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Assemblage and geographical distribution of dinoflagellate cysts in surface sediments of coastal waters of Sabah, Malaysia

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Abstract—The preliminary results from the analysis of dinoflagellate cyst mapping from surface sediments of four sampling sites in Sabah, Malaysia, have demonstrated unique resemblance in species composition and diversity of dinoflagellate cysts assemblages typical with those of tropical Southeast Asian waters. Dinoflagellate cysts taxa are sparse and relatively low diverse in assemblages in all sampling sites and are generally characterized by species belonged to the orders Gonyaulacales, Gymnodiniales and Peridiniales which includes Calciodinoloides and Diplopsaloides. Despite the frequent occurrence of harmful algal blooms of *Pyrodinium bahamense* var. *compressum*, its resting cyst, *Polysphaeridium zoharyii* is sporadically distributed in relatively low density at surface sediments of all sampling areas.

Key words: dinoflagellate, cyst, dinoflagellate cyst, Sabah, Malaysia, *Pyrodinium*, *Polysphaeridium zoharyii*, harmful algal bloom, distribution of cyst, sediment

Introduction

Investigations of sediment cores have been found to contain dinoflagellate cysts which remain viable in the sediment for several decades. If cysts of toxic species can trigger blooms of toxic species, this is of ecological importance when considering the effects of sediment type, water depth, wind force, currents and site geography as all possible factors in cyst distribution (McKenzie 1996). Resting cysts may be introduced into new locations through the movement and transfer of sediments, *i.e.*, through dredging and dumping practices, or through shellfish transplantation (Anderson & Wall 1978). Analysis of dinoflagellate cysts can provide information about the mechanisms of spreading and recurrence of harmful algal blooms (HABs). Harper et al. (1996) found cysts remained viable after ingestion by bivalves, which indicated resistance of the multi-layered resting stage to the bivalve acidic gut, extracellular digestion and mechanical action. This may enable the transfer of viable hypnozygotes, capable of seeding a toxic dinoflagellate bloom in previously uncontaminated sites, i.e., through the transportation of contaminated bivalves via aquaculture practices. Additionally, a number of well-documented invasions of non-native aquatic organisms have implicated ballast waters as significant human vectors in the transport and introduction of dinoflagellates (Hallegraeff 1993, 1995). Ballast water is an integral part of daily vessel operations. Ballast water will contain a representative population of organisms and suspended sediments present in the water column at the time of loading. Ballast is then discharged in port when the next cargo is loaded. Resting cysts are highly resilient, 'long lived' and can survive many years in ballast tanks and once discharged in the water, they would settle to the bottom sediment in new locations and remaining dormant until conditions are right for germination to colonize previously unaffected areas (Anderson 1994). The cyst population can provide potential "seed" source or inoculum to initiate recurrence of blooms of harmful plankton species (Anderson 1994, Dale 1983). Excystment of introduced toxic dinoflagellate cysts within sediments can inoculate overlying waters with motile, vegetative cells.

A cyst mapping with emphasis on benthic life stages of harmful dinoflagellate species assemblage is one of the vital research themes of HAB. It is essentially and equally important with that of study of planktonic stages of harmful phytoplankton species if one has to understand the population dynamics, spreading and mechanism of HAB events in the Southeast Asian (SEA region). In particular, the dearth of such scientific information is quite evident in the SEA region; hence, the Research Group "Cyst Mapping" was formed under the ORI-HAB in the JSPS-ASEAN Multilateral Program to muster the collaborating members of the scientific community in the SEA region to work as a team in cyst mapping research. This project aims to survey Southeast Asian waters for harmful dinoflagellate cysts, particularly the cyst of paralytic shellfish poison (PSP)-producing species *Pyrodinium bahamense* var. *compressum* (=*Polysphaeridium zoharyii* in paleontological nomenclature) in order to map and ascertain probable *Pyrodinium* cyst beds in the region; identify and determine relative abundance and spatial distribution of other harmful species in the total dinoflagellate cysts assemblage; and establish sediment age and sedimentation rates to look into past undetected blooms in the region.

The research described here is the preliminary outcome of the first collaborative survey conducted from four sampling sites in the northern (Kota Kinabalu Bay and Tuaran Estuary) and southern (Sipitang Bay and Kuala Penyu lagoon) coastal waters of Sabah, Malaysia. This research was conducted in cooperation of the researchers from Indonesia, Japan, Malaysia, the Philippines and Thailand forming the "Dinoflagellate Cyst Mapping" Research Group.

Harmful algal blooms (HABs) have been periodically reported in the coastal waters of west Sabah since 1976 where *Pyrodinium bahamense* var. *compressum* frequently dominate the phytoplankton community (Usup et al. 1989). Moreover, intermittent blooms of fish killer species, *Cochlodinium polykrikoides*, have been recently recorded in the area (personal comm., Puyong and Anton 2004). Increasing toxic algal bloom incidents in Sabah now present considerable ecological, social and economic implications for the future. This report describes species assemblage, spatial distribution, and abundance of the deposited dinoflagellates cysts in the surface sediments with emphasis on toxic species to aid in the interpretation of the frequency of the blooms of motile dinoflagellates in the coastal waters of Sabah.

