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Study of Dissolved Nutrient Condition at Pulau Perhentian, Terengganu

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ABSTRACT

This study compares the distribution of dissolved nutrients (NO_3^- and PO_4^{3-}) between two seasons (pre-monsoon and post-monsoon) in Pulau Perhentian, Terengganu. The concentration of dissolved PO_4^{3-} was found to be 16 to 83 times higher during the post-monsoon period (April 2015) compared to the pre-monsoon period (October 2014). On the other hand, the concentration of dissolved NO_3^- was two (2) to three (3) times higher during the post-monsoon period (April 2015) compared to the pre-monsoon period (October 2014). These nutrients' inputs were converted from P limitation condition during the pre-monsoon period to N limitation condition during the post-monsoon period at our study area. The results of this study suggest that the Northeast monsoon plays an important role in influencing the distribution of dissolved nutrients between seasons in Pulau Perhentian. It is thought that during the post-monsoon period, a considerable input of nutrients from bottom water is responsible for increasing dissolved nutrients in surface water, in particular PO_4^{3-}.

Keywords: Dissolved nutrients, Monsoon, N-limitation, P-limitation, seawater

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INTRODUCTION

Dissolved nutrients in seawater are essential for phytoplankton growth (Malone et al., 1996) and are considered as one of the most important parameters in the ocean environment (Mohamed & Amil, 2015), as well as for reproduction and metabolic activities of living beings. Knowledge of

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seasonal growth-rate responses of coastal phytoplankton communities to increasing nutrient loading offers insights into the potential effects of eutrophication on energy transfer within the ecosystem. It also provides a tool for establishing ecologically relevant management strategies (Olson et al., 2001). High rates of nutrient supply to these environments frequently enhance phytoplankton growth and biomass, and increase the rate of organic matter loading (Smith & Bennett, 1999). The rate of nutrient supply is subject to many factors, including human activities, which add to the variability and uncertainty of the nutrient budget of its zone (Rabouille et al., 2001).

The relative concentrations of N and P have been used to estimate which of these nutrients is limiting the growth of phytoplankton in aquatic systems. The approach is simple and easy to use provided that data exists on N and P concentrations. However, interpretation of the results should be undertaken with caution as the N:P ratio may not correctly indicate the limiting nutrient of the system. Redfield (1934, 1958) argued that marine phytoplankton contains a molecular C:N:P ratio of 106:16:1 (50:7:1 by weight), and application of the ratios has become widespread not only in marine, but also in freshwater phytoplankton studies. A departure from this ratio has been assumed to imply nutrient deficiency. In such a case, there is not only sub-optimal growth of phytoplankton, but also sub-standard food resources for primary consumers of phytoplankton.

It is known that the nutrient condition is not constant but varies according to seasonal and environmental conditions. Previous studies reported that a mass N:P ratio above 17 indicates P limitation while a ratio below 10 is N limitation. Values between 10 and 17 indicate that either of the nutrients may be limiting (Forsberg & Ryding, 1980; Hellström, 1996). A recent study by Adiana et al. (2014) concerning the South China Sea off peninsular Malaysia suggested that the climatic changes between Northeast monsoons had a major influence on metal partitioning as well as affecting the metal's distribution in the waters off the southern Terengganu coast. It drives the mixing and transport that determine upper ocean structure; where metals are carried to the surface by water mixing. These phenomena may supply nutrients into surface water to support the growth of phytoplankton in the area. In coastal areas where water mixing is seasonal or intermittent, the nutrient content of the surface waters may show marked fluctuations and may actually increase during the season of monsoon events.

In addition, a previous study by Mohamed and Amil (2015) found a lack of dissolved nutrients during the pre-monsoon event (October 2014) at Pulau Perhentian. A dramatic growth of phytoplankton biomass in the incubation bottles was recorded when enriched with a combination of nitrogen (N), phosphorus (P) and carbon (C) as well as exposure to sunlight for three days. These results suggested that during the pre-monsoon period, phytoplankton were living in a low-nutrient condition which could possibly be due to a monsoon event. However, this study was only based on nutrient enrichment incubation analysis. Further comprehensive study is needed to evaluate the impact of a Northeast monsoon event upon the condition of nutrients in Pulau Perhentian. For that reason, this study aims to observe and examine the temporal and spatial distribution of dissolved NO_3^- and PO_4^{3-} in Pulau Perhentian during pre- and post-monsoon events. Findings from this study are important in order to understand a possible relationship between dissolved nutrient condition and phytoplankton growth in the area.

