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Effects of Meteorological Conditions on the Occurrence of *Cochlodinium polykrikoides* and *Pyrodinium bahamense* var. *compressum* in Coastal Waters of Kota Kinabalu, Sabah, Malaysia

(Kesan Keadaan Meteorologi ke Atas Kemunculan *Cochlodinium polykrikoides* dan *Pyrodinium bahamense* var. *compressum* di Perairan Kota Kinabalu, Sabah, Malaysia)

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ABSTRACT

In the Kota Kinabalu coastal area, the episodic occurrences of harmful algal bloom (HAB) species had been reported more than a decade ago. But, the time of the occurrence and factors contributing to the occurrence are still inadequately understood. To fill the gap, a study using 4 years field data from 2007 to 2010 was conducted. Cell densities of two HAB species, physicochemical parameters such as temperature, salinity, pH and dissolved oxygen together with rainfall data, wind data and general influence of ENSO episodes were taken into account to identify the most probable factors that trigger the occurrence of HAB species in the Kota Kinabalu coastal waters. From the analysis, C. polykrikoides *blooms after 1 to 2 days of rain and significantly high nutrient concentrations were recorded during the blooms. Other physicochemical parameters were almost the same during the bloom and non-bloom events. Climate phenomena like ENSO (El Niño Southern Oscillation) affected the occurrence of* P. bahamense *var.* compressum *and* C. polykrikoides. P. bahamense *var.* compressum *occurred during El Niño due to high salinity and no blooms were recorded during La Niña. This indicates that unusual climate condition suppressed the bloom formation. The results gained from this study provide important information in managing HAB species particularly in the Kota Kinabalu coastal area.*

Keywords: Algal blooms; El Niño phenomena; meteorological data; paralytic shellfish poisoning; Sabah

ABSTRAK

Di Kota Kinabalu, kehadiran kembangan alga bahaya telah direkodkan seabad yang lalu. Malangnya masa kemunculan dan faktor yang mempengaruhi kemunculannya masih kurang difahami. Untuk memahami masalah ini, kajian menggunakan data 4 tahun iaitu dari 2007 sehingga 2010 telah dijalankan. Kelimpahan sel dua alga bahaya, parameter fiziko-kimia seperti suhu, angin serta keberkesanan ENSO telah diambil kira untuk mengenal pasti faktor penyumbang kepada kemunculan alga bahaya di perairan Kota Kinabalu. Daripada analisis, didapati C. polykrikoides *hadir dengan banyaknya 1 hingga 2 hari selepas hujan dan dalam masa yang sama kandungan nutrient yang tinggi telah direkodkan. Bacaan parameter fiziko-kimia yang lain adalah lebih kurang sama semasa ledakan dan tiada ledakan kecuali kehadiran cahaya matahari. Cuaca yang tidak menentu mempengaruhi kehadiran* C. polykrikoides *dan* P. bahamense *var.* compressum. P. bahamense *var.* compressum *hadir semasa El Niño kerana kemasinan yang tinggi dan tidak muncul semasa La Nina. Ini menunjukkan cuaca yang tidak menentu menyebabkan ledakan tidak terjadi. Keputusan daripada kajian ini menyumbang kepada maklumat penting di dalam menguruskan kembangan alga bahaya terutamanya di perairan Kota Kinabalu.*

Kata kunci: Data meteorologi; fenomena El Niño; keracunan kerang-kerangan melumpuhkan; ledakan alga bahaya; Sabah

INTRODUCTION

Many studies on the factors contributing to the occurrence of harmful algal bloom (HAB) have been reported. The studies are based on field data collected during the bloom events or before and after the bloom events and they suggested the optimum conditions that might have triggered the bloom (Anton et al. 2008; Lee & Lee 2006; Lee 2006, 2008). Others tried to simulate the events by performing the studies in the laboratory (for example growth studies) or modelled the bloom dynamics using data collected from field (Sitti-Raehanah et al. 2010; Villanoy et al. 2006).