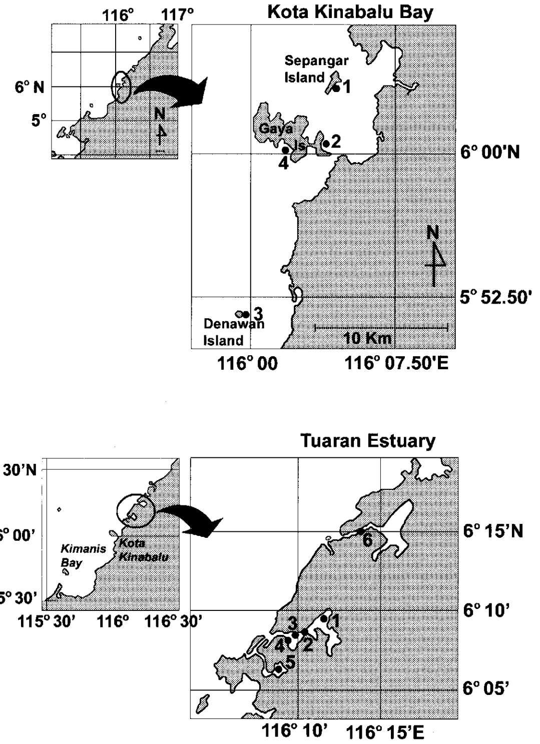

Fig. 1. Locations of sampling stations in the north coastal waters (Kota Kinabalu Bay and Tuaran Estuary), Sabah, Malaysia.

Materials and Methods

A total of 19 surface sediment core samples were taken from various sampling stations at four coastal zones of Sabah, Malaysia from February 17 to 21, 2005. Nine surface sediment core samples were obtained from 9 stations at Kota Kinabalu Bay and Tuaran Estuary, northern side (Fig. 1). Likewise, ten stations were also sampled with surface sediment core samples from Sipitang Bay and Kuala Penyu Lagoon at the southern side (Fig. 2). The upper 2-cm surface sediment core samples were collected by a TFO gravity corer in each station for palynological analyses (Matsuoka and Fukuyo 2000) to investigate the assemblage and geographical distribution of dinoflagellate cysts. Samples were divided into two, after the actual sample volume was measured. The first larger sub-samples were subjected to wet and dry weight to determine the percentage rate of moisture content of each sample, which were the basis for the calculation of cysts g^{-1} dry weight. The smaller sub-samples were decalcified in diluted HCl. Afterward, concentrated HF (~40%) was added up to the samples and kept them for 24 hours. After washing with distilled water, the samples were subjected for ultrasonic sonication and sieved from 125 μm to 20 μm mesh sieves. The final residues were stored in 20-ml vials and microscopically analyzed for various species of dinoflagellate cysts. Samples were counted until either 200 dinoflagellate cysts were found or each Sedgewick-Rafter counting slide with specimen had been completely analyzed to provide relative abundance of dinoflagellate cysts taxa. Dinoflagellate cysts were identified and described using both paleontological and biological nomenclatures (Fensome et al. 1993). To account for the abundance, evenness, species richness and diversity of dinoflagellate cysts in the assemblage of each area, the Shannon diversity index was calculated. To document and accurately identify various species of dinoflagellate cyst taxa, photomicrography under higher magnification was done using light microscope equipped with differential interfer-

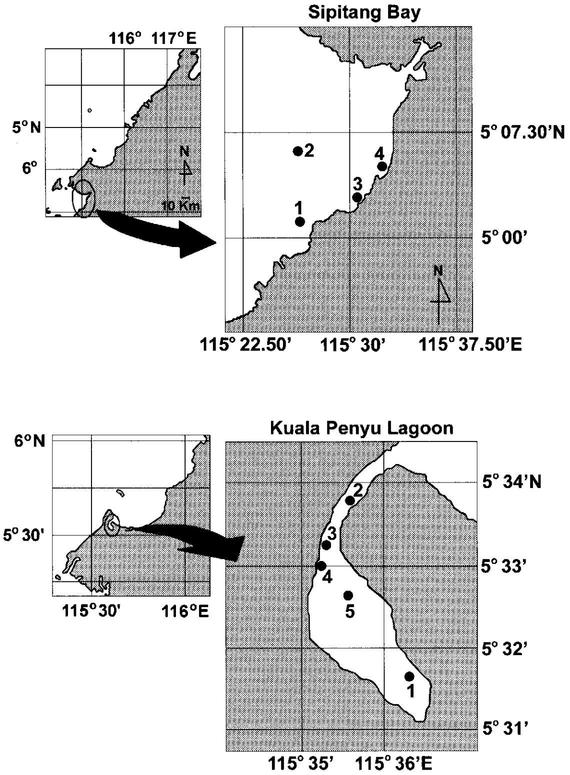

Fig. 2. Location of sampling stations in the south coastal waters (Sipitang Bay and Kuala Penyu Lagoon), Sabah, Malaysia.

ence contrast, phase contrast and epi-fluorescence optics.

Results and Observation

Species composition of dinoflagellate cysts assemblages

Dinoflagellate cysts are sparse in all samples. A list of dinoflagellate cysts counted with paleontological and corresponding biological nomenclatures and the whole total composition is provided in Table 1a, b, c and d.

Northern Coastal Waters of Sabah

Kota Kinabalu Bay

More than 25 dinoflagellate cyst taxa were identified and counted in the surface sediments of 4 core samples from Kota Kinabalu Bay. The assemblage is relatively diverse which belonged to orders Gonyaulacales, Gymnodiniales and Peridiniales including Calciodinelloides and Diplopsaloides. Relatively low proportions of autotrophic species were found in the samples which shares 35.44% of the total cyst assemblage (Fig. 3). Of these, there are 10 autotrophic species of Gonyaulacales, representing 32.77% of the total assemblage, and is dominated by *Spiniferites* spp., *Alexandrium affine* type, and *Lingulodinium machaerophorum* (Table 1a). *Polysphaeridium zoharyii* was rarely found, yielding a total count of 12 cysts/g dry weight and constitutes 1.12% of the total cyst assemblage. Two species belonging to order Gymnodiniales were identified, consisted of autotrophic *Pheopolykrikos hartmanii* and heterotrophic *Polykrikos kofoidii*. Autotrophic cyst of *Scrippsiella* spp which belongs to Calciodinelloides of order Peridiniales accounted for only 1.77% of the total cyst assemblage.