MATERIALS AND METHODS

Seawater Sampling

Samplings were carried out in October 2014 (pre-monsoon) and April 2015 (post-monsoon) at Pulau Perhentian, Terengganu (Figure 1). Seawater profile samples were collected by using Van Dorm water sampler and filled into 1.0 L low-density polyethylene (LDPE) bottles. The 1.0 L seawater samples were collected at five to six different depths from each station for nutrients and trace element analysis after filtration and acidifying (trace element analysis) procedures. Seawater samples of 10.0 L in the surface layer (3 m depth) were collected at Station 1 for nutrient enrichment incubation analysis.

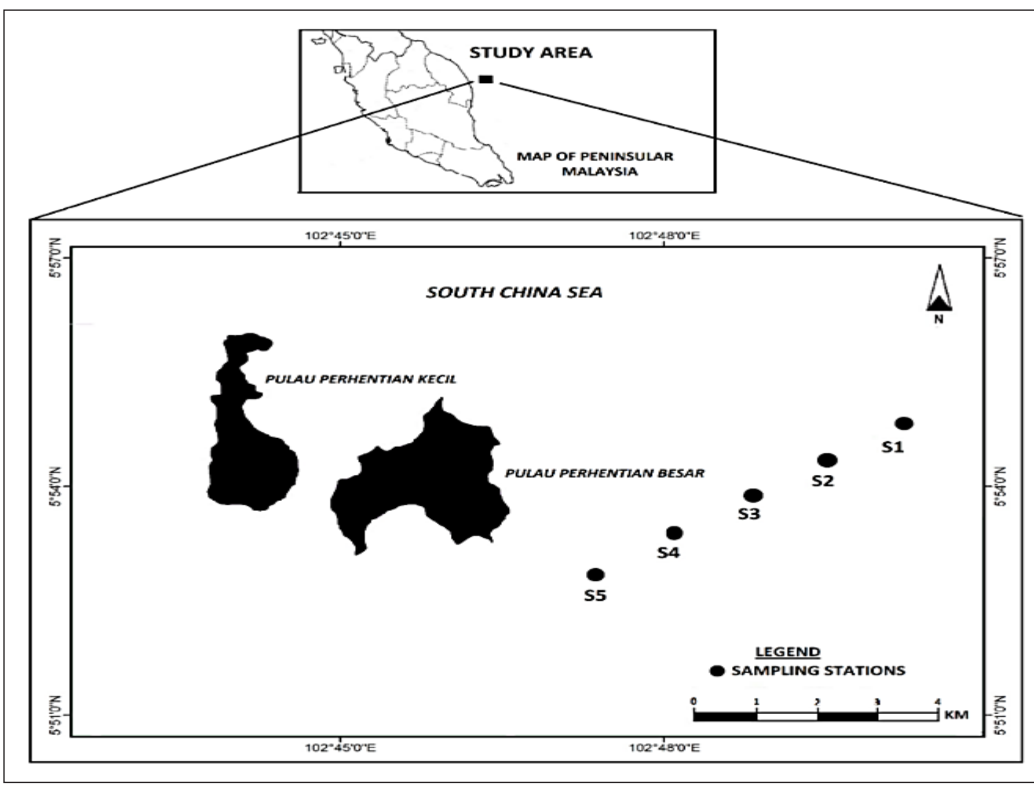


Figure 1. Map showing the location for each of the selected stations during pre-monsoon and post-monsoon sampling at Pulau Perhentian

In-situ Measurements

In-situ parameters for each seawater sample were measured by using: SCT YSI Model 30; YSI Model 54 conductivity meter; Thermo Orion AQ 4500 turbidity meter; and Thermo Orion 230A Plus pH meter. All samples (1.0 L) were filtered with 0.45µm pore size of filter paper, for further nutrient analysis in the laboratory field.

