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Distribution of dinoflagellate cysts in the surface sediment of the coastal areas in Chonburi Province, Thailand

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Abstract—Distribution of dinoflagellate cysts were investigated in rainy and dry seasons in the surface sediment of the coastal areas in Ang-sila, Bang-pra, Si-racha and Laem-chabang, Chonburi Province, Thailand. Sampling cruises were conducted in February and September 2005 that were during the dry and rainy seasons, respectively. Thirty types of cysts were found of which 28 cysts belonged to the orders Gonyaulacales, Gymnodiniales and Peridiniales and two were of unknown cyst types. The dominant species were *Pheopolykrikos hartmannii* and *Pyrophacus steinii* and the most common species were *P. hartmannii*, *Gonyaulax spinifera* (*Spiniferites mirabilis*), *Lingulodinium polyedrum*, *P. steinii*, *Protoperidinium pentagonum* and *P. leonis*. Dinoflagellate cysts were widely found in most stations of the study area. The total numbers of dinoflagellate cysts in dry season were higher than those in rainy season. The abundance of dinoflagellate cysts in both seasons was higher at the stations deeper than 10 meter around Ang-sila and Bang-pra areas than at the stations near Laem-chabang areas. These findings suggest that cyst abundance and distribution might be affected by seasonal changes of environment and fishery activity.

Key words: distribution, dinoflagellate cysts, surface sediment, Thailand

Introduction

Approximately 10–16% of marine dinoflagellate species are known to produce benthic resting cysts in their life cycle (Dale 1983, Head 1996). The formations of resting cysts are initiated by sexual reproduction with fusion of two gametes in response to favorable environmental condition (Sonneman and Hill 1997). The resting cysts are deposited on the surface of sediments as a dormant stage cell of life cycle, and survive in sediment for several years (Lewis et al. 1999). After the dormancy period, cysts may germinate and return to water column to recruit a new population under external favorable condition. This is the specific strategy of survival from the environment unsuitable for growth of dinoflagellate cyst forming species (Pfiester and Anderson 1987).

The ecological functions of dinoflagellate cysts have been documented as follows: (i) genetic recombination (Anderson 1984), (ii) survival during unfavorable conditions (Nehring 1993), (iii) species dispersal (Hallegraeff 1993), (iv) regulation on dinoflagellate bloom dynamics by simultaneous germination (Ishikawa and Taniguchi 1996, Kemp 2000), and (v) direct source of toxin (Dale et al. 1978). Dinoflagellate communities can be indicators of history of environmental conditions in coastal zones of enclosed seas, because cyst walls are highly resistant to degradation and preserved for a long time (Fujii and Matsuoka 2006).

Although the importance of cyst study has been well recognized, studies on cyst assemblage in Thai waters are quite limited. Lirdwitayaprasit (1997) investigated the distribution of dinoflagellate cysts at 48 stations along the Gulf of Thailand and the east coast of Peninsular Malaysia and found 20 dinoflagellate cyst species in these areas.

The Upper Gulf of Thailand, especially the coastal area of Chonburi Province where international port for commercial ships is located, might be a risk area for invasive toxic dinoflagellate species, as their cysts may be transported by ship's ballast water. Furthermore, two toxic species, *Alexandrium tamarense* and *A. tamiyavanichii*, were previously found in this area (Pholpunthin 1987, Fukuyo et al. 1988). With this circumstance, this study aims to observe distribution of dinoflagellate cysts in the area, in order to obtain useful information for early preparation and warning of toxic dinoflagellate occurrence in the future.

Materials and Methods

Figure 1 and Table 1 show sampling stations along Chonburi Province, which is located in the eastern part of the upper Gulf of Thailand. Sediment samples were collected with a gravity corer equipped with a 10 cm diameter pvc pipe at 14 stations in February and September, 2005, representing dry and rainy seasons, respectively. The top 2 cm of sediment in the cores were separated and immediately preserved in darkness at 4°C in a refrigerator to prevent cyst germination.

A 3-g sediment taken from each surface sample was prepared using sieving method described by Matsuoka and Fukuyo (2000). Both live and empty cysts were recorded and identified under Olympus inverted microscope according to several literatures such as Wall and Dale (1968), Fukuyo et al. (1990), Bolch and Hallegraeff (1990) and Matsuoka and Fukuyo (2000).

