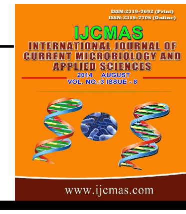

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Original Research Article

Comparison between the Diversity and Density of Marine Dinoflagellates in Northern and Southern zone of Malacca straits

Mohamed Amar Naqqiuddin*, Norsalwani Muhamad Nor, Azura Alim, Idris Abdul Ghani, Hishamuddin Omar and Ahmad Ismail

Department of Biology, Faculty of Science, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor Darul Ehsan, Malaysia
**Corresponding author*

A B S T R A C T

Dinoflagellates are the second most abundant phytoplankton group throughout the world. Other than incidents of harmful algal blooms, studies are carried out to keep track on changes to diversity, composition and abundance of dinoflagellates species almost annually. Nonetheless, there is insufficient information collected from previous studies. The main objective of this study is to distinguish the abundance, species composition and distribution of dinoflagellate in the northern and southern zone of Malacca Straits during northeast and pre southwest monsoon season. Samples were collected by using "Van Dorm" water sampler and observed under inverted and scanning electron microscope (SEM). Under Division Pyrrophyta, 71 dinoflagellates species from 21 genus, 13 families and six orders were identified in the northern zone while in southern zone, 53 species were found from 15 genus, 11 families and six orders. During northeast monsoon, Peridiniales dominated in both north and south zone with total density of 89.76% and 80.84% respectively. Peridiniales also constitute an important group during pre southwest monsoon with an average total density of dinoflagellates at 61.89% in north zone and 79.3% in south zone. Total concentration of dinoflagellates in north zone ranged from 18.02 cells/L to 180.01 cells/L during pre southwest monsoon season. For south zone, the range was from 7.93 cells/L to 99 cells/L during northeast monsoon season and was highest from 26.01 cells/L to 577.3 cells/L during pre southwest monsoon season. Overall, *Ceratium furca* was the most dominant in the northern zone during northeast monsoon season (maximum cell density reached 69.96 cells/L at Station 2) and during pre southwest monsoon in the southern zone of Malacca Straits.

Keywords

Dinoflagellates
Phyrrophyta;
Peridiniales;
Ceratium furca;
Straits of Malacca

Introduction

Dinoflagellates species are microscopic phytoplankton (Hallegraeff, 1988) and highly abundant in both marine and fresh waters. These organisms play important role for food web in the aquatic ecosystem. Some dinoflagellates live close to shore for the nutrients supply and lower salinity than open sea (Smetacek et al., 1991). A phytoplankton bloom becomes in contrast when the density reach over than 10^8 cell/L

(Lalli & Parsons, 1993). Over thousands of dinoflagellates species have been described (Fukuyo & Taylor, 1989) and only 20 species were known to be harmful. Recently, there are many reports of harmful algae bloom (HAB) in the South East Asia region (Fukuyo et al., 2011; Lim et al., 2006; Lim et al., 2012). Hence, there is a need to look at species diversity and density of dinoflagellates in bigger perspective. Salinity decrease and temperature changes favor the growth of dinoflagellates (Bodeanu, 1993) and other factors that could promote blooms were nutrients supply; weather pattern, light intensity and water current (Tan et al., 2006). Human activities in coastal area such as agriculture can cause nutrient imbalance. Sewage released directly into the sea could upset the nutrient balance which later will increase the probability of HAB occurrence. Earliest event of toxic blooms occurred in Papua New Guinea, then occurred in Sabah and Brunei, Malaysia in 1976, followed in Manila Bay and Mindanao, Philippines in 1983, the Pacific coast of Guatemala in 1987 Ambon, Indonesia in 1994, and Palawan Island, the Philippines in 1998 (Roy, 1977; Maclean, 1989; Rosales-Loassener, 1989; Wiadnyana et al., 1996 and Sombrito et al., 2004). *Pyrodinium bahamense var. compressum* has caused deaths and illness since 1983 (Corrales and Maclean, 1995) and also involved in majority of the poisoning case in Malaysia (Usup et al., 2002). More reported algal blooms events in Malaysia were from the species of *Prorocentrum minimum* in Tebrau Strait (Usup et al., 2008), *Noctiluca scintillans* in Penang from 2005-2006 (Sin Chew Daily 2005), both Lumut and Pangkor, Perak with *Neocratium furca*, *Karlodinium veneficum* was observed at high cell density in Tebrau Straits water (Lim et al., 2012) and the latest incident of red tides were reported from West Coast of Sabah (The Star, 2013). Recent case of mass fish deaths estimated four tonnes in Tanjung Kupang, Johor Bahru, was believed to be caused by 'red tide' phenomenon as the excessive phytoplankton cuts off oxygen in water (The Star, 2014). Another similar case reported in Singapore, the Agri-Food and Veterinary Authority (AVA) stated that 160 tonnes of fish from fish farms on both East and West Johor Straits have been found dead with same possibility either due to low level of oxygen in water, plankton bloom or weather pattern condition (Today Online, 2014). The primary objective of this study is to compare information of the dinoflagellates in two different zone of Malacca Straits which are the northern zone and southern zone during northeast and pre southwest monsoon season.

Materials and Methods

JICA-MASDEC Straits of Malacca Expedition on board R/V K. K. Mersuji was performed from November 23 to December 2, 1998 (northeast monsoon season) and March 25 to April 4, 1999 (pre southwest monsoon season). For northern zone, the sampling stations were located from the latitudes N 06° 00´, longitudes E 100° 00´ to latitudes N 05° 30´, longitudes E 100° 00´ which was from Langkawi to Penang Island. The southern zone of Malacca Straits was located from Port Klang to Kukup Island which was from the stations located at the latitudes N 03° 00´, longitudes E 101° 00´ to latitudes N 01° 10´, longitudes E 103° 30´. As the weather was bad during sampling time, both cruises (northeast and pre southwest monsoon) manage to cover 5 stations for sampling around the northern zone of Malacca Straits. The five stations were Station 1, 2, 3, 7 and 8. In the southern zone, first and second cruise (northeast and pre southwest monsoon season) cover six stations: Station 19, 20, 21, 22, 23 and 24 respectively. Three replicates of 1 liter sample were collected with "Van Dorm" water sampler and were concentrated with a 32µm plankton mesh net hauls vertically from 10m to the surface. Water samples were preserved in Lugol's iodine solution and 4% formalin solution (Pomeroy, 1984). Both taxonomic and enumeration of cells were carried out by using a Nikon Diaphot inverted microscope and compound microscope (Utermöhl, 1958; Sournia, 1978; Andersen, 1996). Enumeration process was done following procedure described by Utermöhl (1958). All physical and chemical parameter such as pH, temperature (°C), salinity (ppt), conductivity (mS/cm) and dissolved oxygen (mg/l) (Table 3 and Table 4) were determined and recorded by using Hydrolab DS4. Identification key were referred to Subrahmanyan (1968), Bold &Wynne (1978), Taylor (1980), Dodge (1982), Yamaji (1983), Dodge (1985), Hallegraeff (1988) and Tomas (1997). For scanning electron microscopy sample preparation, samples were fixed with glutaraldehyde and were rinsed with a series of alcohol. Specimen were dried, mounted and coated by using a Polaron E5100 (gold or gold palladium) sputter coater and was examined using a JEOL 6400+Link EXL EDX scanning electron microscope (Marr et al., 1992). ANOVA and t-test were used for tests of difference between parameters data. Shannon-Weaver index (1949), and Margalef Species Richness were used for calculation. A software package was used to carry out the Cluster Analysis (CA) on dinoflagellates density as practiced by Ludwig & Reynolds (1988).

Results and Discussion

Species composition

A total of 71 dinoflagellates species from 21 genus, 13 families and six orders under Division of Pyrrophyta were identified and recorded during the Straits of Malacca Expedition in the northern zone from both monsoon (Table 1). From the southern zone, fifty-three dinoflagellates species from 15 genus, 11 families and six orders under Division of Pyrrophyta were found (Table 2). There were eight families represented for Peridiniales or peridinoid group and most thecate species belong to this group. Non-thecate dinoflagellates under Order Gymnodiniales were represented by both *Gymnodinium* and *Gyrodinium* genera.

In the northern zone, the largest genera collected during northeast monsoon were *Protoperidinium*. The most dominant species was *P. ovum. Ceratium* were the largest genera found during the pre southwest season and *C. furca* was the most dominant species. For other genus species, *Ceratocorys horrida* was only found at Station 3 during northeast monsoon. *A. bidentata* occurred in small numbers during northeast monsoon which was relatively rare species. Three species of *Dinophysis* were known as toxic species that can cause Diarrhetic Shellfish Poisoning (DSP). Other species were found in low density. During pre southwest monsoon, *Gymnodinium simplex* was the most dominant species and *Gyrodinium* was widespread with one species, *Gyrodinium* sp. Other groups were represented with small number of species.

