunei Shell Petroleum Limited and fixed-wing aircraft of the state airline, Royal Brunei, on their normal routes. Observations were also obtained from these sources.

For aerial surveys, the best height for observation was found to be around 333 m. At this height, a wider area can be viewed. The best time for observing the bloom is between 08:30 and 10:30 hours because these are the times during which the blooms are nearest the surface and most intense. Polarizing sunglasses were found to be useful for making visual observations and polarizing filters aided in recording the blooms on colour film.

Toxicology Tests

In view of the associated toxic nature of red tides, toxicological tests were carried out to ascertain the effect of red-tides on fish and shellfish. In the initial stage of the 1976 red tide occurrence, the samples were sent to Singapore for testing by the Department of Pharmacology of the Univesity of Singapore. In the meantime, a mouse bioassay unit was established at the Brunei Medical Department to undertake the investigations during the latter part of the occurrence. For the 1980 occurrence, toxicological investigations were carried out by the Fisheries Department.

The method utilized involved intraperitoneal injection of supernatant extracted from suspected fish and shellfish samples into healthy mice. The time of death was then recorded and converted into toxin content with the aid of a conversion factor obtained with standard solutions of paralytic shellfish poison. Paralytic shellfish poison standard solution was obtained from the Division of Criteria and Standards, Environmental Control Administration, Rockville, MD, USA. The method is described in detail in Horwitz (1970).

Table 1 provides a summary of the 23 samples found toxic during the 1976 red-tide occurrence. Table 2 provides a summary of the results of the bioassays carried out during the 1980 red-tide occurrence. The locations from which the specimens were collected are shown in Figs. 3 and 4. Values greater than 80 $\mu g/100$ g flesh are considered harmful. This level of toxin has been referred to by Clem (1979) and Hurst (1979).

Discussion

The first occurrence of red tide in 1976 overwhelmed the tiny state. During the first week, a total of 52578 kg of seafoods, with a retail value of approximately B$198000, were seized from the markets and condemned. Swimming on beaches exposed to the South China Sea was also banned. These actions, however, could have been responsible for the low incidence of PSP. Only 14 cases of PSP were recorded during this occurrence.

More information was available for the red tide occurrence in 1980. As a result, only the consumption of molluscs, especially bivalves, was advised against.

It is worth mentioning that there were several significant differences in the features of the red tides that occurred in 1976 and 1980. Whereas the 1976 red tide manifested itself very prominently in streaks, the 1980 occurrence was much more diffused and in most instances the organisms were not visually evident even though they were present in the samples. The earlier red tide was observed to be concentrated on the surface, whereas the 1980 red tide was evident much deeper and in some instances was detected only on vertical plankton samples taken from a depth of 15 m. They were found to be most dense at about 10 m below the surface of the water. In most of these instances, the causative organism was not detected in horizontal tows. Even though no quantative samplings were undertaken during either of the 1976 or 1980 occurrences, it was evident that the 1976 occurrence was more widespread and dense than the latter. During the first occurrence, the weather was fine and the seas were calm. The reverse held true for the 1980 incident, however, with the days being rainy and overcast and the seas rough.

Aerial surveys proved to be an essential part of the monitoring and surveillance of the visible blooms of the red tide. With this type of surveillance, a wider area could be covered, thus facilitating the reporting procedure. In addition, the shape and extent of the bloom can be recorded more accurately. Furthermore, this type of surveillance is quicker than surveillance by boat but has the disadvantage of being expensive as well as presenting difficulties in the collection of samples.

Both methods of surveillance have their advantages and disadvantages but utilized in conjunction with each other they have proven to be very useful. During the initial and latter phases of the occurrences, it is important to ensure that reports of its existence or absence be accurately confirmed. Thus, when a report was received, both helicopters and boats were dispatched to the general area. As soon as the bloom was sighted from the helicopter, a flare was dropped to mark the exact location for the benefit of the people in the boat. This in itself reduces the search time and provides more time for sampling other locations.

Toxicological tests were conducted on various seafood items but efforts were concentrated on species that have been implicated to accumulate toxins or thought to cause PSP.

Toxicology tests involving intraperitoneal injection of mice have provided good indicators of the toxin contents of the seafoods sampled. However, the following disadvantages to this method (Taylor and Seliger 1979) should be recognized: (1) the need to maintain a mouse colony, (2) mice must be in the 19-21 g weight range, (3) death time is subjective, (4) limits of sensitivity are dependent on mouse strain, and (5) assays are not linear (death time vs toxic level).