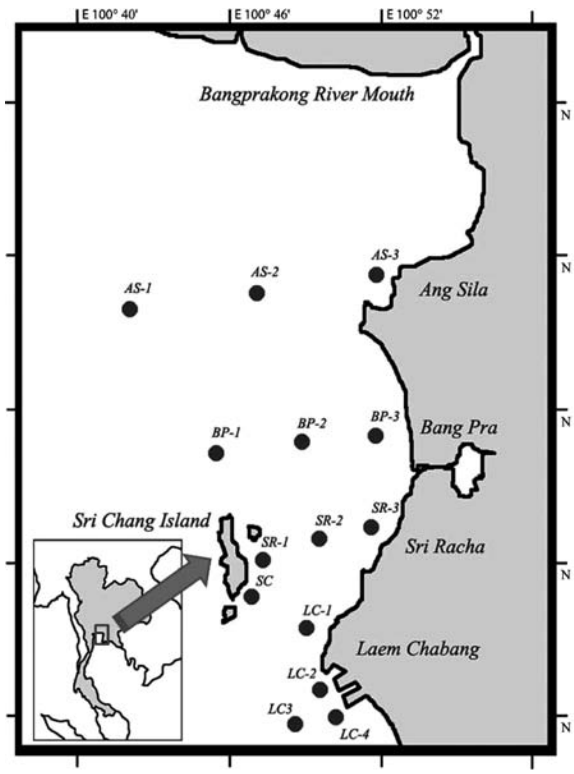

Fig. 1. Location of sampling stations along coastal areas of Chonburi province, Thailand.

Results

Dinoflagellate cysts composition

Thirty distinctive dinoflagellate cysts were identified belonging to 3 groups, representing 8 genera, and seventeen of these were identified to species level and two unknown cyst types (Table 2). All cysts species are shown in Figs. 2 and 3.

Cysts abundance and distribution

The abundances of the 30 types of cysts identified from the sediments of Chonburi coastal areas were very low and varied by seasons and sampling stations (Tables 3, 4 and Fig. 4).

In the dry season, 30 types of cysts were found and total cysts concentrations ranged from 0 to 128 cyst g^{-1} dry sediment. The majority of cysts occurred in the northern part of study areas at Ang-sila (AS-1 and AS-2 station) and Bang-pra Areas (BP-2) (Table 3, Figs. 4–6). The cysts of *Pheopolykrikos hartmanii* and *Pyrophacus steinii* were most abundant and broadly distributed. The cysts of *Gonyaulax scrippsae*, *G. spinifera* complex (*Spiniferites mirabilis*), *Lingulodinium polyedrum*, *Protoperidinium pentagonum*, *P. leonis, P. oblongum, P. subinerme, P. conicum* and *Protoperidinium* sp. 6 were common and broadly distributed, but their cell numbers were very low (Tables 3 and 4).

In the rainy season, only 19 types of cysts were found. The abundance of cysts was extremely low, with the total cysts concentration ranging from 0 to 39 cyst g^{-1} dry sediment. The cysts of *P. hartmanii* and *P. steinii* were most

Table 1. Location, water depth and sediment characteristics of the sampling site.

Station	Depth (m)	Location Lat. (N)	Location Lon. (E)	Sediment characteristics
AS-1	19.0	13°18.900	100°40.000	Brownish mud
AS-2	15.9	13°19.637	100°49.337	Brownish silt clay
AS-3	3.7	13°20.070	100°54.706	Brownish silt clay
BP-1	16.7	13°12.411	100°51.984	Brownish mud
BP-2	11.0	13°13.312	100°53.510	Greenish mud
BP-3	8.0	13°13.966	100°54.815	Sandy mud
SR-1	12.4	13°08.877	100°49.637	Coarse sandy mud
SR-2	15.8	13°10.162	100°52.141	Coarse sandy with shell fragment
SR-3	4.0	13°10.391	100°54.153	Brownish muddy sand
SC	18.4	13°07.147	100°49.830	Brownish mud
LC-1	24.4	13°07.300	100°51.700	Brownish silt clay
LC-2	7.6	13°03.708	100°52.521	Fine sandy mud
LC-3	15.5	13°13.439	100°51.888	Fine sandy mud
LC-4	8.6	13°02.157	100°53.199	Fine sandy mud

Table 2. Dinoflagellate cyst assemblages in Chonburi coastal areas.