In the southern zone, there was no dominant species found during the northeast monsoon, however *Ceratium furca* was the only dominant species observed during pre southwest monsoon season. In contrast, dinoflagellates species were represented in small number during northeast monsoon season which was fairly categorized as frequent and rare species (Table 4). All three species of *Dinophysis* were known as toxic species which can cause Diarrhetic Shellfish Poisoning (DSP) were found during the first cruise.

Pattern of Species Abundance for Northern Zone

Total cell concentration of dinoflagellates 99.00 cells/l was found at Station 2 (Figure 2). Among all species, *C.furca* was the only dominant species found at all station (Figure 3) and also reached the highest cell density at 69.96 cells/l at Station 2. During the northeast and pre southwest monsoon, the most frequent species were recorded in Table 2. During the pre southwest monsoon, highest density of dinoflagellates was found at Station 1 with cell concentration of 5.77×10^2 cells/l (Figure 2). *Gymnodinium simplex* was the most dominant species during the pre southwest monsoon in the northern zone of Malacca Straits; refer to Figure 4 and Table 3.

C. furca was found as subdominant species during this term compared to the previous cruise. All common and rare dinoflagellates species were listed in the Table 3. During the northeast monsoon, there were no significant difference showed in dinoflagellate density between inshore and offshore localities ($F = 1.493$, $p > 0.05$) while during pre southwest monsoon, it showed a significant difference between inshore and offshore localities ($F = 7.288$, $p < 0.05$). The range of dinoflagellates species during the northeast monsoon were from the lowest at 11 species to the highest at 23 species. Lowest number of species was found at Station 7 while, the highest was at Station 2. On the other hand, the range of dinoflagellates during the pre southwest monsoon was from the lowest at 18 to 38 numbers of species (Figure 6).

Pattern of Species Abundance for Southern Zone

The cell density ranged from Station 19 at 11.56 cells/l to Station 24 at 2.64 cells/l (Figure.2) during northeast monsoon and there was no dominant species found. Other species found were classified and recorded as frequent and rare species (refer Table 4). During pre southwest monsoon season, the highest density of dinoflagellates was found at Station 22 with cell concentration of 180.01 cells/l and the lowest at Station 19 with cell density of 18.02 cells/l (Figure 2). The most dominant species during pre southwest monsoon was *Ceratium furca* (Figure 5 and Table 4). Statistical analyses also showed both number of dinoflagellates species, diversity and cell density were higher at offshore stations during pre southwest monsoon season (Table 5 & 6). The number of dinoflagellates species during the northeast monsoon ranging from the lowest at 4 species to the highest at 11 species. Whereas, the range of dinoflagellates species during pre southwest monsoon varied from the lowest at 9 to 31 numbers of species (Figure 6).

Species Diversity

For northern zone from station 1 to station 8, Shannon Diversity Index (Cruise1 or northeast monsoon season) showed species diversity ranged from 1.311 at Station 8 to 2.859 at Station 3. Meanwhile (Cruise 2 or pre southwest monsoon season) showed diversity ranged from 1.345 at Station 1 to 3.130 at Station 8. For the southern zone from station 19 to station 24, Shannon Diversity Index (Cruise 1) showed species diversity ranged from the lowest 1.386 at Station 24 to 2.243 at Station 21, meanwhile index (Cruise 2) for the second cruise showed diversity ranged from 2.057 at Station 19 to the highest 2.967 at Station 22. Changes in species diversity, evenness and richness were represented and shown in Figure 4, 5 and 6. Some of the physical and chemical parameters data obtained were recorded and presented in Table 7 and 8.

The first and second sampling of dinoflagellates species for this study was conducted during the northeast monsoon season and the pre southwest monsoon season respectively in the northern and southern zone of Malacca Straits. As from earlier studies conducted on dinoflagellates species in the Straits of Malacca, 26 species were identified from 10 genera (Chua and Chong, 1975). Later, 35 species from 12 genera, nine families and six orders of dinoflagellates were reported by Normawaty (1998) at Sebatu, Melaka. The most common dinoflagellates obtained during sampling in the period of northeast and pre southwest monsoon in the northern zone of Malacca Straits are from genus *Ceratium* and *Protoperidinium*. There were no dinoflagellates species categorized as dominant species during the northeast monsoon in the southern zone. Nevertheless, the most dominant dinoflagellates in the southern zone of Malacca Straits during pre southwest monsoon are only *Ceratium furca*.

The genus *Ceratium* has been classified as an important part in marine phytoplankton assemblage. Moreover, it has a wide range of biogeographical distribution which can be used for studies that related to it (Dodge and Marshall, 1994). The blooms of *C. furca* which caused red tides were observed along Japanese coast (Fukuyo et al., 1990). Ann et al. (2000) reported *C. furca* a known harmful species capable of paralytic shellfish poisoning (PSP) was recorded in Sebatu and Sungai Rambai. Under the same Order Peridiniales, the second largest genus is *Protoperidinium* found on this study. Some of identified dinoflagellates species were classified poisonous such as *Dinophysis* (Kat, 1983), *Gonyaulax* (Davison and Yantsch, 1985), *Gymnodinium* (Cardwell et al. 1979) and *Prorocentrum* (Lassus and Berthome, 1988), though the cell density of these dinoflagellates were recorded low. *D. caudata* was found highest in the northern zone during pre southwest monsoon season at Station 8 with density at 46.67 cells/L and it belongs to one of three species collected under *Dinophysis*. *D. caudata* is wide ranging and present in every ocean from temperate region to tropical region of waters (Larsen and Moestrup, 1992). *G. splendens* and *Prorocentrum micans* were both classified as red tide species which were found in low density at all stations in the north and south zone except Station 1 with density of 60.67 cells/L. Another non harmful species causing red tide, *Noctiluca scintillans* was reported to cause a bloom in Johor Straits and Penang (Jothy, 1984). Although *N. scintillans* is non-toxic species, it could cause other problems related to ammonium concentrations and could harm some aquatic life (Mendez, 1993; Anderson, 1996). Nonetheless, the cell concentration of *Noctiluca scintillans* was low and no bloom occurrence during this study.

The northeast monsoon (Figure 12) brings substantial precipitation and is the real stormy season along the east coast states in Peninsular Malaysia and east Malaysia. The southwest monsoon is tolerably drier in most states and accomplished month to month least precipitation. As been recorded (Figure 2 and 6), the density of dinoflagellates were recorded higher throughout pre southwest monsoon than northeast monsoon season. Fundamentally, the current flows throughout northeast monsoon moves along the east coast of Peninsular Malaysia, has little effects on the west coast of Peninsular Malaysia indicated less change with bit disturbances to the marine ecological condition. Throughout pre southwest monsoon (Figure 12), the current began to moves southwards along west coast of Peninsular Malaysia specifically on Malacca Straits.

Table.1 Species list of dinoflagellates in the northern zone of Malacca Straits during northeast monsoon and pre southwest monsoon

Phylum or Division : PYRROPHYTA (DINOPHYTA)			
Class: DINOPHYCEAE			
Order	Family	Genera	Species
1. Dinophysiales	1. Dinophysaceae	1. *Amphisolenia*	*1. Amphisolenia bidentata*
		2. *Dinophysis*	*2. Dinophysis caudata*
			3. Dinophysis hastata
			4. Dinophysis miles
		3. *Parahistioneis*	*5. Parahistioneis* sp
		4. *Phalacroma*	*6. Phalacroma doryphorum*
			7. Phalacroma mitra
			8. Phalacroma rotundatum
		5. *Ornithocercus*	*9. Ornithocercus magnificus*
2. Gymnodiniales	2. Gymnodiniaceae	6. *Gymnodinium*	*10. Gymnodinium simplex*
			11. Gymnodinium splendens
			12. Gymnodinium sp.
		7. *Gyrodinium*	*13. Gyrodinium* sp.
3. Noctilucales	3. Noctilucaceae	8. *Noctiluca*	*14. Noctiluca scintillans*
4. Peridiniales	4. Ceratiaceae	9. *Ceratium*	*15. Ceratium breve*
			16. Ceratium carriense
			17. Ceratium extensum
			18. Ceratium furca
			19. Ceratium fusus
			20. Ceratium gibberum
			21. Ceratium horridum
			22. Ceratium inflatum