Nutrients Analysis

Nutrient analysis was performed with the USEPA method. The concentration of dissolved nitrate (NO_3^-) and phosphate (PO_4^{3-}) were measured by adding NitraVer 5 (range of detection: 0.3-30.00 mg/L) and PhosVer 3 (range of detection: 0.02-2.50 mg/L) Reagent Powder Pillow (HACH) into 10.0 mL seawater samples. The measurement was conducted using an SHIMADZU HACH DR 2800 spectrophotometer. Distilled water was used as a blank solution.

RESULTS AND DISCUSSION

The vertical profile for in-situ parameters such as temperature, dissolved oxygen, salinity, pH and turbidity during pre-monsoon and post-monsoon events are shown in Tables 1 and 2, respectively. All the parameters' horizontal and vertical profiles showed variations in their spatial distribution in the water column (Figure 2).

Table 1
In-situ parameters and concentration of nutrients at Pulau Perhentian, Terengganu during pre-monsoon event (October 2014)

St.	Depth (m)	In situ parameters						Concentration (mg/L)		
		pH	Temp. (°C)	Cond. (uS/cm)	Sal. (ppt)	DO (mg/L)	Turb. (NTU)	PO_4^{3-}	NO^{3-}	N:P
1	3	7.19	29.90	52.30	31.50	7.53	0.10	0.02 ± 0.00	1.52 ± 0.10	76
	6	7.84	29.80	52.50	31.60	6.38	0.02	0.12 ± 0.00	2.94 ± 0.12	25
	15	7.80	29.90	53.10	31.90	7.46	0.00	0.11 ± 0.02	2.83 ± 0.00	26
	20	7.84	29.80	53.20	31.90	6.66	0.00	0.14 ± 0.00	2.51 ± 0.17	18
	30	7.84	29.50	53.20	31.80	6.80	0.01	0.11 ± 0.00	2.54 ± 0.00	23
2	3	7.86	29.60	52.50	31.50	8.68	0.05	0.06 ± 0.02	2.23 ± 0.10	37
	10	7.94	29.60	53.30	31.90	8.30	0.00	0.04 ± 0.01	2.26 ± 0.38	57
	20	7.96	29.60	53.30	31.90	8.34	0.00	0.04 ± 0.00	1.77 ± 0.12	44
	30	7.66	29.60	53.50	32.10	8.07	0.03	0.02 ± 0.00	2.01 ± 0.06	100
3	3	7.68	29.40	52.50	31.50	6.89	0.04	0.04 ± 0.03	1.04 ± 0.60	26
	10	7.66	29.50	53.30	31.90	7.34	0.04	0.04 ± 0.00	1.34 ± 0.00	34
	20	7.65	29.60	53.40	32.00	7.75	0.03	0.03 ± 0.00	1.19 ± 0.06	40

Table 1 *(continue)*

St.	Depth (m)	In situ parameters						Concentration (mg/L)		
		pH	Temp. (°C)	Cond. (uS/cm)	Sal. (ppt)	DO (mg/L)	Turb. (NTU)	PO_4^{3-}	NO^{3-}	N:P
4	3	7.91	29.30	52.80	31.70	6.43	0.00	0.19 ± 0.00	1.14 ± 0.00	6
	10	7.45	29.40	53.40	32.00	6.78	0.00	0.26 ± 0.00	1.59 ± 0.06	6
	20	7.32	29.50	53.30	31.99	6.92	0.00	0.25 ± 0.00	1.30 ± 0.00	5
5	3	7.82	29.10	52.70	31.70	5.90	0.06	0.23 ± 0.01	0.73 ± 0.00	3
	15	7.36	29.30	52.90	31.80	6.17	0.05	0.21 ± 0.02	1.85 ± 0.23	9

Table 2
In-situ parameters and concentration of nutrients at Pulau Perhentian during Post-monsoon event (April 2015)