In the west coast of Sabah, HAB has been reported since 1976 (Roy 1977). This event is a recurring problem and has caused a lot of negative impacts to the human health, aquaculture, fishery industries and tourism operations. To date, 3 species have been identified as causative species, which are *Pyrodinium bahamense* var. *compressum* (Roy 1977), *Cochlodinium polykrikoides* (Anton et al. 2008) and *Gymnodinium catenatum*

(Mohammad-Noor et al. 2010). The *G. catenatum* and *C. polykrikoides* were first observed in this area in 2003 and 2005, respectively. Although the events have been reported in this area more than a decade ago (especially for *Pyrodinium bahamense* var. *compressum*), understanding on the time of occurrence and factors contributing to the occurrence is still limited.

Study using 15 years data to understand the effects of meteorological factors on the occurrence of *P. bahamense* var. c*ompressum* in the west coast of Sabah has been done by Usup and Yu (1991). Their results indicated that this species occurred during both northeast and southwest monsoon periods, but no clear combination of environmental conditions was observed. Laboratory study by Sitti-Raehanah et al. (2010) on unialgal cultures of *P. bahamense* var. *compressum* and *C. polykrikoides* that isolated from this area indicated that each species preferred different salinity. *Pyrodinium bahamense* var. c*ompressum* grows optimally at 35°C while *C. polykrikoides* prefers to grow in optimal condition at 30°C. But, in combination of salinity and temperature, *C. polykrikoides* growth was highest at 35 and 26°C (Sitti-Raehanah et al. 2010). These show that when more than one species occur together, the preferred environmental conditions of each of the species change accordingly. This indicates the difficulty in identifying the triggering condition when many parameters are involved. Even minute differences in these factors may play a vital role in promoting HAB.

To increase our understanding on the co-occurrence of these species, a study using 4 years field data collected from 2007 to 2010 was conducted. The cell density of two HAB species namely *P. bahamense* var. *compressum* and *C. polykrikoides,* physicochemical parameters (salinity, pH, temperature and dissolved oxygen), nutrient analyses (nitrate and phosphate) and secondary data (monthly rainfall and wind) were used to identify the most probable combination of factors that contributed to the HAB occurrence in Kota Kinabalu coastal waters. To investigate the influence of meteorological factor, in this case rain, daily cell density and daily rain data of *C. polykrikoides* were collected. As this area is one of the crucial areas for HAB in the west coast of Sabah, the results will provide important knowledge on which environmental factors to be considered in dealing with HAB.

MATERIALS AND METHODS

STUDY AREA

Kota Kinabalu coastal waters have experienced regular harmful algal bloom (HAB) problems. The coastal waters comprise of 3 bays named Sepangar Bay, Gaya Bay and Likas Bay as shown in Figure 1. This coastal area has many shipping activities from both local and international fronts. In addition, many human settlements and industries are located along the coastal areas. Kota Kinabalu is also under the influence of monsoons namely northeast monsoon (NEM) from November to March, southwest monsoon (SWM) from May to September and inter-monsoon (April and October).

CELL DENSITY OF *C. POLYKRIKOIDES* AND *P. BAHAMENSE* VAR. *COMPRESSUM*

Cell densities of the two HAB species were counted at one station every month for 4 years viz. from January 2007 to December 2010. During the blooms period that occurred in 2007 and 2008, sampling was done every day whenever possible. For cell counts, 1 L of water sample was collected at 1 m depth and preserved with Lugol's iodine. The

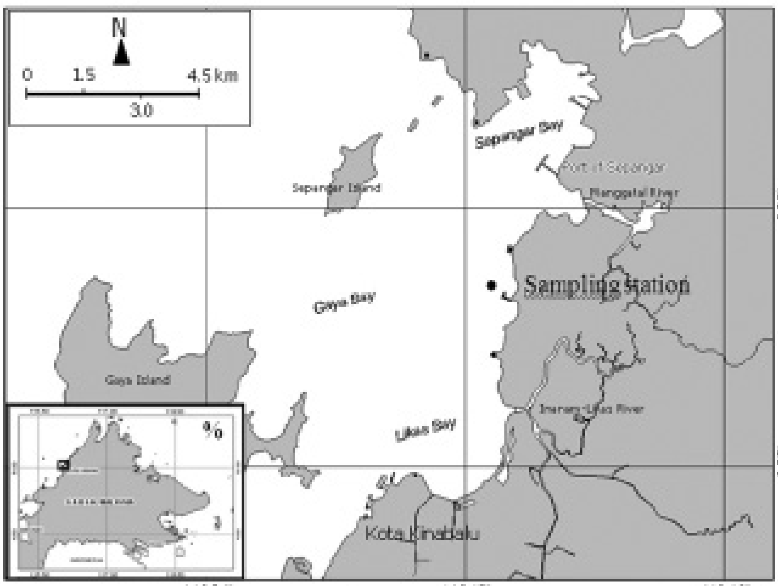

FIGURE 1. Location of the study area in Kota Kinabalu coastal waters

samples were then concentrated into 50 mL before being counted using Sedgwick Rafter cell under light microscope at 100× magnification.