			23. Ceratium kofoidii *24. Ceratium longissimum* *25. Ceratium longirostrum* *26. Ceratium macroceros* *27. Ceratium sumatranum* *28. Ceratium teres* *29. Ceratium trichoceros* *30. Ceratium tripos* *31. Ceratium vultur*
	5. Ceratocorythaceae	10. *Ceratocorys*	*32. Ceratocorys horrida*
	6. Goniodomataceae	11. *Goniodoma*	*33. Goniodoma polyedricum*
		12. *Gonyaulax*	*34. Gonyaulax monocantha* *35. Gonyaulax spinifera* *36. Gonyaulax turbynaii* *37. Gonyaulax* sp
	7. Heterodiniaceae	13. *Heterodinium*	*38. Heterodinium whittingae*
	8. Oxytoxaceae	14. *Oxytaxum*	*39. Oxytoxum reticulatum* *40. Oxytoxum scolopax* *41. Oxytoxum tesselatum*
	9. Peridiniaceae	15. *Diplopsalis*	*42. Diplopsalis assymetrica* *43. Diplopsalis lenticula* *44. Diplopsalis globula*
		16. *Protoperidinium*	*45. Protoperidinium bidentatum* *46. Protoperidinium cerasus* *47. Protoperidinium claudicans* *48. Protoperidinium conicum* *49. Protoperidinium crassipes* *50. Protoperidinium*

			depressum
			51. Protoperidinium divergens
			52. Protoperidinium monospinum
			53. Protoperidinium oblongum
			54. Protoperidinium ovum
			55. Protoperidinium pallidum
			56. Protoperidinium pellucidum
			57. Protoperidinium pentagonum
			58. Protoperidinium puncutulatum
			59. Protoperidinium pyriforme
			60. Protoperidinium sphaericum
		17. *Scrippsiella*	*61. Scripsiella trochoidea*
	10.Podolampadaceae	18. *Podolampas*	*62. Podolampas bipes*
			63. Podolampas palmipes
			64. Podolampas spinifera
	11. Pyrophacaceae	19. *Pyrophacus*	*65. Pyrophacus horologicum*
			66. Pyrophacus steinii
5. Prorocentrales	12. Prorocentraceae	20. *Prorocentrum*	*67. Prorocentrum micans*
			68. Prorocentrum minimum
6. Pyrocystales	13. Pyrocystaceae	21. *Pyrocystis*	*69. Pyrocystis fusiformis*
			70. Pyrocystis lunula
			71. Pyrocystis noctiluca

Table.2 List of identified dinoflagellates species in the southern zone of Malacca Straits during northeast monsoon and pre southwest monsoon.

Phylum or Division : PYRROPHYTA (DINOPHYTA) Class: DINOPHYCEAE	
Order	Species
1. Dinophysiales Lindemann 1928	*1. Dinophysis caudata* Saville-Kent
	2. Dinophysis hastata Stein
	3. Dinophysis miles Cleve
	4. Phalacroma rotundatum Kofoid &Michner
	5. Ornithocercus magnificus Stein
2. Gymnodiniales Lammermann 1910	*6. Gymnodinium coeruleum* Dogiel
	7. Gymnodinium simplex (Lohmann) Kofoid & Swezy
	8. Gymnodinium splendens Lebour
	9. Gymnodinium sp.
	10. Gyrodinium sp.
3. Noctilucales Haeckel 1894	*11. Noctiluca scintillans* (Macartney) Kofoid & Swezy
4. Peridiniales Haeckel 1894	*12. Ceratium belone* Cleve
	13. Ceratium breve (Ostenfeld & Schmidt) Schröder
	14. Ceratium furca (Ehrenberg) Claparède & Lachmann
	15. Ceratium fusus (Ehrenberg) Dujardin
	*16. Ceratium horridum (*Cleve) Gran
	17. Ceratium kofoidii Jörgensen
	18. Ceratium macroceros (Ehrenberg) Cleve
	19. Ceratium schmidtii Jörgensen
	20. Ceratium tenue (Ostenfield &Schmidt) Jörgensen
	21. Ceratium trichoceros (Ehrenberg) Kofoid
	22. Ceratium tripos (O.F. Müller) Nitzsch
	23. Ceratium vultur Cleve
	24. Gonyaulax monocantha Pavillard
	25. Gonyaulax spinifera (Claparède & Lachmann) Diesing
	26. Gonyaulax turbynaii Murray & Whitting
	27. Gonyaulax sp

	28. Oxytoxum tesselatum (Stein) Schütt
	29. Diplopsalis assymetrica Drebes & Elbrachter *30. Diplopsalis lenticula* Bergh *31. Diplopsalis globula* Abé
	32. Protoperidinium bidentatum Abé *33. Protoperidinium cerasus* (Paulsen) Balech *34. Protoperidinium conicum* (Gran) Balech *35. Protoperidinium crassipes* (Kofoid) Balech *36. Protoperidinium depressum*(Bailey) Balech *37. Protoperidinium divergens* (Erhrenberg) Balech *38. Protoperidinium monospinum* Abé *39. Protoperidinium oblongum* (Aurivillius) Parke & Dodge *40. Protoperidinium ovum* Schiller *41. Protoperidinium pallidum* (Ostenfeld) Balech *42. Protoperidinium pellucidum* Bergh *43. Protoperidinium pentagonum* (Gran) Balech *44. Protoperidinium puncutulatum* (Paulsen) Balech *45. Protoperidinium sphaericum* Okamura
	46. Podolampas palmipes Stein
	47. Pyrophacus steinii (Schiller) Wall & Dale
5. Prorocentrales Lemmermann 1910	*48. Prorocentrum gracile* Schütt *49. Prorocentrum micans* Ehrenberg *50. Prorocentrum minimum* (Pavillard) Schiller
6. Pyrocystales Apstein 1909	*51. Pyrocystis fusiformis* Murray *52. Pyrocystis lunula* Schütt *53. Pyrocystis noctiluca* Murray ex Schütt

Figure.1 Map showing the sampling location (1, 8, 21, 24) inshore stations and (2, 3, 7, 19, 20, 22, 23) offshore stations in the northern zone of Malacca Straits

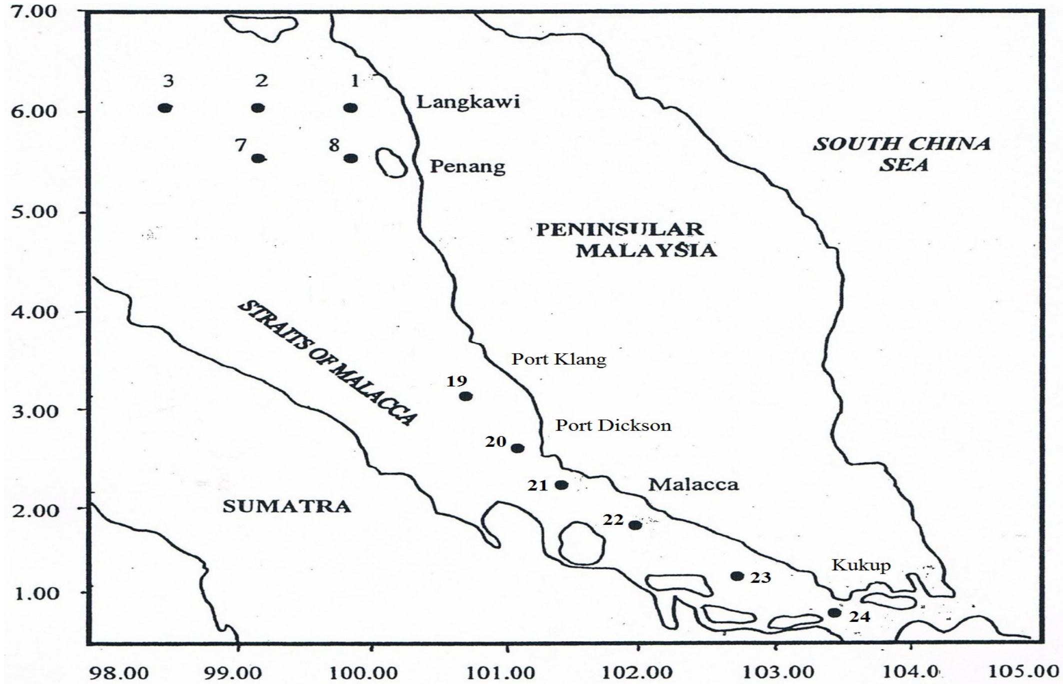


Figure.2 Comparison between total density of dinoflagellates during the northeast monsoon (NE) and pre southwest monsoon season (SW) in the northern and southern zone of Malacca Straits; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