Order	Biological name	Paleontological name	Synonym
Gymnodiniales			
	Pheopolykrikos hartmannii (Zimmerman) Matsuoka and Fukuyo		
	Polykrikos schwartzii Buetschli		
	Polykrikos kofoidii Chatton		
Gonyaulacales			
	Alexandrium sp.		
	Gonyaulax scrippsae Kofold	*Spiniferites bulloideus*	
	Gonyaulax spinifera complex (Claparede and Lachman) Diesing		
	Spiniferites membranaceus (Rossignal) Sarjenat	*Spiniferites membranaceus*	
	Spiniferites mirabilis (Rossignal) Sarjenat	*Spiniferites mirabilis*	
	Lingulodinium polyedrum (Stein) Dodge	*Lingulodinium machaeophorum*	*Gonyaulax polyedra*
	Pyrophacus steinii (Schiller) Wall and Dale	*Tuberculodinium vancompoae*	*Pyrophacus horologiam*
	Spiniferites sp. 1		
	Spiniferites sp. 2		
	Spiniferites sp. 3		
Peridiniales			
	Protoperidinium compressum (Abe) Balech	*Stelladinium stellatum*	*Peridinium stellatum*
	Protoperidinium latissinum (Kofoid) Balech		*Peridinium latissinum*
	Protoperidinium leonis (Pavillard) Balech	*Quinquecuspis concretum*	
	Protoperidinium oblongum (Aurivillius) Parke and Dodge	*Votadinium calvum*	*Peridinium oblongum*
	Protoperidinium claudicans (Paulsen) Balech	*Votadinium spinosum*	*Peridinium cludicans*
	Protoperidinium pentagonum (Gran) Balech	*Trivantedium capotatum*	*Peridinium pentagonum*
	Protoperidium subinerme (Paulsen) Balech	*Selenopemphix alticintum*	*Peridinium subinerme*
	Protoperidium conicum (Gran) Balech	*Seleopemphix quanta*	*Peridinium conicum*
	Diplopelta parva (Abe) Matsuoka		
	Protoperidinium sp. 1		
	Protoperidinium sp. 2		
	Protoperidinium sp. 3		
	Protoperidinium sp. 4		
	Protoperidinium sp. 5		
	Protoperidinium sp. 6		
	Protoperidinium sp. 7		
Unknown cyst type			
	Unknown type 1		
	Unknown type 2		

abundant. (Table 4, Figs. 4–6)

Only two cysts of the potentially toxic dinoflagellate *Alexandrium* sp. were found at AS-2 station of Ang-sila in the dry season. (Table 3).

Discussion

Seventeen among the 30 morphotypes of dinoflagellate cysts were identified to species level. Same species have also been found in other areas of the world such as India (Godhe et al. 2000), South Korea and Japan (Kim 1991, Lee and Matsuoka 1996), Australia (Bolch and Hallegraeff, 1990) and Sweden (Presson et al. 2000).

In this study, dinoflagellate cysts were distributed in low concentration at all stations. These results are comparable to those of previous cyst surveys in some tropical regions (Godhe et al. 2000, Matsuoka et al. 1999), but extremely low in density when compared to those reported from temperate regions such as Korea and Japan (Kim 1991, Lee and Matsuoka 1996). However, the cyst assemblage in this investigation was more variable than those reported by Lirdwitayaprasit (1997), who observed distribution of dinoflagellate cysts from 48 stations in the Gulf of Thailand and the east coast of Peninsular Malaysia. He found 20 cyst species, total cyst concentrations of which ranged from 0 to 56 cyst g^{-1} dry sediment.