Higher proportion (64.56%) of heterotrophic dinoflagellate cysts was recorded in the area (Fig. 3). Heterotrophic species were dominated by *Polykrikos kofoidii* which shares 25.35% of the total cyst assemblage. A total of 11 species with known thecal affinities for genus *Protoperidinium* were identified under order Peridiniales which shares 61.64% of the total cyst assemblage (Table 1a). The most dominant species is the round brown cysts *Brigantedinium* spp. comprise 16.57% and total count of 177 cysts/g dry weight. *Quinquecuspis concreta* is the next species that dominate the samples constitute 8.47% of the total cyst assemblage. Other taxa present include: *Selenopemphix quanta*, *Votadinium calvum*, *Selenopemphix nephroides*, *Stelladinium abei*, *Trinovantedinium capitatum*, *Brigantedinium irregulare*, *Brigantedinium asymmetricum*, and *Votadinium spinosum*, in that order of abundance. Order Peridiniales also includes 2 species identified as *Dubridinium caperatum* and *Diplopelta parva* for Diplopsaloides, which represent 2.93% of the total cysts assemblage.

Tuaran Estuary

The main characteristics of surface sediment cores in Tuaran Estuary are the low diversity and concentrations of only 11 dinoflagellate cysts taxa in assemblage (Table 1b). A low proportion of 18.98% is accounted for autotrophic Gonyaulacales, with *Spiniferites* spp as the most dominant species yielding 6.95% of the total cyst assemblage (Fig. 3). This was followed by *Lingulodinium machaerophorum* and *Polysphaeridium zoharyii*, each in a relatively low cyst abundance of 3.38% and 3.62%, respectively. Scarce distribution of other Gonyaulacales species, *Alexandrium affine* type, *Spinifeirtes bulloideus*, *Spiniferites mirabilis* and *Spiniferites* spp., were also observed in the area. A high proportion (81.02%) of cysts of heterotrophic dinoflagellates that consist of 6 species of order Peridiniales was recorded (Fig. 3). Peridiniales is dominated by *Brigantedinium* spp and *Votadinium spinosum* constituting relative abundances of 39.24% and 25.15%, respectively. These are followed by scarce distribution of some other species namely: *Brigantedinium irregulare*, *Quinquecuspis concreta*, *Selenopemphix nephroides*, *Selenopemphix quanta*, *Votadinium spinosum*. *Polykrikos kofoidii* is a single representative of heterotrophic Gymnodiniales with nominal count was found only in station 5.

Southern Coastal Waters of Sabah

Kuala Penyu Lagoon

A total of 22 dinoflagellate cysts taxa were identified in a shallow inshore Kuala Penyu Lagoon and the assemblage is

Table 1a. Dinoflagellate cyst assemblage and density in Kota Kinabalu Bay.

Station		St. 1	St. 2	St. 3	St. 4	TOTAL	Relative
wet weight for observation (g)		4.020	4.280	5.300	3.560		Abundance
water content rate of this sample (%)		74.286	66.667	68.627	42.000		%
total observed volue in 10 ml (ml)		3	3	3	3		
Biological cyst name	Paleontological cyst name						
Autotrophic species	Autotrophic species						
Gonyaulacales	Gonyaulacales						
Alexandrium affine type	*Alexandrium* spp	22.57	35.05	6.01	4.84	68	6.41
Gonyaulax scrippsae	*Spiniferites bulloideus*	19.35	7.01	8.02	1.61	36	3.37
Gonyaulax sp.	*Spiniferites cf. delicatus*	0	2.34	0	0	2	0.22
Gonyaulax sp.	*Spiniferites hyperacanthus*	6.45	7.01	14.03	4.84	32	3.03
Gonyaulax spp.	*Spiniferites* spp.	25.80	25.70	18.04	19.37	89	8.33
Gonyaulax spinifera	*Spiniferites mirabilis*	12.90	4.67	2.00	1.61	21	1.98
Lingulodinium polyedrum	*Lingulodinium machaerophorum*	25.80	32.71	6.01	9.69	74	6.95
Protoceratium reticulatum	*Operculodinium centrocarpum*	6.45	0.00	0.00	3.23	10	0.91
Pyrodinium bahamense	*Polysphaeridium zoharyi*	0	2.34	8.02	1.61	12	1.12
Pyrophacus steinii	*Tuberculodinium vancampoae*	0	0	0	4.84	5	0.45
Gymnodiniales	Gymnodiniales					0	
Pheopolykrikos hartmannii	*Pheopolykrikos hartmannii*	9.67	0	0	0	10	0.91
Peridiniales	Peridiniales						0
Scrippsiella spp.	*Scrippsiella* spp.	3.22	14.02	0	1.61	19	1.77
Subtotal cyst density of Autotrophic	Subtotal cyst density of Autotrophic	132.21	130.84	62.15	53.27	378	35.44
Heterotrophic species	Heterotrophic species						
Gymnodiniales	Gymnodiniales						
Polykrikos kofoidii	*Polykrikos kofoidii*	83.84	95.79	78.18	12.91	271	25.35
Peridiniales	Peridiniales	0					
Protoperdinium claudicans	*Votadinium spinosum*	0	0	2.00	0	2	0.19
Protoperdinium conicum	*Selenopemphix quanta*	22.57	2.34	10.02	6.46	41	3.88
Protoperdinium leonis	*Quinquecuspis concreta*	51.59	16.36	16.04	6.46	90	8.47
Protoperdinium oblongum	*Votadinium calvum*	6.45	11.68	4.01	6.46	29	2.68
Protoperdinium pentagonum	*Trinovantedinium capitatum*	0	4.67	0	0	5	0.44
Protoperidinium denticulatum	*Brigantedinium irregulare*	0	2.34	2.00	0	4	0.41
Protoperidinium latissinum	*Protoperidinium latissinum*	0	0	0	0	0	0
Protoperidinium sp.	*Stelladinium abei*	9.67	0	2.00	0	12	1.09
Protoperidinium sp.	*Brigantedinium asymmetricum*	3.22	0	0	0	3	0.30
Protoperidinium sp.	*Brigantedinium* spp.	96.74	42.06	22.05	16.14	177	16.57
Protoperidinium subinerme	*Selenopemphix nephroides*	22.57	0	0	1.61	24	2.26
Diplopsales	Diplopsales						
Diplopelta parva	*Dubridinium* sp.	19.35	4.67	2.00	0	26	2.44
Diplopeltopsis minor	*Dubridinium caperatum*	3.22	0	2.00	0	5	0.49
Protoperidinium nudum	*Protoperidinium* sp	0	0	0	0	0	0
Subtotal cyst density of Heterotrophic	Subtotal cyst density of Heterotrophic	319.24	179.91	140.33	50.05	690	64.56
Total cyst density	Total cyst density	451	311	202	103	1068	100.00