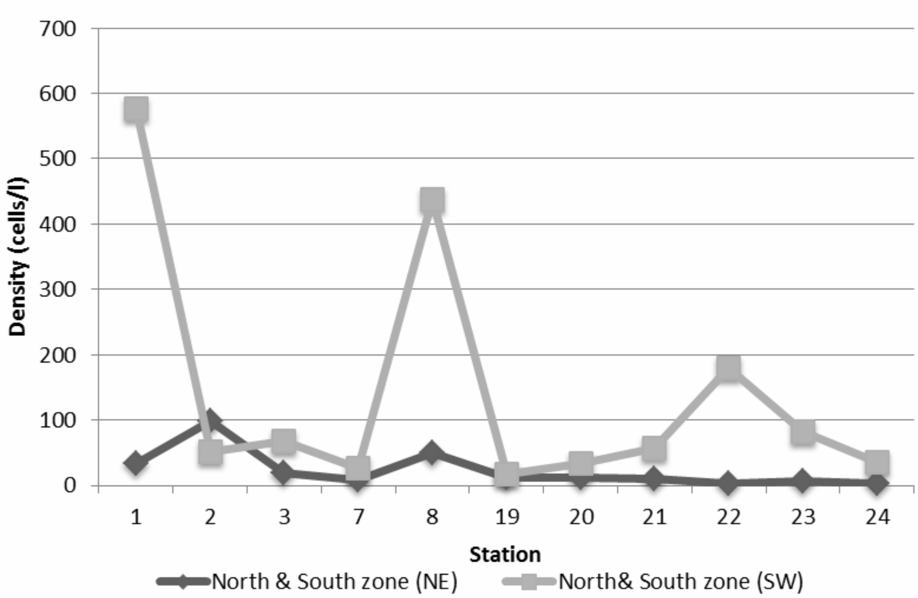


Figure.3 Dominant species of dinoflagellates (*Ceratium furca*) in the northern part of Malacca Straits during northeast monsoon season

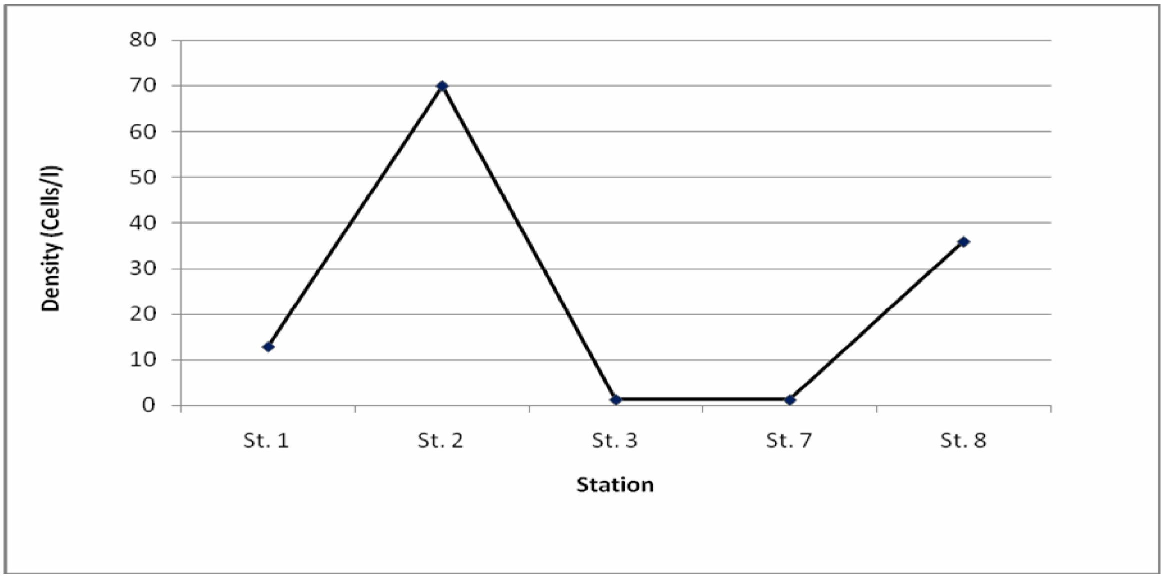


Figure.4 Dominant species of dinoflagellates (*Gymnodinium simplex*) during pre southwest monsoon in the northern zone of Malacca Straits

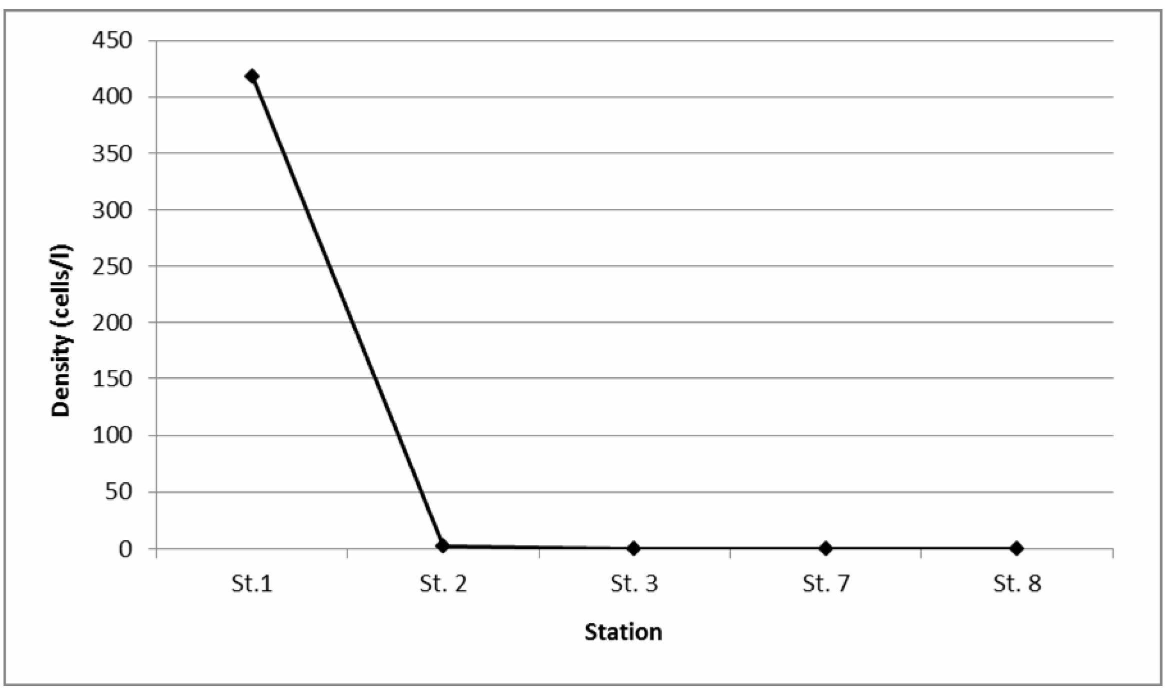


Figure.5 Dominant dinoflagellates species (*Ceratium furca*) in the southern zone of Malacca Straits during pre southwest monsoon

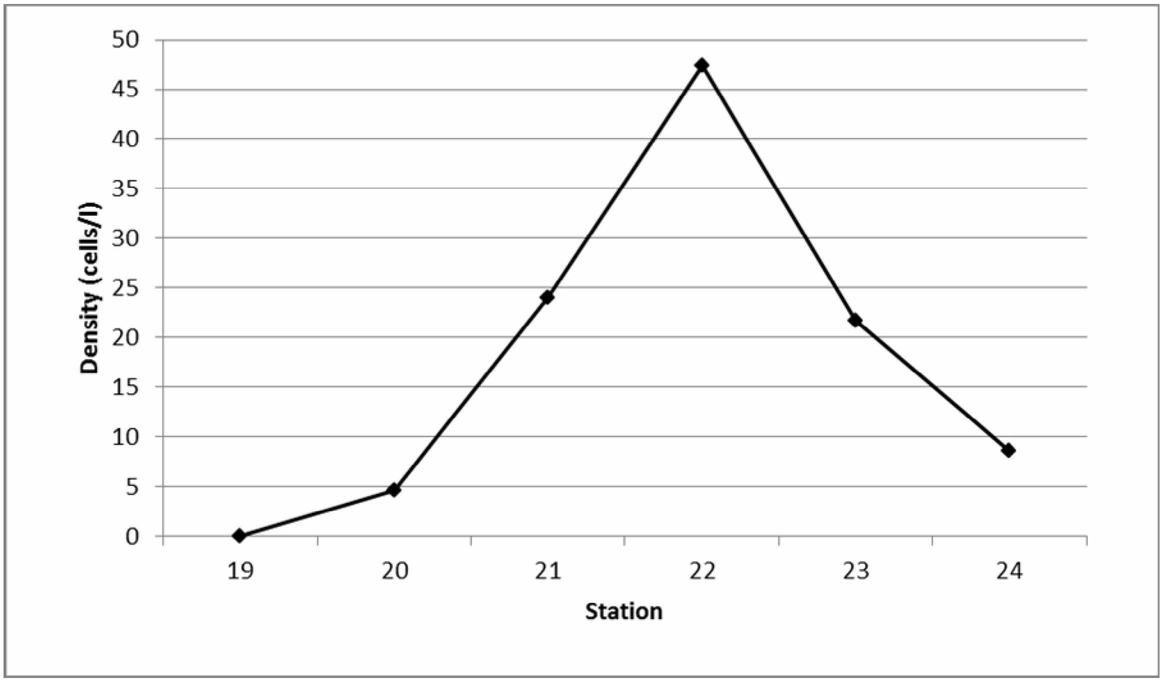


Figure.6 Comparison of the total dinoflagellates species number at each station between the northeast monsoon (NE) and pre southwest monsoon season (SW) in the north and south zone of Malacca Straits; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