St.	Depth (m)	In situ parameters						Concentration (mg/L)		
		pH	Temp. (°C)	Cond. (uS/cm)	Sal. (ppt)	DO (mg/L)	Turb (NTU)	PO_4^{3-}	NO^{3-}	N:P
1	3	8.25	29.80	28.70	31.30	5.90	0.08	1.67 ± 0.29	4.33 ± 2.89	3
	6	8.20	29.90	28.70	31.10	5.90	0.04	1.00 ± 0.00	6.00 ± 0.00	6
	15	8.22	29.90	22.90	31.10	5.90	0.00	3.00 ± 0.02	6.17 ± 2.89	2
	20	8.19	29.90	48.30	31.40	5.90	0.06	2.50 ± 0.00	4.00 ± 0.00	2
	30	8.21	29.90	31.40	31.30	5.90	0.06	1.00 ± 0.00	10.83± 2.89	11
2	3	8.28	30.00	47.90	31.30	5.86	0.06	1.00 ± 0.00	7.50 ± 0.00	8
	10	8.22	30.00	47.70	31.00	5.86	0.02	3.50 ± 0.00	4.00 ± 0.00	1
	20	8.25	30.00	47.80	31.00	5.86	0.02	1.83 ± 0.58	5.00 ± 0.00	3
	30	8.22	30.00	48.00	31.20	5.86	0.11	3.00 ± 0.00	9.00 ± 0.00	3
3	3	8.28	30.00	47.80	31.00	4.37	0.06	0.50 ± 0.00	7.50 ± 0.00	5
	10	8.27	30.00	43.80	31.00	4.37	0.06	1.00 ± 0.00	6.50 ± 0.00	7
	20	8.23	30.00	48.00	31.30	4.37	0.09	2.50 ± 0.00	3.50 ± 0.00	1
4	3	8.26	33.00	47.50	30.80	5.39	0.04	0.50 ± 0.00	8.00 ± 0.00	16
	10	8.28	33.00	47.70	30.90	5.39	0.01	0.83 ± 0.20	9.33 ± 0.06	11
	20	8.28	33.00	47.80	31.00	5.39	0.14	1.00 ± 0.00	6.00 ± 0.00	6
5	3	8.32	29.00	47.90	31.10	6.37	0.22	0.50 ± 0.01	5.50 ± 0.00	11
	15	8.29	29.00	48.00	31.10	6.37	0.13	0.50 ± 0.01	6.50 ± 0.00	13

Surface Physicochemical Characteristics (3 m Depth)

During pre-monsoon sampling activity, the surface water temperature was found to vary between 29.1°C and 29.9°C as highlighted in Table 1 and Figure 2b. However, it was found to be slightly warmer during the post-monsoon sampling activity with a temperature range between 29.0°C and 33.0°C (Table 2). The low temperature readings recorded during the pre-monsoon period could be attributed to strong land sea breezes and precipitation as suggested by Govindasamy et al. (2000).

Figure 2(c) shows that the surface seawater salinity levels between the stations were constant during pre-monsoon sampling (31.5 to 31.7 ppt) as opposed to a high variability of salinity recorded during a post-monsoon event (30.8 to 31.3 ppt). However, maximum salinity reading was recorded during the pre-monsoon period while minimum reading was recorded during the post-monsoon period. According to Saravanakumar et al. (2008), a high salinity value during the pre-monsoon period might be due to: low rainfall; the absence of river discharge; tidal mixing; and dominance of neritic water from the open sea.

The pH of surface seawater was found to be between 7.19 and 7.91 as shown in in Table 2 and Figure 2(a) during the pre-monsoon period, and between 8.25 and 8.32 during a post–monsoon event. It was discovered that the surface seawater at the stations remained alkaline during both sampling activities. The different in pH between both seasons can be attributed to several factors such as: removal of CO_2 by photosynthesis through bicarbonate degradation; reduction in salinity and temperature; and decomposition of organic matter (Rajasegar, 2003). Maximum pH was observed during the post-monsoon period, and the minimum was observed during the pre-monsoon season. It followed a trend similar to that of surface temperature. Statistical analysis revealed that pH has a highly significant negative correlation with rainfall and a positive correlation with water temperature, but dissolved oxygen has an inverse relationship with pH (Anitha & Kumar, 2013).