Anderson and Morell (1979), Pfiester and Anderson (1987) and Bravo and Anderson (1994) suggested that distribution and abundance of dinoflagellate cysts were strongly

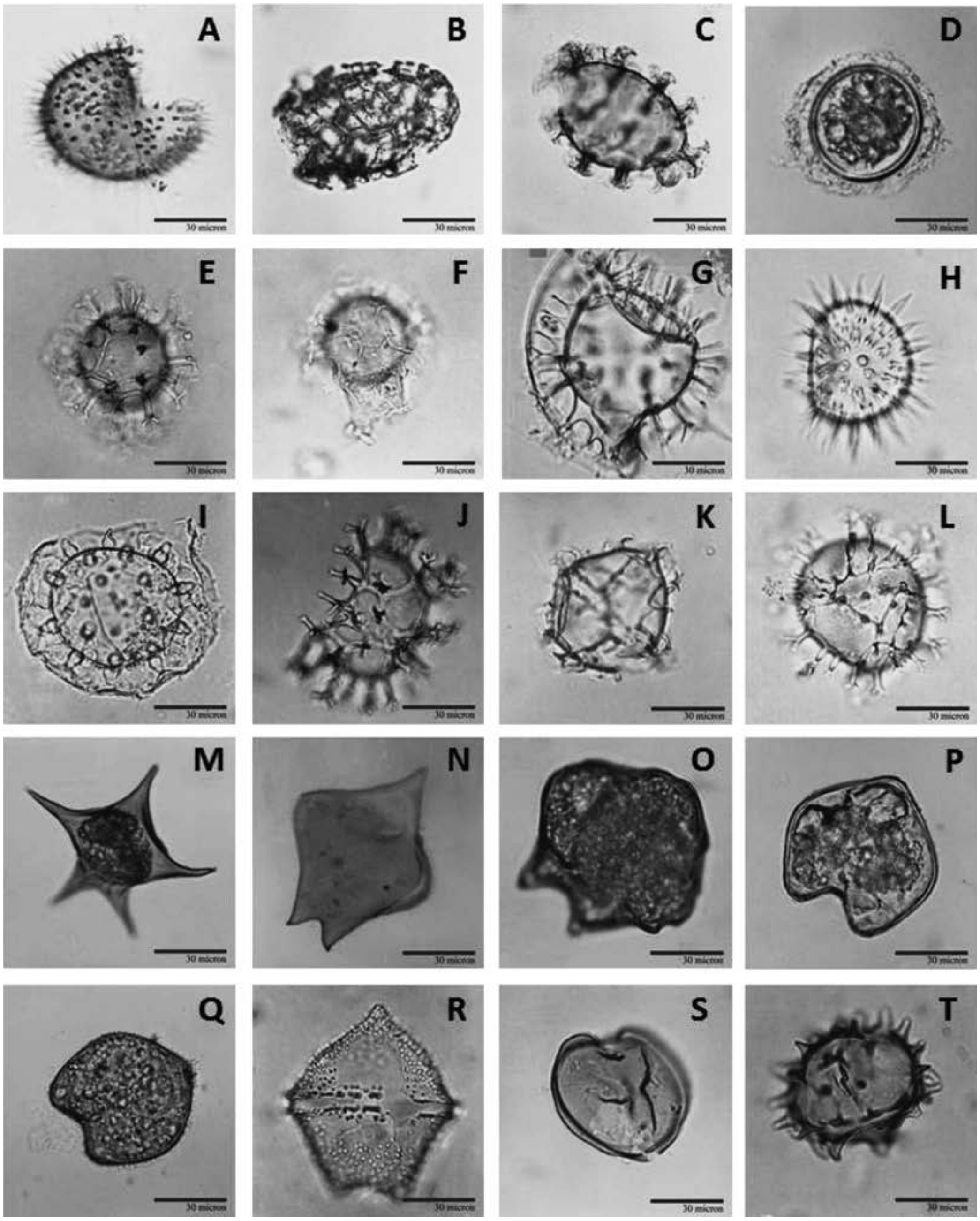

Fig. 2. Dinoflagellate cysts identified in this study. A, *Pheopolykrikos hartmanii*; B, *Polykrikos schwartzii*; C, *Polykrikos kofoidii*; D, *Alexandrium* sp.; E. *Gonyaulax scrippsae* (*Spiniferites bulloides*); F, *Gonyaulax spinifera* complex (*Spiniferites membranaceus*); G, *Gonyaulax spinifera* complex (*Spiniferites mirabilis*); H, *Lingulodinium polyedrum* (*Lingulodinium machaeophorum*); I, *Pyrophacus steinii* (*Tuberculodinium vancompoae*); J, *Spiniferites* sp.1; K, *Spiniferites* sp.2; L, *Spiniferites* sp.3; M, *Protoperidinium compressum* (*Stelladinium stellatum*); N, *Protoperidinium latissimum*; O, *Protoperidinium leonis* (*Quinquecuspis concretum*); P, *Protoperidinium oblongum* (*Votadinium calvum*); Q, *Protoperidinium claudicans* (*Votadinium spinosum*); R, *Protoperidinium pentagonum* (*Trivantedium capotatum*); S, *Protoperidium subinerme* (*Selenopemphix alticintum*); T, *Protoperidium conicum* (*Seleopemphix quanta*).

correlated with those of vegetative cells in the water column, especially those during red tide occurrences. However any red tides by the cyst forming dinoflagellates has not reported in the Chonburi coastal region, and no correlation was observed in the present study.

In this study, we found greater cyst abundances in Ang-sila area, i.e. AS-1 and 2, than in other areas in the rainy season. These two stations were close to the mouth of Bangpakong River. Under influence of Bangpakong River discharge in the rainy season, the water of relatively high nutrient in Ang-sila area induced high abundance of dinoflagellate vegetative cells, including several common dinoflagellates such as *P. steinii, G. spinifera,* and *P. leonis,* the cysts of which were found in the surface sediment in the area.