Table 1b. Dinoflagellate cyst assemblage and density in Tuaran Estuary.

Station		St. 1	St. 2	St. 3	St. 5	St. 6	TOTAL	Relative
wet weight for observation (g)		6.18	6.82	6.38	6.78	6.82		Abundance
water content rate of this sample (%)		73.74	61.94	60.37	56.95	75.63		%
total observed volue in 10 ml (ml)		1.1	1	1	1	1		
Biological cyst name	Paleontological cyst name							
Autotrophic speices	Autotrophic speices							
Gonyaulacales	Gonyaulacales							
Alexandrium affine type	*Alexandrium* sp.	0	0	0	3.43	0	3	1.21
Gonyaulax scrippsae	*Spinifeirtes bulloideus*	0	0	0	3.43	0	3	1.21
Gonyaulax spinifera	*Spiniferites mirabilies*	0	0	3.95	3.43	0	7	2.60
Gonyaulax spp.	*Spiniferites* spp.	0	0	0	13.71	6.02	20	6.95
Lingulodinium polyedrum	*Lingulodinium machaerophorum*	6.16	0	0	3.43	0	10	3.38
Pyrodinium bahamense	*Polysphaeridium zoharyi*	0	0	0	10.28	0	10	3.62
Subtotal cyst density of Autotrophic	Subtotal cyst density of Autotrophic	6.16	0	3.95	37.69	6.02	54	18.98
Heterotrophic species	Heterotrophic species							
Gymnodiniales	Gymnodiniales							
Polykrikos kofoidii	*Polykrikos kofoidii*	0	0	0	3.43	0	3	1.21
Peridiniales	Peridiniales							
Protoperdinium claudicans	*Votadinium spinosum*	4.11	19.26	0	47.97	0	71	25.15
Protoperdinium conicum	*Selenopemphix quanta*	6.16	0	0	0	0	6	2.17
Protoperdinium leonis	*Quinquecuspis concreta*	0	3.85	0	6.85	0	11	3.77
Protoperdinium subinerme	*Selenopemphix nephroides*	12.33	3.85	0	0	0	16	5.70
Protoperidinium denticulatum	*Brigantedinium irregulare*	0	3.85	0	6.85	0	11	3.77
Protoperidinium sp.??	*Brigantedinium* spp.	45.19	19.26	3.95	30.84	12.03	111	39.24
Subtotal cyst density of Heterotrophic	Subtotal cyst density of Heterotrophic	67.79	50.08	3.95	95.94	12.03	230	81.02
Total density of cysts	Total density of cysts	73.95	50.08	7.91	133.63	18.05	284	100.00

(cysts/g dry weight)

Table 1c. Dinoflagellate cyst assemblage and density in Sipitang Bay.

Station		St. 1	St. 2	St. 3	St. 4	TOTAL	Relative
wet weight for observation (g)		1.20	1.20	1.50	1.50		Abundance
water content rate of this sample (%)		60.75	66.99	80.20	77.48		%
total observed volue in 10 ml (ml)		3.00	4.50	4.50	4.50		
Biological cyst name	Paleontological cyst name						
Autotrophic species	Autotrophic species						
Gonyaulacales	Gonyaulacales						
Alexandrium affine type	*Alexandrium* sp.	14.15	173.91	149.63	111.82	450	42.90
Alexandrium pseudogoniaulax	*Alexandrium* sp.	0	0	0	13.16	13	1.26
Gonyaulax scrippsae	*Spinifeirtes bulloideus*	0	22.44	0	19.73	42	4.02
Gonyaulax scrippsae (morphotype sp.?)	*Spiniferites ramosus*	7.08	0	0	0	7	0.68
Gonyaulax sp. (?)	*Spiniferites hyperacanthus*	0	0	0	6.58	7	0.63
Gonyaulax spinifera	*Spiniferites mirabilies*	0	0	7.48	6.58	14	1.34
Lingulodinium polyedrum	*Lingulodinium machaerophorum*	0	16.83	7.48	13.16	37	3.58
Protoceratium reticulatum	*Operculodinium centrocarpum*	0	0.00	7.48	6.58	14	1.34
Pyrodinium bahamense	*Polysphaeridium zoharyi*	0	11.22	52.37	0	64	6.07
Pyrophacus steinii	*Tuberculodinium vancampoae*	0	0	7.48	0	7	0.71
Spiniferites spp.	*Spiniferites* spp.	7.08	0	7.48	19.73	34	3.27
Peridiniales	Peridiniales						
Scrippsiella spp.	*Scrippsiella* spp.	0	5.61	14.96	6.58	27	2.59
Subtotal cyst density of Autotrophic	Subtotal cyst density of Autotrophic	28.31	230.01	254.37	203.91	717	68.38
Heterotrophic species	Heterotrophic species						
Gymnodiniales	Gymnodiniales						
Polykrikos kofoidii	*Polykrikos kofoidii*	0	5.61	14.96	0	21	1.96
Peridiniales	Peridiniales						
Protoperidinium compressum	*Stelladinium reidii*	0	0	7.48	0	7	0.71
Protoperidinium conicum	*Selenopemphix quanta*	0	11.22	7.48	13.16	32	3.04
Protoperidinium leonis	*Quinquecuspis concreta*	0	0	14.96	19.73	35	3.31
Protoperidinium pentagonum	*Trinovantedinium capitatum*	0	0	0	6.58	7	0.63
Protoperidinium sp.	*Stelladinium* abei	0	0	22.44	6.58	29	2.77
Protoperidinium sp.	*Brigantedinium* spp.	7.08	5.61	67.33	72.36	152	14.54
Protoperidinium sp.	*Brigantedinium asymmetricum*	0	0	7.48	0	7	0.71
Protoperidinium subinerme	*Selenopemphix nephroides*	0	0	14.96	13.16	28	2.68
Protoperinium oblongum	*Votadinium calvum*	0	0	0	6.58	7	0.63
Diplopsaloides	Diplopsaloides						
Diplopeltopsis minor	*Dubridinium caperatum*	0	0	0	6.58	7	0.63
Diplopelta parva	*Dubridinium* sp.	0	0	0	6.58	7	0.63
Subtotal cyst density of Heterotrophic	Subtotal cyst density of Heterotrophic	7.08	22.44	157.11	144.71	338	32.25
Total density of cysts	Total density of cysts	35	252	411	349	1048	100.00