NUTRIENT ANALYSIS

Five hundred mL of water samples was collected using Von Dorn water sampler from the same station from December 2007 to August 2008. Before analysis was done, samples were filtered through membrane filter GF/C. The water samples analysis were then performed following the methods of Parsons et al. (1984).

PHYSICOCHEMICAL PARAMETERS AND RAINFALL DATA

Physicochemical parameters including temperature, salinity, pH and dissolved oxygen were recorded *in situ* using a multiprobe (Cyberscan pH300 and Ecoscan Portable Meter SALT 6). Secondary data of daily rainfall and wind data from 2007 to 2010 of Kota Kinabalu coastal waters were obtained from Meteorology Department, Kota Kinabalu, Sabah.

DATA ANALYSES

Kruskal-Wallis test was used to find the significant difference of total cell densities of *P. bahamense* var. *compressum* and *C. polykrikoides* and physicochemical parameters between months. The correlation with rain was studied using *C. polykrikoides* data collected in 2007 and 2008 to judge the influence of El Niño and La Niña events in 2009 and 2010. Continuous data for 6 to 10 days in these years were chosen. *C. polykrikoides* was considered bloom if the cell density reached 10^5 cells/L and above whereas *P. bahamense* var. *compressum* was considered bloom if the cell density reached 10^3 cells/L and above.

Occurrences of *C. polykrikoides* and *P. bahamense* var. *compressum* and environmental variables of water (temperature, pH, Salinity, NO_3^-, PO_4^{3-} and rainfall) from the study area were subjected to principal component analysis (PCA) and correspondence analysis (CA). In PCA, varimax was selected to apply a rotation. It could reduce the number of factors with maximum loadings and consequently make it easier to clarify each of the potential components. According to the PCA result (correlation matrix of HAB abundance and water quality parameters), two components were extracted and they represented 75.481% of the cumulative variance (Table 1). The PCA and CA analyses were performed using SPSS software (version for Windows 07, SPSS 16 inc).

RESULTS

It was found that in 2007 to 2008, *C. polykrikoides* dominated the sampling area and the occurrence covered both the SWM and NEM with the highest cell density of 7×10^6 cells/L recorded in December 2007 (Figure 2). Within these 2 years, *P. bahamense* var. *compressum* occurred in lower number compared to *C. polykrikodes* (Figure 2). The correlation coefficients and leading and lagging time between rain and cell density of *C. polykrikoides* in 2007 and 2008 showed that the blooms occurred 1 to 2 days after rain (Table 2) (correlation coefficients of 0.46-0.96, between 80 and 99% significance). NO_3^- and PO_4^{3-} concentrations recorded during the bloom events were significantly higher compared to during non-bloom events (Table 3). The ranges of concentrations of NO_3^- and PO_4^{3-} during the bloom events were from 23.26 to 32.96 µM and from 1.53 to 2.34 µM, respectively. During the non-bloom events, the concentration of NO_3^- and PO_4^{3-} were from 6.32 to 12.18 µM and from 0.35 to 0.66 µM, respectively.

As shown by factor loadings (Table 4) and Figure 3, component 1 was influenced by 3 *in situ* parameters primarily by high temperature and pH and low salinity which associated with *C. polykrikoides* bloom. Meanwhile, component 2 explained that bloom of *C. polykrikoides* was influenced by high NO_3^- and PO_4^{3-} concentrations. CA analysis also indicated that blooms of *C. polykrikoides* were related to high nutrients level (Group 1) (Figure 4). No correlation was found between *P. bahamense* var. *compressum* bloom and water quality parameters studied.