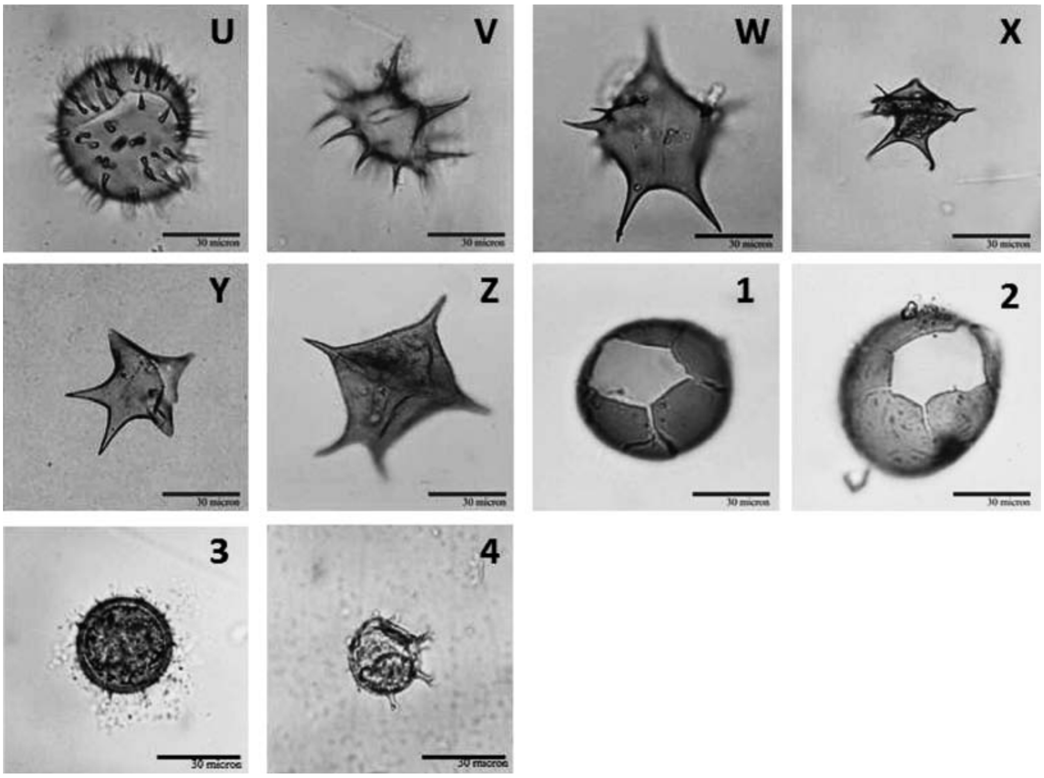

Fig. 3. Dinoflagellate cysts identified in this study. U, *Diplopelta parva*; V, *Protoperidinium* sp. 1; W, *Protoperidinium* sp. 2; X, *Protoperidinium* sp. 3; Y, *Protoperidinium* sp.4; Z, *Protoperidinium* sp.5; 1, *Protoperidinium* sp. 6; 2, *Protoperidinium* sp. 7; 3, Unknown cyst type 1; 4, Unknown cyst type 2.

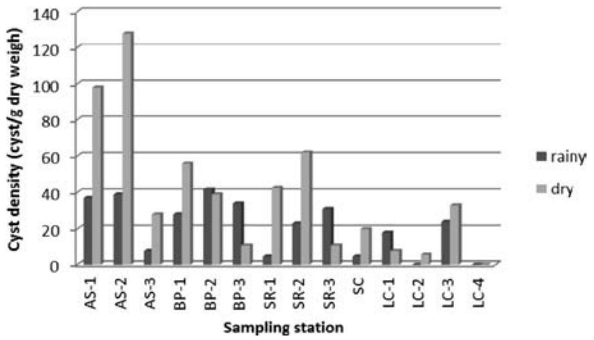

Fig. 4. Abundance of dinoflagellate cysts in Chonburi coastal areas.

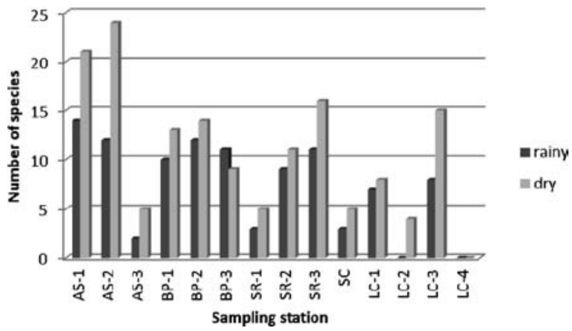

Fig. 5. Dinoflagellate cyst diversity in Chonburi coastal areas.

Pholpunthin (1987) also found that the abundance of dinoflagellate vegetative cells in the water column of this area was higher than in the neighboring areas.

Besides the influence of vegetative cell abundance in the water column, another important factor that affects abundance of cysts is physical and hydrological properties in each area. For example, tides and wind-driven waves have an effect on sediment deposition and distribution. Since dinoflagellate cysts share similar physical properties with sand particles of sediments, the cysts are also under the influence of physical and hydrological characteristics (Matsuoka et al. 1999). In addition, sedimentation rate is another factor affecting the abundance of dinoflagellate cysts. In tropical regions, sedimentation rate is relatively high, resulting in low abundance of dinoflagellate cysts (Matsuoka et al. 1999). Srisuksawad et al. (1997) reported the sedimentation rate at the Bangpakong river mouth of $0.8\,\mathrm{cm\,yr^{-1}}$. However, since there is no direct study on sedimentation rate in the study area, it is difficult to clarify that sedimentation rate is a factor that control dinoflagellate abundance in this study site.

Nevertheless, there are two possible explanations for the low abundance and the spatial difference of dinoflagellate cysts in the Chonburi coastal region. First, the Chonburi coastal area is one of the important fishery grounds in the Gulf of Thailand. Many an active fishery operations in Chonburi have an impact on deposition of sediments (Kan-Atireklap et al. 1997), which consequently would affect dep-

Table 3. The occurrence and abundance of dinoflagellate cysts in surface sediment from Chonburi coastal areas in dry season.