The distribution of surface dissolved oxygen showed as being higher during the pre-monsoon event than the post-monsoon event. The range of dissolved oxygen was 5.90-8.68 mg/L (Table 1, Figure 2(d)) and 4.37-6.37 mg/L (Table 2, Figure 2(d)) during pre-monsoon and post-monsoon sampling, respectively. In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter (Granier et al., 2000), and physicochemical properties of water (Aston, 1980).

Turbidity values varied from 0.00-0.10 NTU (Table 1, Figure 2(e)) and 0.04-0.22 NTU (Table 2, Figure 2(e)) during pre-monsoon and post–monsoon events, respectively. High turbidity was recorded during the post-monsoon period and minimum during the pre-monsoon period. This could be attributed to an increase of wave action during the post-monsoon event due to the northerly wind and the current prior to the onset of the Northeast monsoon. This would result in turbulent conditions in the coastal waters favoring the resuspension of the bottom sediment due to stirring action that causes low water transparency (Nixon, 1988).

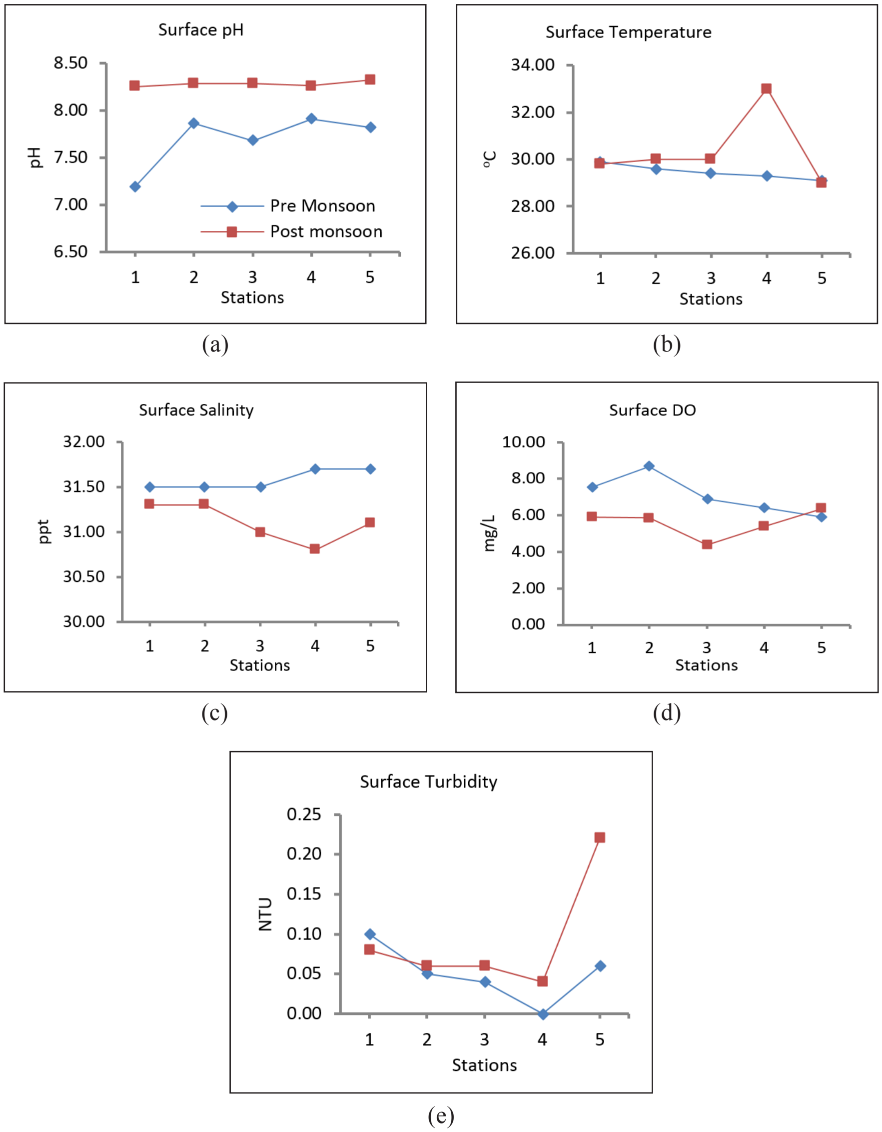
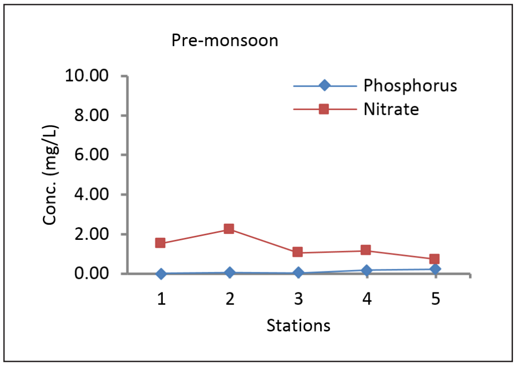