(cysts/g dry weight)

Table 1d. Cyst assemblage and density in Kuala Penyu Lagoon.

Station Name/Code		TS 1	TS 1	TS 2	TS 3	TS 4	TS 5	TOTAL	
Wet sample wt for observation (g)		15.90	15.90	14.17	2.59	8.52	10.40		SPECIES
Water content rate of this sample (%)		41.07	41.07	46.86	68.73	67.72	69.04		%
Total observed volue in 10 ml (ml)		4.00	4.00	3.00	3.00	3.00	2.50		
Paleontological Nomenclature	Paleontological Nomenclature								
Autothrophic Species	Autothrophic Species								
Gonyaulacales	Gonyaulacales								
Alexandrium (?)	Unknown	1.33	1.33	0.44	0	0	4.97	8	5.02
Gonyaulax scrippsae	*Spiniferites bulloides*	0.27	0.01	0.44	0	0	0	1	0.45
Gonyaulax sp.	*Spiniferites hypercanthus*	0	0	0.44	0	1.21	0	2	1.03
Gonyaulax spinifera complex	*Spiniferites mirabilis*	0	0	0.44	0	0	0	0	0.27
Gonyaulax sp.	*Spiniferites cf. delicatus*	0	0	0.44	0	0	0	0	0.27
Protoceratium reticulatum	*Operculodinum centricarpum*	1.07	0.04	0.44	24.69	0	4.97	31	19.38
Pyrodinium bahamense	*Polysphaeridium zoharyii*	0	0	0.89	0	1.21	3.73	6	3.62
Peridiniales	Peridiniales								
Calciodineloides	Calciodineloides								
Scrippsiella spp. (?)	*Scrippsiella* spp.	6.14	0.23	2.21	8.23	7.27	1.24	25	15.72
Sub-total of autotrophic species	Sub-total of autotrophic species	8.80	1.61	5.76	32.93	9.70	14.91	74	45.75
Heterotrophic Species	Heterotrophic Species								
Peridiniales	Peridiniales								
Protoperidinium compressum	*Stalldinium reidii*	0	0	0	0	1.21	0	1	0.75
Protoperidinium conicoides	*Brigantedinium simplex*	1.07	0.04	0.44	4.12	4.85	1.24	12	7.30
Protoperidinium conicum	*Selenopemphix quanta*	0	0	0	4.12	1.21	2.48	8	4.85
Protoperidinium denticulatum	*Brigantedinium irregulare*	0	0	0.44	8.23	1.21	1.24	11	6.91
Protoperidinium leonis	*Quinquecuspis concreta*	1.07	0.04	0	0	0	0	1	0.69
Protoperidinium oblongum	*Votadinium calvum*	0	0	0.44	0	0	0	0	0.27
Protoperidinium subinerme	*Selenopemphix alticinctum*	0.27	0.01	0	0	0	0	0	0.17
Protoperidinium sp.	*Trinovantedinium pallidifurvum*	1.07	0.04	0	0	0	0	1	0.69
Protoperidinium spp. (round-brown cyst)	*Brigantedinium* sp.	0	0	1.77	4.12	4.85	1.24	12	7.43
Diplopsaloides	Diplopsaloides								
Diplopeltopsis minor	*Dubridinium caperatum*	0	0	0.44	0.0	1.21	1.24	3	1.80
Diplopelta parva	*Dubridinium* sp.	0.80	0.03	0	8.23	2.42	1.24	13	7.90
Diplopelta sp. (Dinocyst 3c)	*Dubridinium* sp.	0	0	1.33	0	2.42	0	4	2.33
Unknown species									
Dinocyst *cf Lingulodinium polyedrum* (similar but varies in body size & short processes)		10.94	0.41	1.33	0	7.27	1.24	21	13.16
Sub-total of heterotrophic species	Sub-total of heterotrophic species	15.21	0.57	6.20	28.81	26.66	9.94	87	54.25
Total cyst density (number of cysts per gram dry sediment weight)		24.01	2.18	11.95	61.74	36.36	24.84	161	100.00