Two blooms of *P. bahamense* var. *compressum* occurred in January and February 2010 with cell density of 1.3×10^5 cells/L and 4.1×10^3 cells/L, respectively (Figure 2). It was during the El Niño since a mild El Niño was observed to start in the end of 2009 until March 2010. During this period, less rainfall was recorded compared with other years (Figure 5) (NTC 2009). A strong La Niña

TABLE 1. Total variance of principal component analysis

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.853	55.049	55.049	3.853	55.049	55.049	2.771	39.588	39.588
2	1.430	20.432	75.481	1.430	20.432	75.481	2.512	35.893	75.481
3	.854	12.202	87.683						
4	.480	6.861	94.544						
5	.246	3.515	98.059						
6	.134	1.919	99.978						
7	.002	.022	100.000						

Extraction method: Principal component analysis

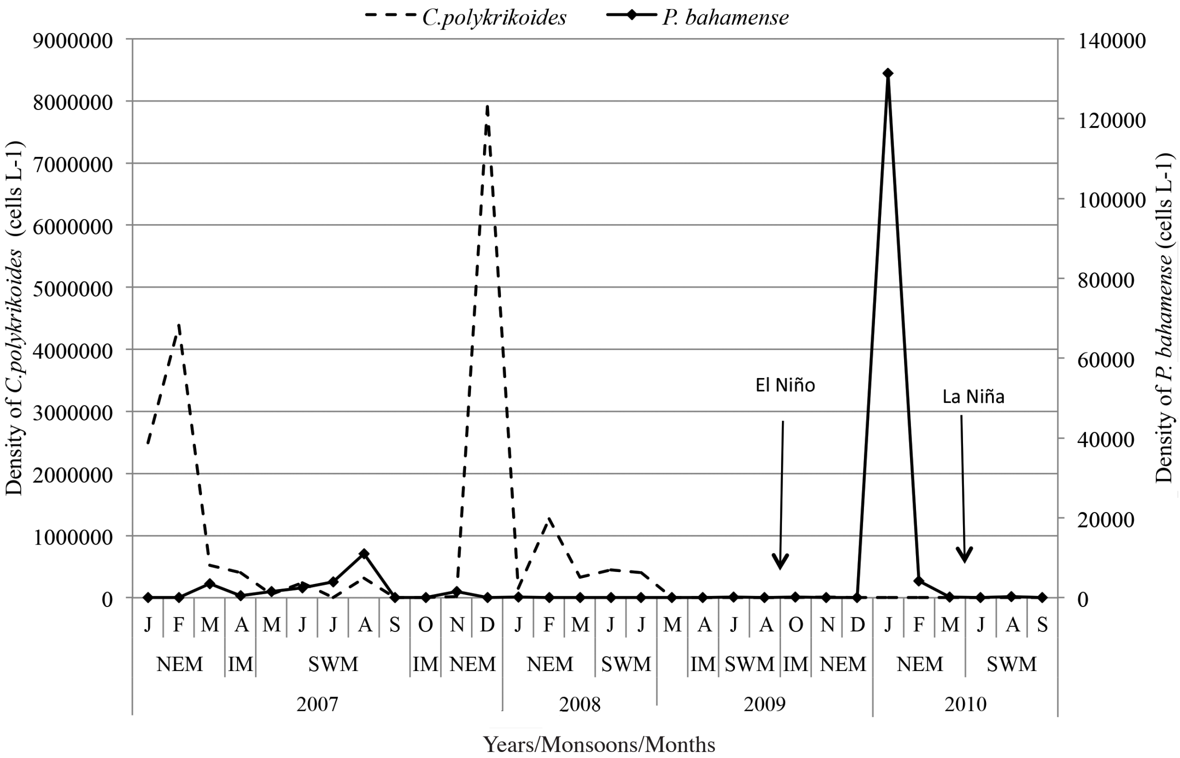

FIGURE 2. Cell density of *C. polykrikoides* and *P. bahamense* var. *compressum* from 2007 to 2010

TABLE 2. Correlation coefficients between time series of cell density of *C. polykrikoides* and dailyrain (-ve lag means rain leads the cell density)

Date	Correlation coefficient	Time lag
13-15 Jan 2007	0.63	-1
17-24 Jan 2007	0.46	-1
21-30 Jan 2007	0.66	-2
19-25 Jan 2008	0.96	-2