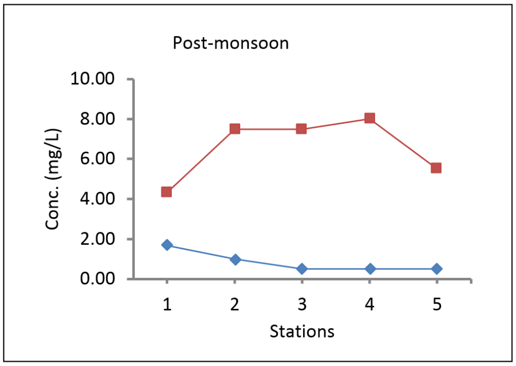
Figure 2. The surface in-situ parameters at selected stations during pre-monsoon and post-monsoon sampling at Pulau Perhentian: (a) surface pH; (b) surface temperature; (c) surface salinity; (d) surface DO; and (e) surface turbidity

Nutrient distribution at surface water (3 m depth). The distributions of dissolved NO_3^- and PO_4^{3-} in surface water at Pulau Perhentian during both monsoon events are shown in Figure 3. During the pre-monsoon event, surface-dissolved PO_4^{3-} concentration was found to decrease with increasing distance from the Pulau Perhentian.

The highest concentration was recorded at St. 4 (0.19±0.00 mg/L) (Table 1) while the lowest concentration was recorded at St. 1 (1.52±0.10 mg/L) (Table 1). On the other hand, during the post-monsoon event, the surface distribution of dissolved PO_4^{3-} was higher at



(a)



(b)

Figure 3. The surface nutrient concentration at selected stations during (a) pre-monsoon and (b) post-monsoon sampling at Pulau Perhentian, Terengganu

St. 1 (1.67±0.29 mg/L) (Table 2) and St. 2 (1.00±0.00 (Table 2) compared to St. 4 and 5. Interestingly, the surface dissolved NO_3^- was found to be higher than dissolved PO_4^{3-} for both seasons. During the pre-monsoon event, as opposed to the trend observed for dissolved PO_4^{3-} mentioned earlier, surface dissolved NO_3^- was found to increase with increasing distance from the Pulau Perhentian. The highest surface concentration of dissolved NO_3^- was recorded at St. 2 (2.23±0.10 mg/L) (Table 1) while the lowest concentration of dissolved NO_3^- was recorded at St. 5 (0.73±0.00 mg/L) (Table 1).