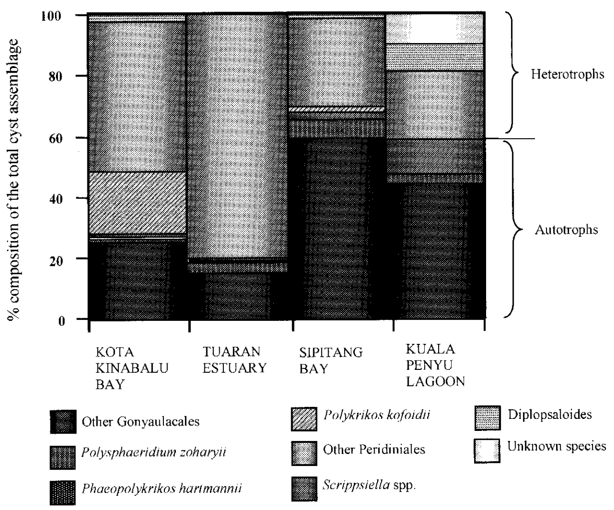

Fig. 3. Relative abundance of dinoflagellate cyst taxonomic groups in Sabah, Malaysia.

mainly characterized by relatively low concentrations of order Gonyaulacales, and order Peridiniales including Calciodinelloides and Diplopsaloides and a single unknown dinocyst (Table 1d). Of these, there are 7 species of autotrophic Gonyaulacales which shares 29.47% of the total cyst assemblage (Fig. 3). These are consisted of *Alexandrium* spp., *Spiniferites bulloides*, *Spiniferites hyperacanthus*, *Spiniferites mirabilis*, *Spiniferites* sp. cf. *delicatus*, *Operculodinium centrocarpum* and *Polysphaeridium zoharyii*. The most abundant taxon is *Operculodinium centrocarpum*, yielding 19.53% of the total cyst assemblage, appearing in almost all stations with total counts of 31 cysts g^{-1} dry weight. *Polysphaeridium zoharyii* was observed in a nominal count of 6 cysts g^{-1} dry weight and shares 3.64% of the total cyst assemblage. Lower proportion (15.85%) is accounted for an autotrophic species, *Scrippsiella* spp of Calciodinelloides. Higher proportion of heterotrophic cyst taxa was observed with relative abundance of 54.68% of the total assemblage (Figure 3). Of which 41.42% represents the order Peridiniales including 12.12% Diplopsaloides. There are 12 species identified for order Peridiniales, where 9 species of which have known thecal affinities for genus *Protoperidinium*, include: *Brigantedinium simplex*, *Brigantedinium irregulare*, *Brigantedinium* sp. (round brown cysts), *Quinquecuspis concreta*, *Stelladinium quanta*, *Stelladinium reidii*, *Selenopemphix alticinctum*, *Trinovantedinium pallidifurvum*, and *Votadinium calvum*. Diplopsaloides is represented by three species, namely: *Dubridinium caperatum*, and other two morphotype species of *Dubridinium* with thecal affinities to *Diplopeltopsis minor* and *Diplopeltopsis orbicularis*. Furthermore, one unknown dinocyst which shares 13.26% of the total cyst assemblage is commonly found in all stations. The species is assumed to have morphological features of dinoflagellate cyst.

Sipitang waters

The dinoflagellate cysts assemblage in deep offshore water of Sipitang contained 24 taxa, mainly composed of orders Gonyaulacales, Gymnodiniales and Peridiniales including Calciodinelloides and Diplopsaloides (Table 1c). The assemblage is characterized with higher proportion of autotrophic dinoflagellate cysts taxa, yielding 67.96% of the total cyst assemblage (Fig. 3). Of these, there are 11 species of Gonyaulacales which contributed 65.38% and one species of Calciodinelloides, *Scrippsiella* spp., which shares 2.57%. The higher abundance of Gonyaulacales is attributed to the common occurrence of *Alexandrium affine* cysts type which shares 42.65% of the total assemblage. The second leading dominant species among Gonyaulacales is the *Polysphaeridium zoharyii* with total counts of 64 cysts g^{-1} dry weight and contributed 6.02% of the total cysts assemblage. Some other autotrophic Gonyaulacales species which occurred in relatively low abundance are *Alexandrium pseudogonyaulax*, *Lingulodinium machaerophorum*, *Operculodinium centrocarpum*, *Spiniferites bulloides*, *Spiniferites hyperacanthus*, *Spiniferites mirabilis*, *Spiniferites ramosus*, *Spiniferites* spp, and *Tuberculodinium vancampoae*.

A lower proportion of heterotrophic dinoflagellate cysts taxa were observed in this area which shares 32.25% of the total cyst assemblage (Fig. 3). *Polykrikos kofoidii* is the only autotrophic species identified for order Gymnodiniales which shares 1.95% of the total cyst assemblage. There are 10 species identified for order Peridiniales which constitutes 29.03% of the total assemblage and these have known thecal affinities for genus *Protoperidinium*. The round brown cysts (*Brigantedinium* spp.) are relatively distributed in all stations which contributed 14.44% of the total cyst assemblage. Other peridinoid taxa present include: *Brigantedinium asymmetricum*, *Quinquecuspis concreta*, *Selenopemphix nephroides*, *Selenopemphix quanta*, *Stelladinium abei*, *Stelladinium reidii*, *Trinovantedinium capitatum*, and *Votadinium calvum*. Order Peridiniales also includes 2 species identified as *Dubrindinium caperatum* and *Diplopelta parva* for Diplopsaloides, which represent 1.26% of the total cysts assemblage.