TABLE 3. Combined effects of all parameters on *C. polykrikoides* species

	Date	*C. polykrikoides* cells density (cells L^{-1})	NO_3^- (μM)	PO_4^{3-} (μM)	Temp. (°C)	Salinity (psu)	pH	DO mg L^{-1}	Rainfall (mm day^{-1})	Comment
Bloom	19 Feb 08	2.8×10^5	32.96	2.34	28.1	31.0	8.3	7.0	38.0	1 day after heavy rain
	29 Feb 08	3.4×10^6	32.54	1.87	29.1	31.7	8.1	7.6	39.4	2 days after heavy rain
	24 July 08	2.1×10^5	23.26	1.53	29.9	32.3	8.1	5.8	58.7	1 day after heavy rain
Non Bloom	4 Dec 07	0	11.94	0.52	28.5	31.8	8.6	8.3	-	No rain
	30 Apr 08	0	12.18	0.66	31.7	32.1	8.3	6.5	-	No rain
	31 Jul 08	0	6.32	0.35	30.3	32.9	8.3	5.1	-	No rain

TABLE 4. Rotated component matrix[a] of PCA

	Component	
	1	2
TEMP	.876	-.025
pH	.927	.275
SALINITY	-.901	-.349
C.P	.087	.854
NO_3^-	.166	.926
PO_4^{3-}	.413	.811
RAINFALL	.357	.263

Extraction method: Principal component analysis
Rotation method: Varimax with Kaiser normalization
[a] Rotation converged in 3 iterations

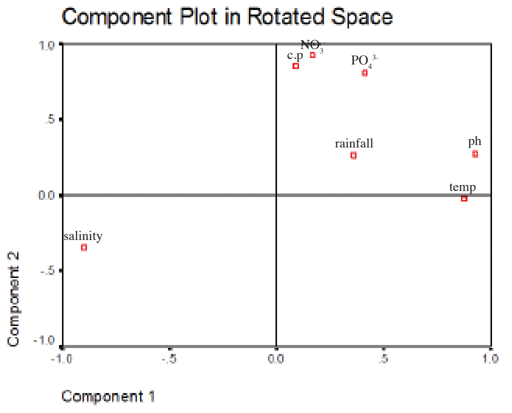

FIGURE 3. Scatter plot matrix of component scores of two HAB species (c.p: *C. polykrikoides*) and water quality parameters

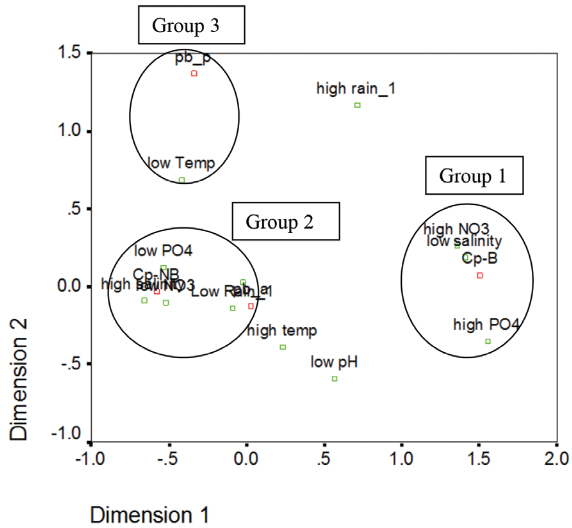

FIGURE 4. Correspondence analysis (CA) showing the bloom of *C. polykrikoides* and *P. bahamense* var. *compressum* in relation to the water quality parameters and rainfall. Cp-B = *C. polykrikoides* bloom, Cp-NB = Non bloom of *C. polykrikoides*, Pb-B = *P. bahamense* var. *compressum* bloom, high-temp = high temperature, low-temp = low temperature, low Rain_1 = low rainfall event

was recorded to bring heavy rain and it started in April 2010 (Figure 5) (NTC 2010). La Niña (wet and cold period) happened when Southern Oscillation Index (SOI)> +7 or +8 and El Niño (dry and warm period) happened when SOI <–7 or –8 (Figure 6). No bloom was recorded for both species during La Niña. Wind came persistently from southwest most of the time and it was difficult to identify the clear influence of wind on bloom events (Figure 7).