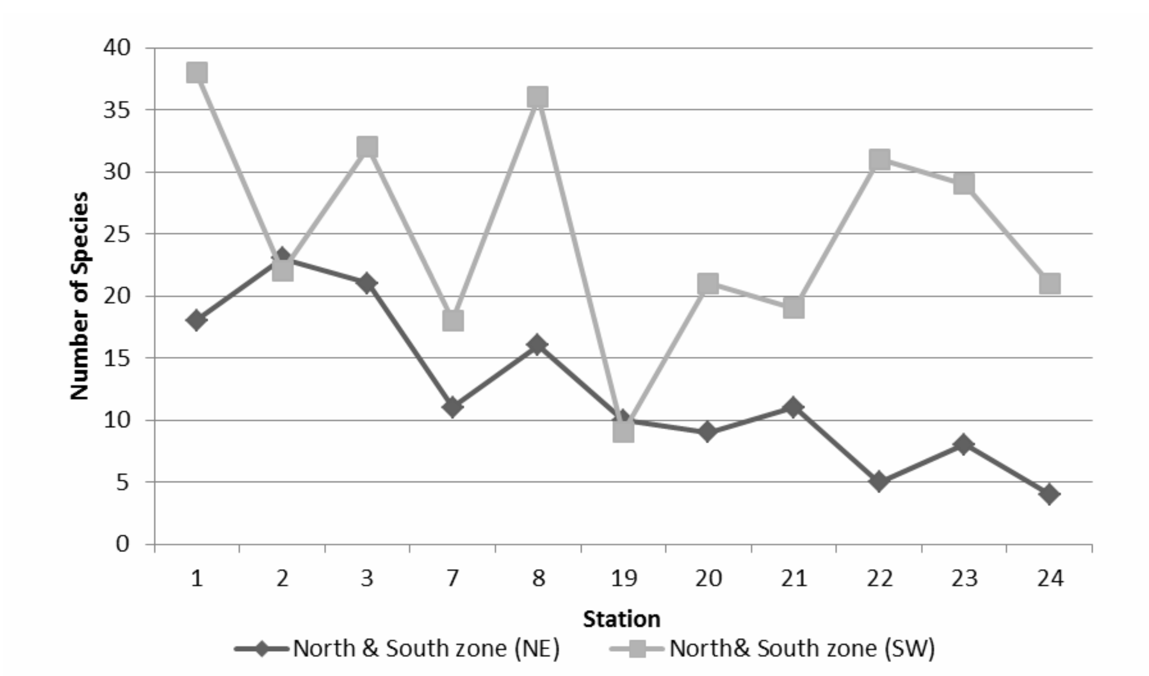


Table.3 Species abundance recorded during the northeast and pre southwest monsoon in the northern zone of Malacca Straits

	List of Species	1	2		List of species	1	2
1	*Amphisolenia bidentata*	R	-	37	*Gonyaulax* sp	F	F
2	*Dinophysis caudata*	F	S	38	*Heterodinium whittingae*	R	F
3	*Dinophysis hastata*	F	-	39	*Oxytoxum reticulatum*	-	S
4	*Dinophysis miles*	F	F	40	*Oxytoxum scolopax*	-	F
5	*Parahistioneis* sp	F	F	41	*Oxytoxum tesselatum*	F	F
6	*Phalacroma doryphorum*	F	F	42	*Diplopsalis assymetrica*	F	S
7	*Phalacroma mitra*	F	-	43	*Diplopsalis lenticula*	F	F
8	*Phalacroma rotundatum*	F	F	44	*Diplopsalis globula*	F	S
9	*Gymnodinium simplex*	-	D	45	*Protoperidinium bidentatum*	-	F
10	*Gymnodinium splendens*	-	S	46	*Protoperidinium cerasus*	F	S
11	*Gymnodinium* sp.	-	F	47	*Protoperidinium claudicans*	R	F
12	*Gyrodinium* sp.	-	S	48	*Protoperidinium conicum*	F	S
13	*Ornithocercus magnificus*	F	F	49	*Protoperidinium crassipes*	-	R
14	*Goniodoma polyedricum*	-	F	50	*Protoperidinium depressum*	F	F
15	*Noctiluca scintillans*	F	F	51	*Protoperidinium divergens*	R	S
16	*Ceratium breve*	F	F	52	*Protoperidinium monospinum*	-	F
17	*Ceratium carriense*	-	R	53	*Protoperidinium oblongum*	-	F
18	*Ceratium extensum*	R	-	54	*Protoperidinium ovum*	F	S
19	*Ceratium furca*	D	S	55	*Protoperidinium pallidum*	R	F
20	*Ceratium fusus*	F	S	56	*Protoperidinium pellucidum*	F	S
21	*Ceratium gibberum*	-	F	57	*Protoperidinium pentagonum*	F	F
22	*Ceratium horridum*	F	R	58	*Protoperidinium puncutulatum*	-	S
23	*Ceratium inflatum*	-	F	59	*Protoperidinium pyriforme*	F	S
24	*Ceratium kofoidii*	R	R	60	*Protoperidinium sphaericum*	-	F
25	*Ceratium longissimum*	R	-	61	*Scripsiella trochoidea*	F	F
26	*Ceratium longirostrum*	R	-	62	*Podolampas bipes*	F	F
27	*Ceratium macroceros*	F	S	63	*Podolampas palmipes*	F	F
28	*Ceratium sumatranum*	-	F	64	*Podolampas spinifera*	-	R
29	*Ceratium teres*	F	R	65	*Pyrophacus horologicum*	F	F
30	*Ceratium trichoceros*	F	S	66	*Pyrophacus steinii*	F	F
31	*Ceratium tripos*	R	F	67	*Prorocentrum micans*	F	F
32	*Ceratium vultur*	-	F	68	*Prorocentrum minimum*	F	-
33	*Ceratocorys horrida*	-	F	69	*Pyrocystis fusiformis*	-	F
34	*Gonyaulax monocantha*	R	-	70	*Pyrocystis lunula*	-	S
35	*Gonyaulax spinifera*	-	F	71	*Pyrocystis noctiluca*	-	F
36	*Gonyaulax turbynaii*	F	S				

Note: 1= first cruise
2= second cruise

Abundance
R= rare occurrence, <1000 cells/ml
F = frequent occurrence, 1000-9999 cells/ml
S = subdominant, 10000-99999 cells/ml
D = dominant, >100000 cells/ml

Table.4 Abundance list of dinoflagellates species in the southern zone of Malacca Straits

S.No.	List of Species	1	2		List of species	1	2
1	*Dinophysis caudata*	R	S	28	*Oxytoxum tesselatum*	-	F
2	*Dinophysis hastata*	F	-	29	*Diplopsalis assymetrica*	F	S
3	*Dinophysis miles*	F	R	30	*Diplopsalis lenticula*	F	S
4	*Phalacroma rotundatum*	R	F	31	*Diplopsalis globula*	F	F
5	*Ornithocercus magnificus*	-	F	32	*Protoperidinium bidentatum*	R	-
6	*Gymnodinium coeruleum*	R	F	33	*Protoperidinium cerasus*	R	F
7	*Gymnodinium simplex*	-	F	34	*Protoperidinium conicum*	-	F
8	*Gymnodinium splendens*	-	S	35	*Protoperidinium crassipes*	F	F
9	*Gymnodinium* sp.	-	F	36	*Protoperidinium depressum*	-	S
10	*Gyrodinium* sp.	-	S	37	*Protoperidinium divergens*	F	F
11	*Noctiluca scintillans*	F	F	38	*Protoperidinium monospinum*	R	F
12	*Ceratium belone*	-	R	39	*Protoperidinium oblongum*	F	F
13	*Ceratium breve*	-	F	40	*Protoperidinium ovum*	R	F
14	*Ceratium furca*	F	D	41	*Protoperidinium pallidum*	-	R
15	*Ceratium fusus*	F	F	42	*Protoperidinium pellucidum*	-	S
16	*Ceratium horridum*	-	F	43	*Protoperidinium pentagonum*	F	F
17	*Ceratium kofoidii*	-	F	44	*Protoperidinium puncutulatum*	R	F
18	*Ceratium macroceros*	-	F	45	*Protoperidinium sphaericum*	-	F
19	*Ceratium schmidtii*	-	F	46	*Podolampas palmipes*	-	F
20	*Ceratium tenue*	-	F	47	*Pyrophacus steinii*	-	F
21	*Ceratium trichoceros*	F	S	48	*Prorocentrum gracile*	R	F
22	*Ceratium tripos*	-	F	49	*Prorocentrum micans*	F	F
23	*Ceratium vultur*	-	F	50	*Prorocentrum minimum*	-	F
24	*Gonyaulax monocantha*	-	F	51	*Pyrocystis fusiformis*	F	-
25	*Gonyaulax spinifera*	-	F	52	*Pyrocystis lunula*	-	F
26	*Gonyaulax turbynaii*	-	F	53	*Pyrocystis noctiluca*	-	R
27	*Gonyaulax* sp.	-	S				