Cyst types	Abundance (cysts g^{-1} dry sediment)														
	Sample stations														
	AS-1	AS-2	AS-3	BP-1	BP-2	BP-3	SR-1	SR-2	SR-3	SC	LC-1	LC-2	LC-3	LC-4	Total
Gymnodiniales															
Pheopolykrikos hartmannii	21	17	0	5	5	10	0	3	8	0	3	0	3	0	75
Polykrikos schwartzii	1	0	0	1	0	0	0	0	1	0	0	0	3	0	6
Polykrikos kofoidii	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Gonyaulacales															
Alexandrium sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2
Gonyaulax scrippsae	5	4	0	9	1	2	1	9	7	3	3	0	2	0	46
Gonyaulax spinifera complex															
Spiniferites membranaceus	7	10	0	6	0	0	0	0	0	1	0	1	0	0	25
Spiniferites mirabilis	1	2	7	0	9	0	2	2	3	3	3	0	1	0	33
Lingulodinium polyedrum	6	15	0	14	6	5	0	4	7	0	0	0	1	0	58
Pyrophacus steinii	17	10	9	1	14	11	5	7	10	0	1	4	3	0	
Spiniferites sp. 1	1	0	0	0	1	0	0	0	0	0	0	0	4	0	6
Spiniferites sp. 2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Spiniferites sp. 3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Peridiniales															
Protoperidinium compressum	2	2	0	0	1	0	0	1	1	0	1	1	0	0	9
Protoperidinium latissimum	0	4	0	0	0	0	0	0	1	0	0	0	3	0	8
Protoperidinium leonis	8	6	2	1	9	1	0	10	5	3	3	0	2	0	50
Protoperidinium oblongum	1	7	0	9	3	3	0	1	9	0	0	0	0	0	33
Protoperidinium claudicans	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Protoperidinium pentagonum	13	17	8	3	9	2	2	2	1	1	3	2	1	0	64
Protoperidium subinerme	3	2	0	2	3	0	0	0	3	0	3	0	3	0	19
Protoperidium conicum	1	2	0	3	1	1	0	2	1	0	0	0	0	0	11
Diplopelta parva	1	2	0	0	1	0	0	0	2	0	0	0	0	0	6
Protoperidinium sp. 1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Protoperidinium sp. 2	2	0	0	0	2	3	0	0	0	0	0	0	0	0	8
Protoperidinium sp. 3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Protoperidinium sp. 4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Protoperidinium sp. 5	0	3	0	0	0	0	0	0	0	0	0	0	1	0	4
Protoperidinium sp. 6	2	4	2	1	0	0	1	0	2	0	0	0	3	0	15
Protoperidinium sp. 7	4	5	0	1	0	0	0	2	1	0	0	0	2	0	15
Unknown cyst type 1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Unkown cyst type 2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total	98	128	28	56	65	39	11	43	62	11	20	8	33	0	602

Table 4. The occurrence and abundance of dinoflagellate cysts in surface sediment from Chonburi coastal areas in rainy season.

Cyst types	Abundance (cysts g^{-1} dry sediment)														
	Sample stations														
	AS-1	AS-2	AS-3	BP-1	BP-2	BP-3	SR-1	SR-2	SR-3	SC	LC-1	LC-2	LC-3	LC-4	total
Gymnodiniales															
Pheopolykrikos hartmannii	2	7	0	4	6	7	0	2	6	0	2	0	3	0	39
Polykrikos schwartzii	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Polykrikos sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonyaulacales															
Alexandrium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonyaulax scrippsae Kofold	0	1	0	5	0	2	0	0	2	0	0	0	0	0	10
Gonyaulax spinifera complex															
Spiniferites membranaceus	1	4	0	0	1	0	1	0	0	0	0	0	0	0	7
Spiniferites mirabilis	5	2	2	1	2	1	0	1	1	1	2	0	2	0	20
Lingulodinium polyedrum	3	4	0	1	2	1	0	5	1	0	0	0	0	0	17
Pyrophacus steinii	7	6	6	6	8	4	2	1	4	2	2	0	4	0	52
Spiniferites sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridiniales															
Protoperidinium compressum	2	2	0	0	1	6	0	2	0	0	3	0	0	0	16
Protoperidinium latissimum	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Protoperidinium leonis	1	5	0	0	3	2	0	6	2	0	1	0	5	0	25
Protoperidinium oblongum	3	1	0	6	0	2	0	1	6	0	0	0	1	0	20
Protoperidinium claudicans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium pentagonum	4	2	0	1	2	4	2	2	3	2	5	0	1	0	28
Protoperidium subinerme	1	0	0	0	10	0	0	0	0	0	0	0	0	0	11
Protoperidium conicum	0	0	0	2	1	0	0	0	0	0	0	0	0	0	3
Diplopelta parva	0	0	0	0	3	0	0	0	1	0	0	0	0	0	4
Protoperidinium sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium sp. 2	3	4	0	0	0	0	0	0	4	0	0	0	0	0	11
Protoperidinium sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Protoperidinium sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium sp. 6	2	1	0	0	0	4	0	3	1	0	3	0	7	0	21
Protoperidinium sp. 7	2	0	0	1	3	1	0	0	0	0	0	0	0	0	7
Total	37	39	8	28	42	34	5	23	31	5	18	0	24	0	294