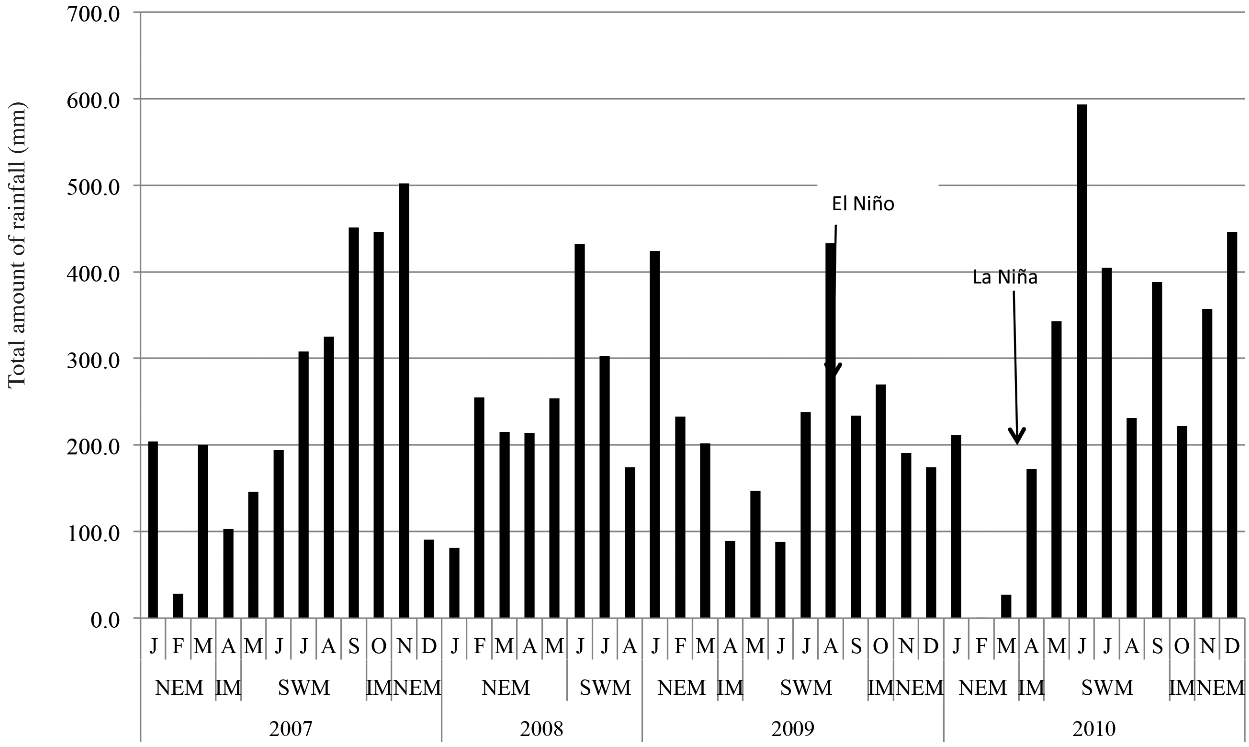

FIGURE 5. Total monthly rainfall from 2007 to 2010

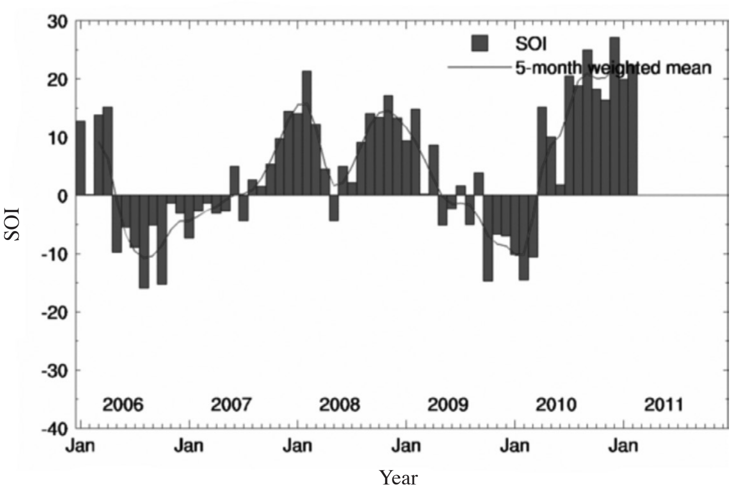

FIGURE 6. Southern Oscillation Index (SOI) values from the Bureau of Meteorology, Melbourne, Australia showing the periods of ENSO phenomena throughout the study period

No significant differences were found for temperature and salinity records throughout the 4 years except the salinity that was higher during the El Niño period (Figure 8). The value of pH fluctuated during the study period with the lowest value recorded in January 2010 (El Niño period) (Figure 8).