Note: 1= first cruise
2= second cruise

Abundance
R= rare occurrence, <1000 cells/ml
F = frequent occurrence, 1000-9999 cells/ml
S = subdominant, 10000-99999 cells/ml
D = dominant, >100000 cells/ml

Table.5 Comparison list of dinoflagellates species recorded between the inshore and offshore stations of Malacca Straits during northeast monsoon season

	List of Species	
Monsoon Season Northeast (First Cruise)	Inshore (Station 1, 8, 21, 24)	Offshore (Station 2, 3, 7, 19, 20, 22, 23)
	Dinophysis caudata	*Amphisolenia bidentata*
	Dinophysis miles	*Dinophysis caudata*
	Parahistioneis sp	*Dinophysis hastata*
	Phalacroma mitra	*Dinophysis miles*
	Phalacroma rotundatum	*Parahistioneis* sp
	Ornithocercus magnificus	*Phalacroma doryphorum*
	Noctiluca scintillans	*Phalacroma mitra*
	Ceratium breve	*Phalacroma rotundatum*
	Ceratium extensum	*Ornithocercus magnificus*
	Ceratium furca	*Gymnodinium coeruleum*
	Ceratium fusus	*Noctiluca scintillans*
	Ceratium horridum	*Ceratium furca*
	Ceratium macroceros	*Ceratium fusus*
	Ceratium trichoceros	*Ceratium horridum*
	Gonyaulax turbynaii	*Ceratium kofoidii*
	Gonyaulax sp	*Ceratium longissimum*
	Heterodinium whittingae	*Ceratium longirostrum*
	Oxytoxum tesselatum	*Ceratium macroceros*
	Diplopsalis assymetrica	*Ceratium teres*
	Diplopsalis lenticula	*Ceratium trichoceros*
	Diplopsalis globula	*Ceratium tripos*
	Protoperidinium bidentatum	*Gonyaulax monocantha*
	Protoperidinium cerasus	*Gonyaulax turbynaii*
	Protoperidinium conicum	*Gonyaulax* sp
	Protoperidinium depressum	*Oxytoxum tesselatum*
	Protoperidinium monospinum	*Podolampas palmipes*
	Protoperidinium ovum	*Diplopsalis assymetrica*
	Protoperidinium pallidum	*Diplopsalis lenticula*
	Protoperidinium pellucidum	*Diplopsalis globula*
	Protoperidinium pentagonum	*Protoperidinium cerasus*
	Protoperidinium pyriforme	*Protoperidinium claudicans*
	Scripsiella trochoidea	*Protoperidinium conicum*
	Pyrocystis fusiformis	*Protoperidinium depressum*
	Pyrophacus horologicum	*Protoperidinium divergens*
	Prorocentrum gracile	*Protoperidinium monospinum*
	Prorocentrum micans	*Protoperidinium oblongum*
	Prorocentrum minimum	*Protoperidinium ovum*

	Protoperidinium pellucidum
	Protoperidinium pentagonum
	Protoperidinium pyriforme
	Scripsiella trochoidea
	Podolampas bipes
	Podolampas palmipes
	Pyrophacus horologicum
	Pyrophacus steinii
	Prorocentrum micans
	Prorocentrum minimum
	Pyrocystis fusiformis

Figure.7 Diversity index changes of dinoflagellates in the northern and southern zone of Malacca Straits during northeast and pre southwest monsoon season (Cruise 1) and (Cruise 2) respectively; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

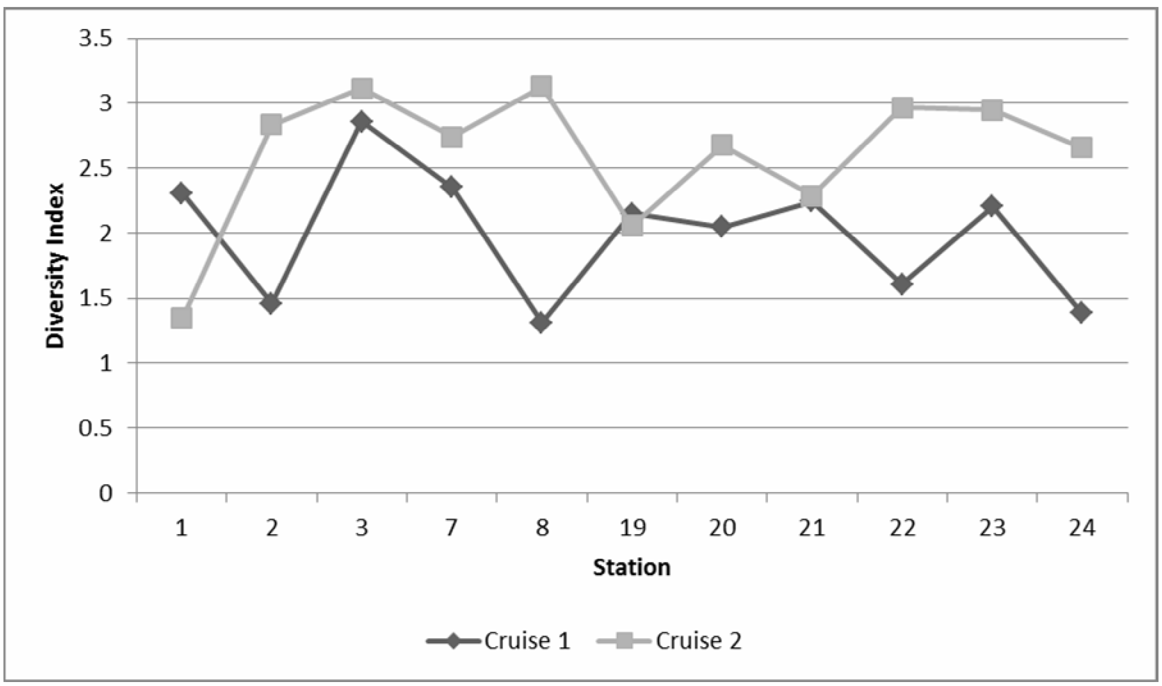


Table.6 Comparison list of dinoflagellates species recorded between the inshore and offshore stations of Malacca Straits during pre southwest monsoon season

	List of Species	
Monsoon Season	Inshore	Offshore
Pre Southwest (Second Cruise)	(Station 1, 8, 21, 24)	(Station 2, 3, 7, 19, 20, 22, 23)
	Dinophysis caudata	*Dinophysis caudata*
	Dinophysis miles	*Parahistioneis* sp
	Parahistioneis sp	*Phalacroma rotundatum*
	Phalacroma doryphorum	*Ornithocercus magnificus*
	Phalacroma rotundatum	*Gymnodinium coeruleum*
	Ornithocercus magnificus	*Gymnodinium simplex*
	G. simplex	*Gymnodinium splendens*
	Gymnodinium splendens	*Gymnodinium* sp.
	Gymnodinium sp.	*Gyrodinium* sp.
	Gyrodinium sp.	*Noctiluca scintillans*
	Noctiluca scintillans	*Diplopsalis assymetrica*
	Diplopsalis assymetrica	*Diplopsalis lenticula*
	Diplopsalis lenticula	*Diplopsalis globula*
	Diplopsalis globula	*Goniodoma polyedricum*
	Goniodoma polyedricum	*Gonyaulax monocantha*
	Gonyaulax spinifera	*Gonyaulax turbynaii*
	Gonyaulax turbynaii	*Gonyaulax* sp.
	Gonyaulax sp.	*Ceratium belone*
	Ceratium breve	*Ceratium breve*
	Ceratium furca	*Ceratium carriense*
	Ceratium fusus	*Ceratium furca*
	Ceratium horridum	*Ceratium fusus*
	Ceratium inflatum	*Ceratium gibberum*
	Ceratium kofoidii	*Ceratium horridum*
	Ceratium macroceros	*Ceratium inflatum*
	Ceratium schmidtii	*Ceratium kofoidii*
	Ceratium trichoceros	*Ceratium macroceros*
	Ceratium tripos	*Ceratium schmidtii*
	Ceratium vultur	*Ceratium sumatranum*
	Heterodinium whittingae	*Ceratium tenue*
	Oxytoxum reticulatum	*Ceratium teres*
	Oxytoxum scolopax	*Ceratium trichoceros*
	Oxytoxum tesselatum	*Ceratium tripos*
	Podolampas bipes	*Ceratium vultur*
	Podolampas palmipes	*Ceratocorys horrida*
	Protoperidinium cerasus	*Oxytoxum reticulatum*
	Protoperidinium claudicans	*Oxytoxum scolopax*