The surface distribution of disolved NO_3^- and PO_4^{3-} was observed to change significantly during the post-monsoon period. In contrast to pre-monsoon trend distribution of dissolved PO_4^{3-}, the post-monsoon distribution of dissolved PO_4^{3-} was found to increase with increasing distance from the Pulau Perhentian. The highest concentration of dissolved PO_4^{3-} was recorded at St. 1 (1.67±0.29 mg/L) (Table 1) while the lowest concentration of dissolved PO_4^{3-} was recorded at St. 3, 4 and 5 (0.50±0.00 mg/L) (Table 1). Conversely, the post-monsoon surface distribution of dissolved NO_3^- was found to decrease with increasing distance from the Pulau Perhentian, as opposed to observations made earlier during the post-monsoon period. The highest concentration of dissolved NO_3^- was recorded at St. 4 (8.00±0.00 mg/L) (Table 2) while the lowest concentration of dissolved NO_3^- was recorded at St. 1 (4.33±0.23 mg/L) (Table 2).

These results suggested that both concentrations of dissolved NO_3^- and PO_4^{3-} were found to be higher during the post-monsoon compared to the pre-monsoon event. For example, the concentrations of dissolved PO_4^{3-} were 83 times higher during the post-monsoon period than during the pre-monsoon period at St. 1. Similarly, the concentrations of dissolved PO_4^{3-} were 16 times higher during the post-monsoon period than during the pre-monsoon period at St. 2. On the other hand, the rate of change for concentrations of dissolved NO_3^- is not as high as that of dissolved PO_4^{3-}. For example, the concentrations of dissolved NO_3^- were twice as high during the post-monsoon period than during the pre-monsoon period at St.1. Similarly, the concentrations of dissolved NO_3^- were three times higher during the post-monsoon period than during the pre-monsoon period at St.2. This observation highlighted the influence of the Northeast monsoon on dissolved NO_3^- and PO_4^{3-} concentration in surface water. The seasonal Northeast monsoon brings a huge input of dissolved PO_4^{3-} into surface water at Pulau Perhentian.

Nutrients Distribution Throughout Water Column

The vertical profiles for dissolved NO_3^- and PO_4^{3-} during both monsoon events at all stations are highlighted in Table 1 and Figure 4. In general, it can be observed that the concentration of dissolved NO_3^- was higher than dissolved PO_4^{3-} along the water column. Furthermore, both concentrations of dissolved NO_3^- and PO_4^{3-} are also recorded as being higher during the post-monsoon period than during the pre-monsoon period. For example, the concentrations of dissolved NO_3^- were between 1.67±0.29 and 1.00±0.00 mg/L (Table 1) while the concentrations of dissolved PO_4^{3-} were between 1.52±0.10 to 2.54±0.00 mg/L (Table 1) at St. 1 during the pre-monsoon event. During the post-monsoon event, the concentrations of dissolved NO_3^- decreased to between 1.00±0.00 and 3.00±0.02 mg/L (Table 2) while the concentrations of dissolved PO_4^{3-} increased to between 4.00±0.00 and 10.83±2.89 mg/L (Table 2) at the same station.

In addition, the profile for both dissolved NO_3^- and PO_4^{3-} shows a nutrient-like profile during the pre-monsoon event throughout the water column as shown in Figures 4(a) and 4(b) below. Both figures highlight the depletion of nutrients at surface layer (3 m depth) and maximum concentration at 6 m depth. Below 6 m depth, their concentrations converged to constant values with column during the pre-monsoon event (Oct. 2014) and the post-monsoon (April 2015) event at Pulau Perhentian.