DISCUSSION

In 2007 and 2008, occurrence of *C. polykrikoides* dominated the sampling areas over *P. bahamense* var. *compressum*. In Kota Kinabalu, heavy rainfall was recorded during SWM and rain has been postulated to generate HAB (Adam et al. 2011). However, insignificant connection was found between rainfall and *P. bahamense* var. *compressum* blooms in Kota Kinabalu coastal area based on 8 years data (Usup & Yu 1991). In this study, rainfall was found to trigger the occurrence of the *C. polykrikoides* blooms after 1 or 2 days. The rainfall is believed to brought high amount of nutrients through run-off and thus causing the species to bloom. Nutrient concentrations (NO_3^- and PO_4^{3-}) recorded during the blooms events were higher compared to non-

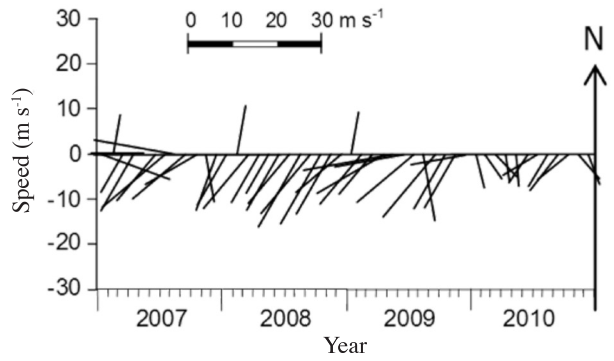

FIGURE 7. Stick plot of monthly winds in Kota Kinabalu area (2007-2010)

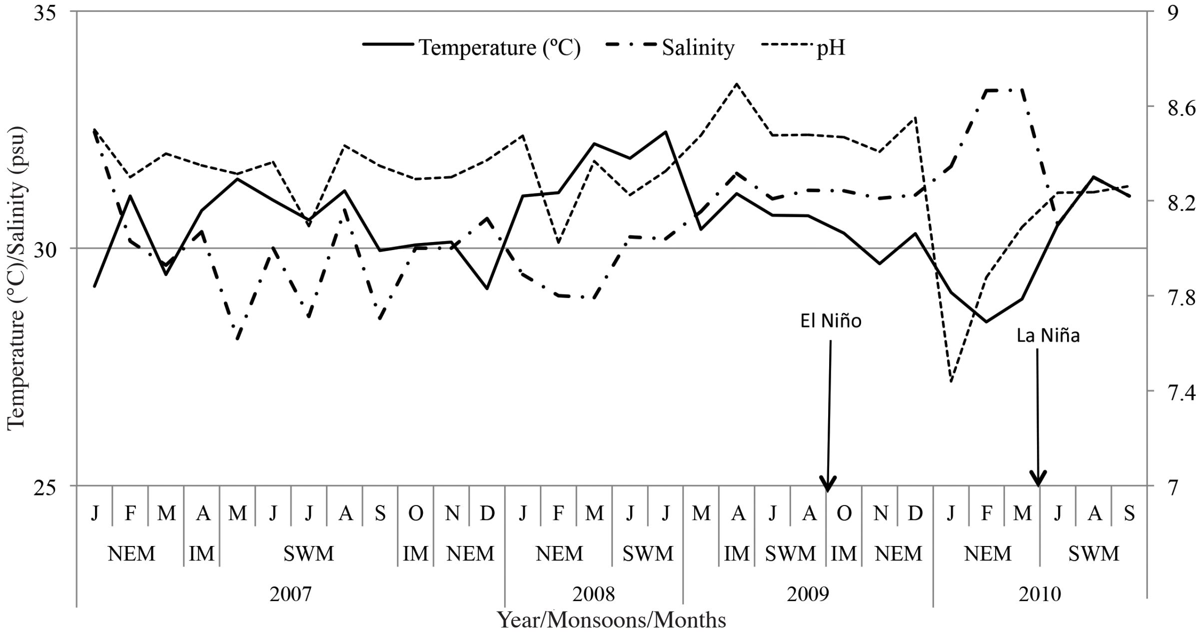

FIGURE 8. Salinity, pH and temperature recorded at the study area from 2007 to 2010