Discussion

In this study, dinoflagellate cysts density are sparse in surface sediments of all sampling sites in the west coast Sabah, and are comparable to other previous cyst mapping studies in some coastal waters of tropical region (Lirdwitayaprasit 1997, 1998, Godhe et al. 2000, Azanza et al. 2004). The dinoflagellate cysts diversity is relatively low in two shallow inshore estuaries (Tuaran and Kuala Penyu Lagoon) than those of deeper offshore sampling sites off the north (Kota Kinabalu Bay) and south (Sipitang Bay) parts. Sediment samples from these two shallow estuaries contain low diversity of dinoflagellate cyst assemblages with 11 and 22 cyst taxa recorded in Tuaran Estuary and Kuala Penyu Lagoon, respectively (Table 1b and 1d). Both estuaries are characterized with higher proportions of heterotrophic cysts, though most of the cysts occurred in relatively low concentrations. *Brigantedinium* spp and *Votadinium spinosum* dominated Tuaran estuary while the cyst of unknown species (Dinocyst 1), *Dubridinium caperatum*, *Brigantedinium* spp, and *Brigantedinium simplex* were dominant in Kuala Penyu Lagoon. Given the cyst species composition of these two estuaries, there seems to be low productivity of cyst-forming dinoflagellates in the water column above, comparable to what have been observed in Tokyo Bay by Matsuoka et al. (2003). Moreover, these dominant heterotrophic dinoflagellate cyst taxa suggest as biological indicators of eutrophic water conditions in estuarine systems (Pospelova et al. 2002, 2005, Matsuoka et al. 2003). Most sampling stations in Tuaran and Kuala Penyu Lagoons are shallow and surrounded by mangroves. The sediments are characterized with silt, rough grainy and full of decaying mangrove debris. Such sediment characteristics are probably unfavourable for cyst deposition. It has been well studied that the finer-grained sediments provide richer samples of dinoflagellate cyst than those coarser-grained sediments (Dale 1979). In Tokyo Bay where waters have been described as hypertrophic, some sections of the Bay such as the marginal section also consisted of few cysts. They attributed this to the dilution effects of terrestrial sediment particle transportation from land, sandy sediments which are unfavourable for the settling of cysts; low productivity of cyst-forming dinoflagellates in the water column above and sedimentary processes unfavourable for sedimentation (Matsuoka et al. 2003). Follosco (1998) in her study of mangrove soil in Quezon Province, Philippines determined the amount of sulphate to range from 153 to 353 ppm and phosphate from 5.76 to 13 ppm. If applied to the sediments of Tuaran and Kuala Penyu Lagoons which are also located within the tropical region as the Philippines, then such values may be high enough to inhibit cyst settlement. Pospelova et al. (2005) found a significant negative correlation between dinoflagellate cyst species richness and toxic pollutants in Buzzards Bay, Massachusetts, USA which has a hypertrophic water system. Sites with the highest levels of toxic pollution and hypertrophic conditions are characterized by the lowest dinoflagellate cyst species-richness and concentrations.

Fairly deep offshore waters of Kota Kinabalu and Sipitang Bays' sediments, on the other hand, can be characterized as being finer than that of Tuaran and Kuala Penyu Lagoons. This could be the reason why there are more dinoflagellate cysts in these areas. Dale (1979) and Nehring (1992) observed that finer mud sediments preserve more cysts. Azanza et al. (2004) also observed that Manila Bay areas with high clay content have higher cyst concentrations than in areas with other sediment types.

There were more heterotrophic dinoflagellate cysts than the autotrophs in all stations of all the sampling sites, except in relatively deep offshore waters of Sipitang Bay in the south part where autotrophs were significantly higher. This is indicative of high-nutrient conditions which has been observed in various studies: Matsuoka (1987) in his study of North Japan; Thorsen and Dale (1997) in a Northern Norway; Azanza et al. (2004) in Manila Bay, Philippines and; Matsuoka et al. (2003) in their study of Tokyo Bay. Human activities such as coastal development/destruction, increased fishfarms operation, domestic and industrial pollution and erosion from nearby tributaries can add excess nutrients to coastal areas. Kota Kinabalu's high-nutrient status may come from being an urbanized to industrialized city where artificial nutrients are transported by rivers while Tuaran and Kuala Penyu's nutrient sources are more from surrounding mangrove forests, thus the higher concentration of heterotrophic dinoflagellate cysts were observed in Kota Kinabalu than in Tuaran Estuary and Kuala Penyu Lagoon. Among the heterotrophs in Kota Kinabalu, *Polykrikos kofoidii* was most abundant. This is also one of the indicator species of hypertrophism in Tokyo Bay (Matsuoka et al. 2003).

Among the sampling sites, Sipitang Bay exhibited exceptional characteristics in terms of dinoflagellate cyst assemblage, abundance and diversity. Dinoflagellate cyst diversity and concentrations is relatively high, where it is represented by higher proportions of autotrophic species than the heterotrophs. This was attributed to greater abundance and widespread distribution of *Alexandrium affine* in all stations. There seems to have high production of autotrophic motile dinoflagellates in the water column above as reflected in the dinoflagellate cysts assemblage in the sediments such as *Lingulodinium machaerophorum*, *Spiniferites* spp., and *Polyphaeridium zoharyii*, apart from the abundance of cyst of *Alexandrium affine*. The sediment in Sipitang has finer grains which could preserve more dinoflagellate cysts. With the exception of Sipitang among the sampling sites, it seems that there is less environmental stress, if compared to other sampling sites. This of the two factors, whether type of sediments or at the stage of hypertrophic condition of the bay, is hard to speculate on the basis of the present lack of information.