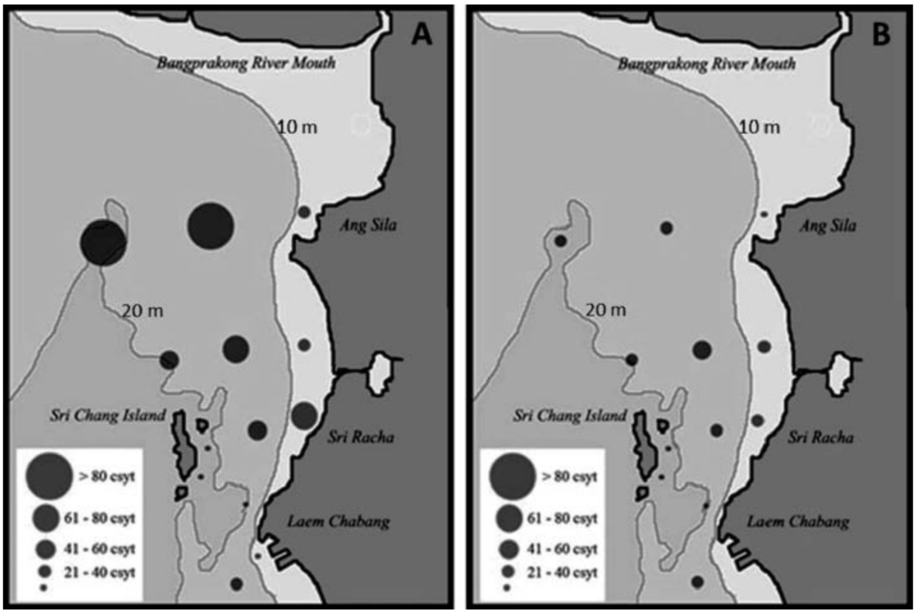

Fig. 6. Distribution and abundance of dinoflagellate cysts along Chonburi coastal areas. A, dry seasons; B, rainy seasons.

osition of dinoflagellate cysts. For example, sediment re-suspension as a result of trolling by fishing boats must prevent cyst deposition on the sediment surface and facilitate them to move out from the area, especially from the shallow water area. As observed in this study, high abundance of dinoflagellate cysts was found at the sampling stations with the sediments characterized as clay and clay-sandy with water depth greater than 10 m. This relatively deep water may reduce disturbance from wind and wave, which play an important role in an increase in sediment re-suspension, germination, and dispersion of cysts into other regions. The absence to low abundance of cysts in the Laem-chabang area may be a result from re-suspension of sediments, since the area is close to a port with active international ship transportation (Kan-Atireklap et al. 1997).

The second explanation for different abundance of cysts observed in this study is seasonal changes in wind, waves, and currents. The first sampling period of this study between May and October represents the rainy season, when the Gulf of Thailand is under an influence of southwest monsoon, which brings damp air mass from the Indian Ocean to the Gulf of Thailand, causing much rain along the coast. Meanwhile, the sampling period of February is in the dry season, which is under northeast monsoon influence. In the dry season, wind and wave conditions are much calmer than those in rainy season, when surface water mixes with the deeper water column (Sojisuporn. 1994). This mixing causes a decrease in sediment deposition and an increase of sediment re-suspension and germination of cysts, which may have resulted in the lower abundance of dinoflagellate cysts in the rainy season than in February.

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