	Protoperidinium conicum	*Oxytoxum tesselatum*
	Protoperidinium crassipes	*Podolampas bipes*
	Protoperidinium depressum	*Podolampas palmipes*
	Protoperidinium divergens	*Podolampas spinifera*
	Protoperidinium monospinum	*Protoperidinium bidentatum*
	Protoperidinium oblongum	*Protoperidinium cerasus*
	Protoperidinium ovum	*Protoperidinium claudicans*
	Protoperidinium pallidum	*Protoperidinium conicum*
	Protoperidinium pellucidum	*Protoperidinium crassipes*
	Protoperidinium pentagonum	*Protoperidinium depressum*
	Protoperidinium puncutulatum	*Protoperidinium divergens*
	Protoperidinium pyriforme	*Protoperidinium monospinum*
	Protoperidinium sphaericum	*Protoperidinium oblongum*
	Scripsiella trochoidea	*Protoperidinium ovum*
	Pyrophacus horologicum	*Protoperidinium pellucidum*
	Pyrophacus steinii	*Protoperidinium pentagonum*
	Prorocentrum gracile	*Protoperidinium puncutulatum*
	Prorocentrum micans	*Protoperidinium sphaericum*
	Pyrocystis fusiformis	*Prorocentrum gracile*
	Pyrocystis lunula	*Prorocentrum micans*
		Prorocentrum minimum
		Scripsiella trochoidea
		Pyrophacus steinii
		Pyrocystis lunula
		Pyrocystis noctiluca

Figure.8 Species evenness changes of dinoflagellates in the northern and southern zone of Malacca Straits during northeast (Cruise 1) and pre southwest (Cruise 2) monsoon season; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

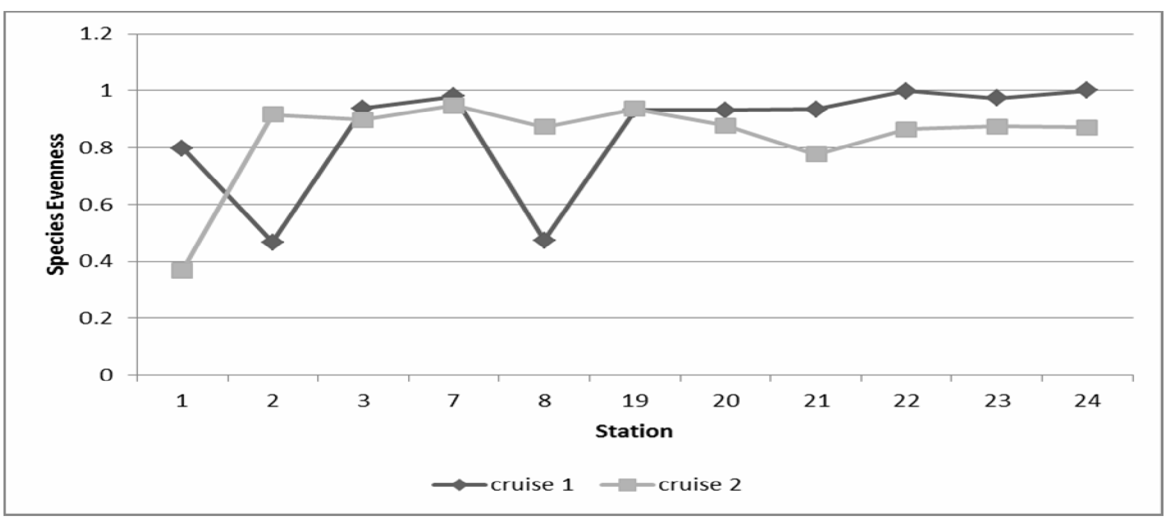


Figure.9 Species richness changes of dinoflagellates in the northern and southern zone of Malacca Straits during the northeast (Cruise 1) and pre southwest (Cruise 2) monsoon season; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

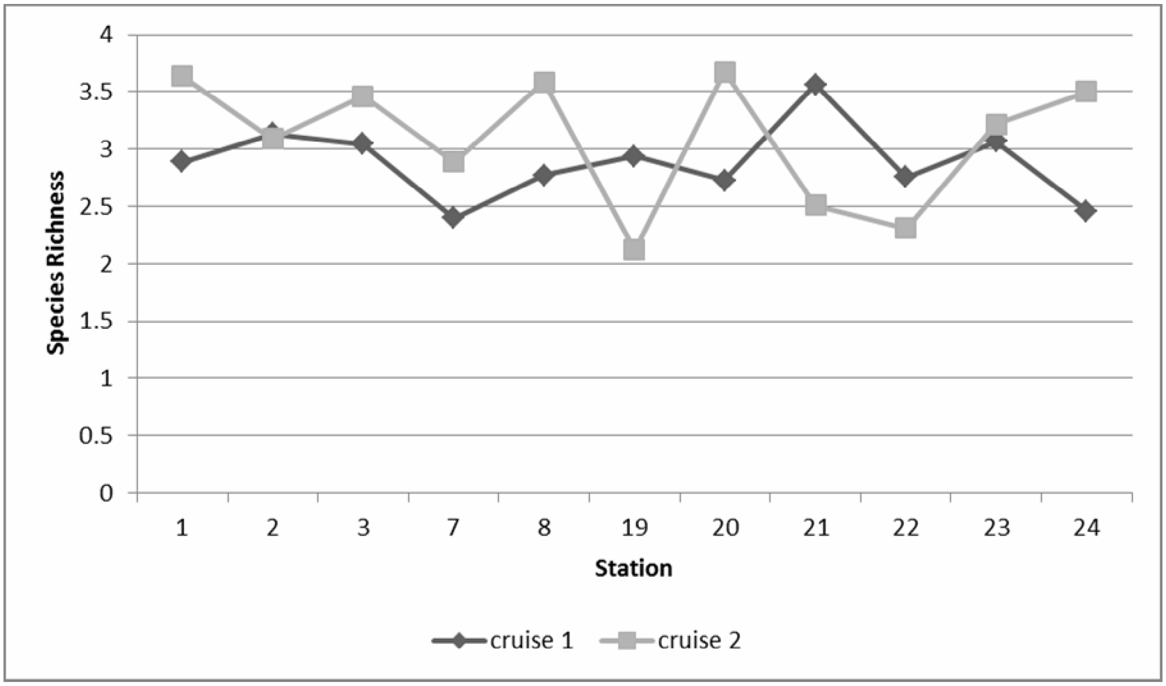


Table.7 Physical and chemical parameters from the first cruise (northeast monsoon) in the northern and southern zone of Malacca Straits

Sampling station	Temperature (°C)	Salinity (ppt)	Conductivity (mS/cm)	Dissolved Oxygen (mg/l)	pH
St. 1	28.24	32.97	50.34	5	8.07
St. 2	27.84	33.81	51.49	5.25	8.13
St. 3	27.61	34.08	51.87	5.9	8.15
St. 7	27.88	33.48	51.04	5.76	8.18
St. 8	28.29	32.74	50.03	4.63	8.09
St. 19	28.24	31.46	48.29	5.79	8.08
St. 20	28.69	31.36	48.15	6.17	8.17
St. 21	28.58	31.26	47.99	6.09	8.14
St. 22	28.46	30.64	47.18	5.96	8.17
St. 23	28.31	29.64	45.8	5.98	8.06
St. 24	28.44	31.01	47.68	5.86	8.1

Table.8 Physical and chemical parameters from the second cruise (pre southwest monsoon) in the northern zone of Malacca Straits

Sampling station	Temperature (°C)	Salinity (ppt)	Conductivity (mS/cm)	Dissolved Oxygen (mg/l)	pH
St. 1	28.08	34.33	51.66	4.69	7.99
St. 2	27.82	35.57	53.92	5	8.07
St. 3	26.15	36.01	54.85	4.81	8.03
St. 7	27.8	35.48	53.55	4.87	8.03
St. 8	27.96	34.42	52.31	4.39	7.88
St. 19	28.36	31.71	48.63	6.21	7.89
St. 20	28.2	32.87	50.21	6.57	7.95
St. 21*					
St. 22	28.09	33.06	50.47	7.22	8.02
St. 23	28.24	33.2	50.67	5.89	8.02
St. 24	28.24	33.32	50.81	5.55	8.14

*no reading obtained

Figure.10 Variation of diversity index versus total density of dinoflagellates in the northern and southern zone of Malacca Straits during the first cruise, northeast monsoon (NE) season; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