Although Brunei Darussalam does not have a mollusc industry to protect, the appearance of red tides in 1976 and 1980 has introduced a new limiting factor to the adoption of mollusc culture. Past investigations into the culture of *Perna viridis* have been encouraging.

The authors thank the air force of the Royal Brunei Armed Forces for the considerable assistance rendered in carrying out aerial monitoring surveys. Thanks are also extended to Dr. Karen A. Steidinger of the Florida Department of Natural Resources for identifying *Pyrodinium bahamense* var. *compressa*.

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Table 1. Summary of toxic samples; red-tide occurrence 1976 (adapted from Beales 1976).

Date	Sample	Location	Toxicity MU/100 g meat
12 March	*Rastrelliger* sp. (Rumahan)[a]	Inner Bay	99
12 March	*Sardinella* sp. (Tamban)	Inner Bay	193
29 March	Gastropod (Tekuyong)	Sg. Bangau	71
29 March	Gastropod (Tekuyong)	Pulau Kitang	663
29 March	Gastropod (Tekuyong)	Tanjong Batu	876
29 March	Gastropod (Tekuyong)	Pulau Pepatan	296
29 March	Lamellibranch (Teritip)[b]	Pulau Chermin	589
29 March	Crab (Ketam)	Sg. Raya	339
29 March	Lamellibranch (Biluyan)[c]	Kg. Masjid Lama	847
29 March	Lamellibranch (Tiram)[d]	Kg. Masjid Lama	57
29 March	Lamellibranch (Karakas)	Kg. Masjid Lama	293
27 April	Lamellibranch (Kunau)[c]	Pulau Bedukang	436
27 April	Lamellibranch (Kunau)	Pulau Muara Besar	218
27 April	Penaeid Prawn (Udang)	Inner Bay	190
1 May	*Rastrelliger* sp. (Rumahan)	Inner Bay	478
2 May	*Rastrelliger* sp. (Rumahan)	Inner Bay	314
2 May	Lamellibranch (Tiram)	Pulau Chermin	1351
2 May	Lamellibranch (Teritip)	Sg. Teritip	864
6 May	Lamellibranch (Teritip)	Sg. Teritip	2310
12 May	Lamellibranch (Tiram)	Pulau Chermin	20
12 May	Lamellibranch (Teritip)	Sg. Teritip	935
15 May	Lamellibranch (Tiram)	Pulau Muara Besar	274
15 May	Lamellibranch (Biluyan)	Pulau Muara Besar	2060

[a]Brunei Malay names are given in brackets.
[b]Teritip: mangrove oyster.
[c]Biluyan and Kunau: clams.
[d]Tiram: oysters.

Table 2. Summary of toxicity tests; red-tide occurrence 1980.

Date	Specimen	Location	Toxin content µg/ 100 g meat
24 June	*Saccostrea cucullata* (Teritip)	Belangkas Jetty, Muara	52
4 July	*Arcuatula arcuatula* (Kupang)	Tanjong Bakalan	nt
12 July	*Perna viridis* (Kupang hijau)	Raft at Serasa	200
19 July	*P. viridis* (Kupang hijau)	Raft at Serasa	94
30 September	*P. viridis* (Kupang hijau)	Raft at Muara	138
6 October	*S. cuccullata* (Teritip)	Belangkas Jetty, Muara	64
28 October	*S. cucullata* (Teritip)	Belangkas Jetty, Muara	nt
28 October	*Meretrix meretrix* (Kunau)	Pulau Muara Besar	nt
28 October	*Anadara granosa* (Tembayangan)	Pulau Muara Besar	108
28 October	*P. viridis* (Kupang hijau)	Raft at Muara	71
26 November	*S. cuccullata* (Teritip)	Belangkas Jetty	nt
26 November	*M. meretrix* (Kunau)	Pulau Muara Besar	nt
26 November	*A. granosa* (Tembayang)	Pulau Muara Besar	83
26 November	*M. viridis* (Kupang Hijau)	Fisheries Station, Muara	64
4 February	*S. cucullata* (Teritip)	Belangkas Jetty	70
4 February	*M. meretrix* (Kunau)	Pulau Muara Besar	nt
4 February	*A. granosa* (Tembayangan)	Pulau Muara Besar	188
19 February	*S. cucullata* (Teritip)	Belangkas Jetty	66
19 February	*M. meretrix* (Kunau)	Pulau Muara Besar	nt
19 February	*A. granosa* (Tembayangan)	Pulau Muara Besar	92
3 March	*S. cucullata* (Teritip)	Belangkas Jetty	66
3 March	*M. meretrix* (Kunau)	Pulau Muara Besar	nt
3 March	*A. granosa* (Tembayangan)	Pulau Muara Besar	184

Notes: nt: not toxic. *S. cucullata* was nontoxic by April 1981, but *A. granosa* was reported to be toxic until at least October 1981.