Toxic dinoflagellate cysts

The present results revealed the presence of cyst of toxic/HAB species, *Pyrodinium bahamense* as earlier reported in the area by Usup et al. (1989) and Matsuoka et al. (1989). It is sporadically distributed in all sampling sites. It is observed entirely in the form of empty cyst. It is present at a low density ranging from 2 to 8 cysts g^{-1} dry weight in stations 2, 3 and 4 at Kota Kinabalu Bay (Fig. 4a). It is rare and could be found only in station 5 with 10 cysts g^{-1} dry weight at Tuaran estuary (Fig. 4b). It is present also in Kuala Penyu

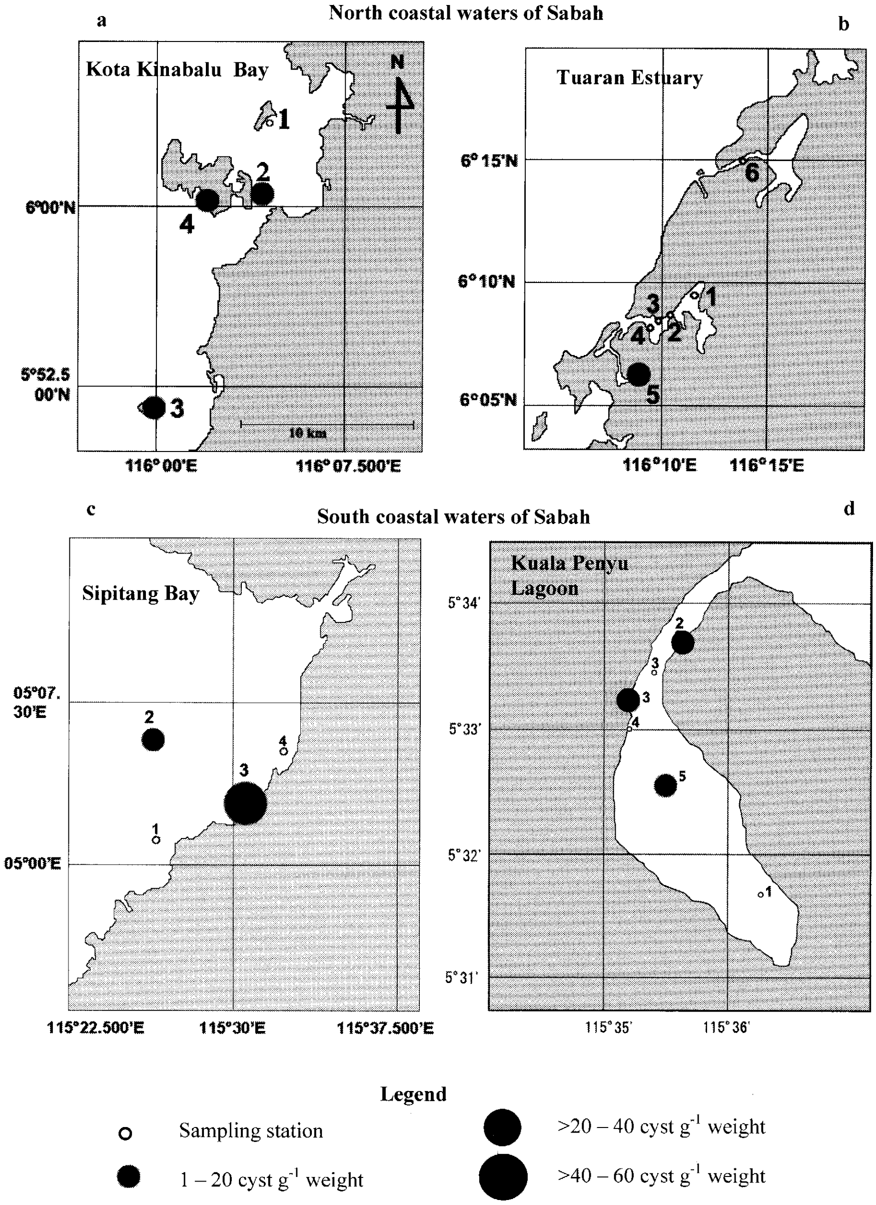

Fig. 4. Spatial distribution of *Polysphaeridium zoharyii* in surface sediments off the northern coastal waters of Sabah (Aug. 17–18, 2005).

Lagoon in nominal counts which ranged from 1 to 4 cysts g^{-1} dry weight at stations 2, 4 and 5 (Fig. 4d). Two stations (stations 2 and 3) in Sipitang Bay contained significant densities with 11 and 52 cysts g^{-1} dry weight of *Polyphaeridium* .ure 4c). These results confirmed the occurrence of *Pyrodinium bahamense* bloom in the water column as earlier reported (Roy 1977, Maclean 1979, Usup et al. 1989). However, despite the frequent bloom occurrence of its motile cells in the overlying waters in these areas, particularly in Sipitang and Kota Kinabalu Bays, there seems to have low production and deposition of *Polyphaeridium zoharyii* cyst in the underlying sediments. The shift in three types of monsoonal winds which contributed to the formation of strong waves and well-developed water circulations in geographical location of Sabah may have transported or wash away the cyst population elsewhere in its neighbouring coastal waters. This seems to prevent the formation of the so called "seed bed" or "point source area" that would inoculate and initiate future bloom of *Pyrodinim. bahamense* in these areas. Anderson (1989) inferred that the presence of cysts of a species of interest does suggest the potential for bloom initiation, but the converse is not true. The absence of detectable cysts of a species does not mean an area is free from the threat of toxic blooms. The paucity of cysts clearly reflects factors such as cyst resuspension and transport and not the continual absence of the species from the plankton (Anderson 1989). The relative abundance and distribution of *Polyphaeridium zoharyii* in this present study is comparatively lower than those found in the same tropical coastal waters in the SEA region such as in Malampaya Sound, Palawan (Furio et al., unpublished), and Manila Bay (Azanza et al. 2004). *Polyphaeridium zoharyii* is dominant today in warm shallow-water, highly fluctuating environments that could be characterized as either hypo- or hypersaline; the common factor is abnormal and/or highly variable salinity (Morzadec-Kerfourn 1983, Bradford and Wall 1984). It is plausible that the presence even in few counts of toxic dinoflagellate cyst, *e.g. Polyphaeridium zoharyii*, in the sediments of the coastal embayment and estuaries of Sabah, suggests a potential threat to human health and economy in this part of the SEA coastal waters.

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