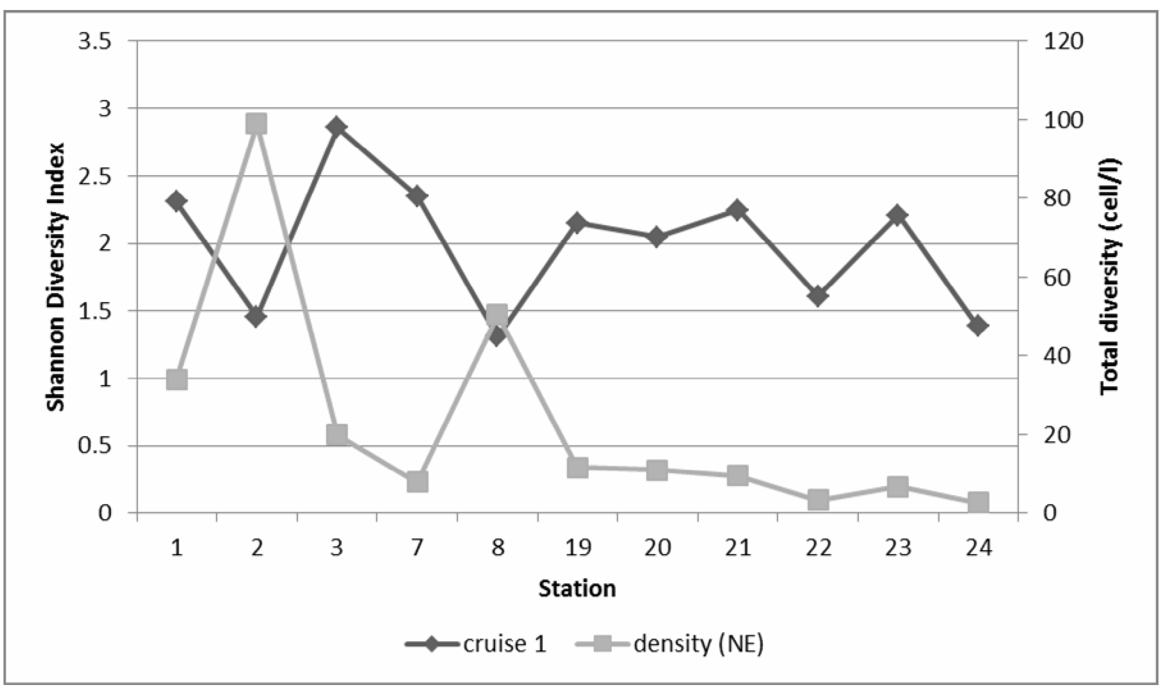


Figure.11 Variation of diversity index versus total density of dinoflagellates in the northern and southern zone of Malacca Straits during pre southwest monsoon season, second cruise; inshore stations (1, 8, 21, 24) ; offshore stations (2, 3, 7, 19, 20, 22, 23)

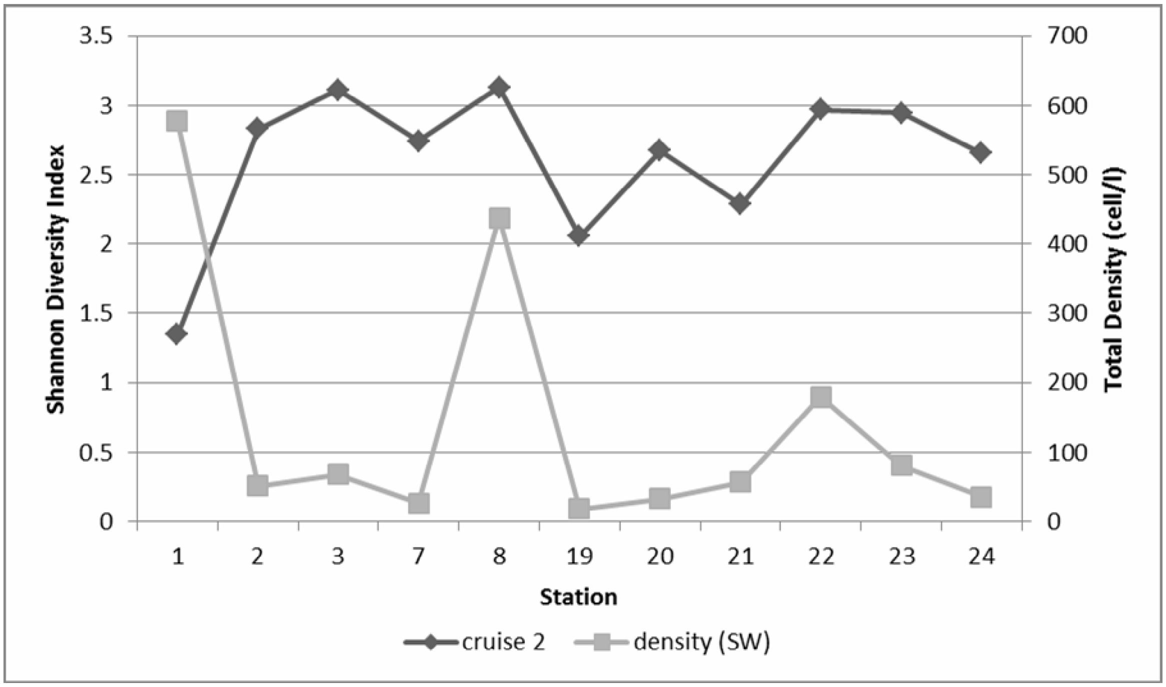
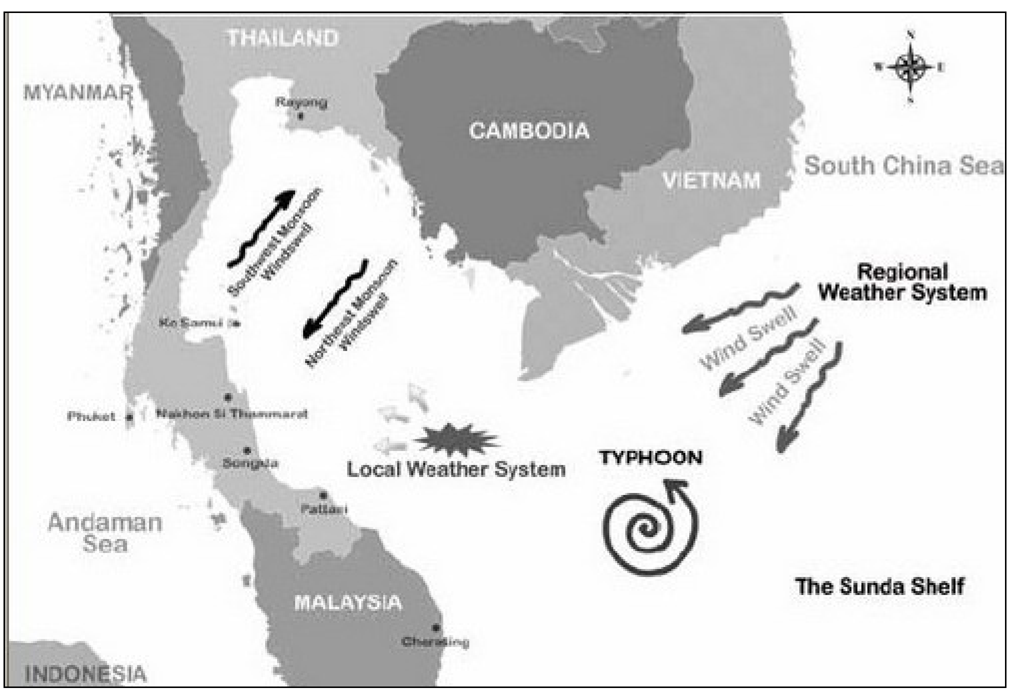


Figure.12 Northeast monsoon and Southwest monsoon season current flow (Source: Thaisurfraider.com)



At this point, climate patterns along Malacca Strait shifts regularly though rainfalls and storms which has influenced the rate of water momentum flushing endlessly microorganisms and nutrients (Doblin et al., 2006). The physical and chemical properties of water in the seaward and inshore zone were adjusted creating unsettling influence in marine food web. Excessive CO_2 and diminished dissolved oxygen contributes algal blooms and stimulates photosynthesis in the aquatic ecology (Beardall and Raven, 2004). In fact, impropriate aquaculture practices in some places could harm aquatic life. Fish farming in oceans may cause big alteration in chemical properties likewise pushes algal sprouts relies on upon the flushed nutrients (Glibert & Terlizzi, 1999). Nutrient sufficiency, temperature and light intensity have a great tendency to affect the dinoflagellate diel vertical migration (Heaney & Eppley, 1981). For some reasons, organisms migrate daily to find optimum light intensity and avoid predators where they could find comfortable place for them to stay in order to survive. As for instant, the light intensity and temperature on the surface layer was too great for dinoflagellates during daylight. Thus, migration of these organisms may occur in order to prevent damaged of ultraviolet radiation (UV). Usually the migrations occur at night to the upper layer of sea while during daylight, the migration turns down to the deep layer (Eppley et al., 1968). These behaviors could thoroughly change the abundance, composition and density of the dinoflagellates at different sampling stations. In rainy season, the sea salinity drop and the nutrients level were probably increased due to agriculture runoff from coastal areas to the study areas causing disturbances in species distribution, composition and abundance of dinoflagellates. Sidabutar et al., (1999) stated that phytoplankton grown well only during wet season. Edward and Manik (1987) and Tarigan (1987) identified some nutrients enrichment during rainy season. Besides, Hodgkiss and Ho (1992) suggested that dinoflagellates could be one dominant species due to high supplies of phosphorus and less nitrogen.

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