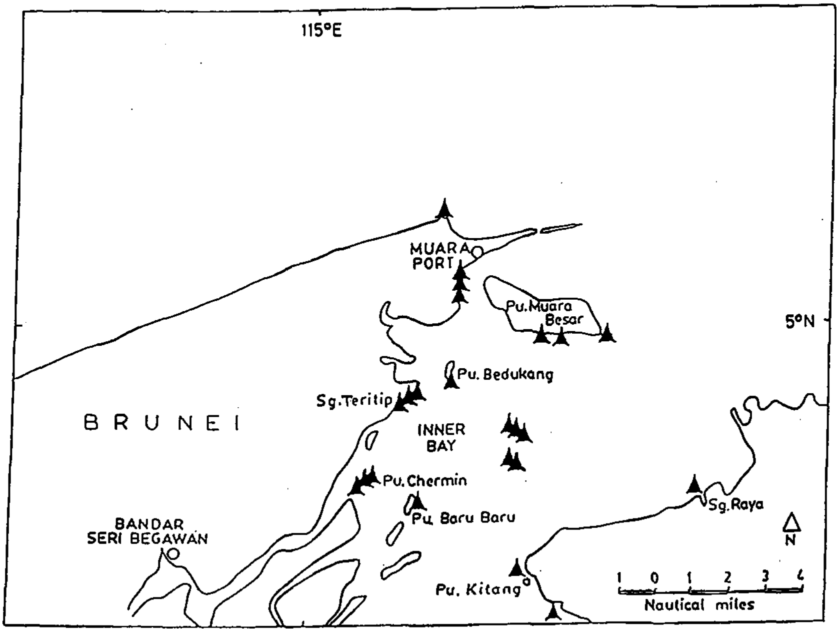

Fig. 3. Collection sites of toxic samples (dark tringles) in the inner bay area of Brunei, 1976 red-tide occurrence (adapted from Beales 1976).

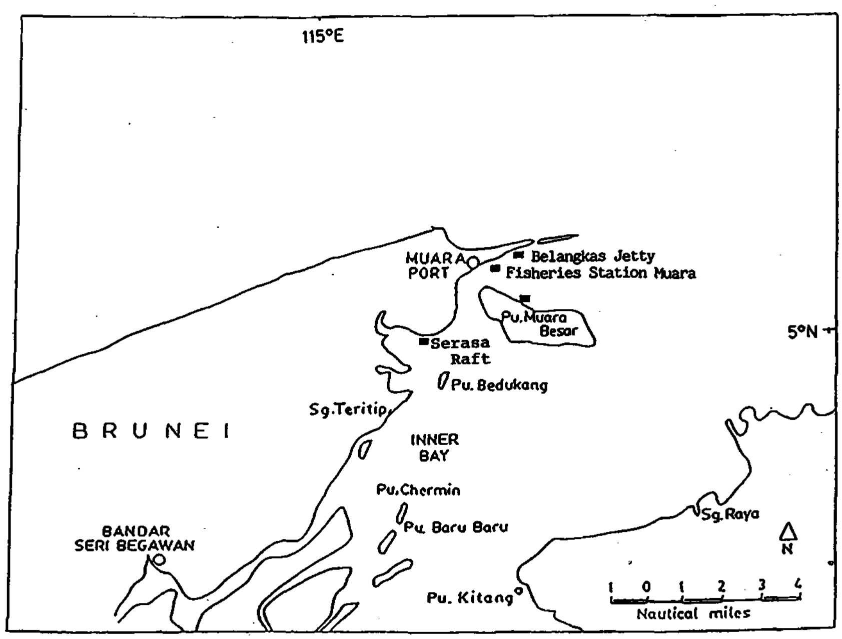

Fig. 4. Collection stations (boxes) of toxic samples in Brunei Darussalam, 1980 red-tide occurrence.