bloom event while other physicochemical parameters (pH, temperature, salinity and dissolved oxygen) were more or less the same. Statistical analysis supported the positive contribution of nutrient towards the bloom formation. It is to be noted that the variations of physicochemical parameters (or the ranges) in the tropics are not as significant as in the temperate regions. However, the right combination of these parameters is needed to promote algal bloom. Study conducted by Anton et al. (2008) on *C. polykrikoides* in the same area has also pointed out that nutrients namely NO_3^- and PO_4^{3-} were important factors in triggering the blooms. The role of nutrients in causing *C. polykrikoides* blooms has also been well-defined by other researchers (Lee & Lee 2006; Lee 2006; Tomas & Smayda 2008). The time lag shown in this study indicated that bloom will not occur immediately after rain. But, an ample time is needed for appropriate environmental conditions to develop including physical and chemical factors and nutrients level. In the coastal area of Wando and the East Sea, Korea, high solar radiation was considered one of the important factors in the proliferation of *C. polykrikoides* besides nutrients (Lee & Lee 2006). This suggests that the availability of sunshine after heavy rain is crucial to trigger *C. polykrikoides* to bloom.

In 2009 especially in the second half of the year, El Niño climate conditions continued to be observed across the equatorial Pacific. Warmer than normal, ocean heat content persisted across the central and eastern equatorial Pacific. The trade winds were weaker than normal for much of December 2009 and the SOI continued to be negative and at levels typical of El Niño (i.e. –7). During the El Niño occurrence of *P. bahamense* var. *compressum* dominated the study area. Salinity was high during this period whereas pH was low. *P. bahamense* var. *compressum* is a tropical species and has been reported to reproduce better in high salinity and temperature (Azanza & Taylor 2001). This may explain the reason that this species dominated the area instead of *C. polykrikoides* during this mild El Niño.

Statistical analysis support that *C. polykrikodes* preferred high temperature, pH and low salinity. Maclean (1989) has also reported that El Niño events triggered the bloom of *P. bahamense* var. *compressum* at one place but not the other and suggested that the different degree of El Niño caused these discrepancies. *Prorocentrum minimum* dislikes high turbulence and during El Niño event, a low number of blooms were recorded (Shaw et al. 2010). Hallegraeff (2010) suggested that climate change has different influences to different species of phytoplankton. This suggests that the presence or absence of *P. bahamense* var. *compressum* and *C. polykrikoides* during this event is determined by several factors including species behaviour and their specific requirement that may differ depending on the environmental conditions.

In April 2010, the situation changed to La Niña climate conditions that strengthened across the equatorial Pacific until September 2010. The SOI reached its highest monthly value since November 1973. It was obvious that widespread heavy rain and floods dominated in the western equatorial Pacific region during the last quarter of 2010. During La Niña, almost no blooms of these species were recorded. Only *P. bahamense* var. *compressum* occurred in cell density of less than 10^3 cells/L. The continuous heavy rain seemed to have depressed the formation of bloom by other species. It has been well-documented that rain increased the nutrient concentrations and finally promoted algal growth. Although this statement is true, only the discrete good rain followed by abundant sunshine is believed to be a must to generate HAB blooms. But, a right combination of factors (salinity, temperature, irradiance and nutrients) are needed by the algae to form a bloom. Study by Lenning et al. (2007) suggested that episodic severe weather conditions are important to enhance the phytoplankton population. However, continuous rain is believed to hamper the blooms formation.

CONCLUSION

In Kota Kinabalu coastal areas, during the normal weather condition, *C. polykrikoides* occurred in both monsoons but more blooms recorded during NEM. The occurrence of *C. polykrikodes* was recorded after 1 to 2 days of rain and this is believed to be connected to high concentration of NO_3^- and PO_4^{3-}. During El Niño period, *P. bahamense* var. *compressum* dominated the coastal areas compared to *C. polykrikoides*. But in La Niña period, neither *P. bahamense* var. *compressum* nor *C. polykrikoides* bloom was recorded. These suggest that the prolonged unusual weather conditions with continuous rain provide unsuitable conditions for both species to bloom. Although rain has been reported to bring nutrient through run-off, other factors such as physical and chemical factors, circulation of the sea and weather conditions must be at optimum condition in order to promote bloom. These findings are important in monitoring HAB species in Kota Kinabalu coastal areas so that better strategies in managing the HAB can be improved.

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