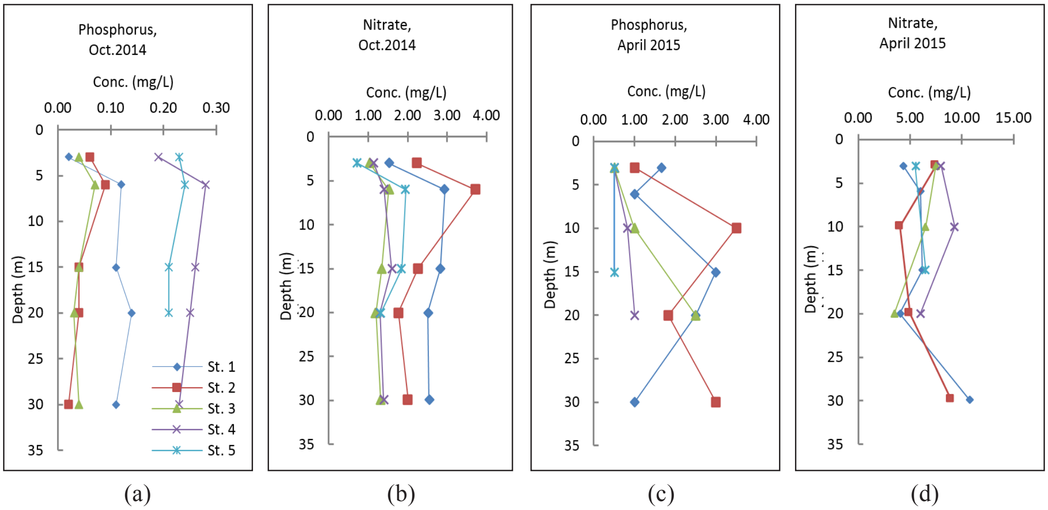


Figure 4. Profile concentration of: (a) phosphate (PO_4^{3-}), October 2015; (b) nitrate (NO_3^-), October 2014; (c) phosphate (PO_4^{3-}), April 2015; and (d) nitrate (NO_3^-), April 2015 in wayer

For example, at St.1, the concentration of dissolved PO_4^{3-} was 0.02±0.00 mg/L (Table 1) at surface layer and increasing to 0.12±0.00 mg/L (Table 1) at 6 m depth before it decreased to a constant concentration below 30 m depth. Similarly, at the same station, the concentration of dissolved NO_3^- was 1.52±0.10 mg/L (Table 1) at surface layer and increased to a maximum concentration 2.94±0.12 mg/L (Table 1) at 6 m depth before decreasing to a constant concentration below 30 m depth. A similar profile between both micronutrients throughout the water column suggested a similar process that influences their distributions in the water column during the pre-monsoon period. This indicated the active dissolved nutrients' uptake by phytoplankton (Bruland & Lohan, 2004) and resulted in the depletion of dissolved PO_4^{3-} and NO_3^- at the surface layer. Nitrate and phosphate concentrations increase with depth, as remineralisation of sinking particulate matter. This remineralisation process (which is the process of degradation of the dead phytoplankton) sinks to the deeper layer and undergoes nitrification, which returns the N in the form of particulate into dissolved nitrate again (Sigman et al., 2009).

In contrast with the pre-monsoon event, the vertical profile for both micronutrients shows unclear profiles and higher concentration throughout the water column during the post-monsoon event as highlighted in Figures 4(c) and 3(d). The concentration of dissolved PO_4^{3-} profile at station 1 was 1.67±0.29 mg/L (Table 2) in the surface layer before decreasing to 1.00±0.00 mg/L (Table 2) at 6 m depth and increasing again to maximum concentration 3.00±0.02 mg/L (Table 2) at 15 m depth. Following this, it then decreased again to minimum concentration 1.00±0.00 mg/L (Table 2) at 30 m depth. An inconsistent profile was also observed for dissolved NO_3^-, which recorded a maximum concentration 10.83±2.89 mg/L (Table 2) at 30 m depth as shown in Fig. 4d). These results seem to indicate the existence of water mixing in the water column during the post-monsoon period.

It is a known fact that the east coast of peninsular Malaysia is strongly influenced by seasonal monsoon winds. These winds provide energy for vertical mixing and force large-scale resuspension of surface sediment during the Northeast monsoon. Recorded measurement of the turbidity, salinity and conductivity profile during both monsoon events at St. 1 as depicted in Figure 5 could explain the condition for the water column at Pulau Perhentian between both seasons. As can be observed in the figure, the measured parameters showed an unclear profile throughout the water column during the post-monsoon period, as opposed to pre-monsoon distributions which were more stable with clear trends. For example, during the pre-monsoon period, turbidity was found to be higher in surface water (0.10 NTU) before decreasing with depth to a constant turbidity (0.00 - 0.02 NTU). In contrast, during the post-monsoon period, the turbidity was highest at the surface 0.08 NTU before reducing to 0.00 NTU at 15 m depth and subsequently increasing again to a constant turbidity at 30 m.

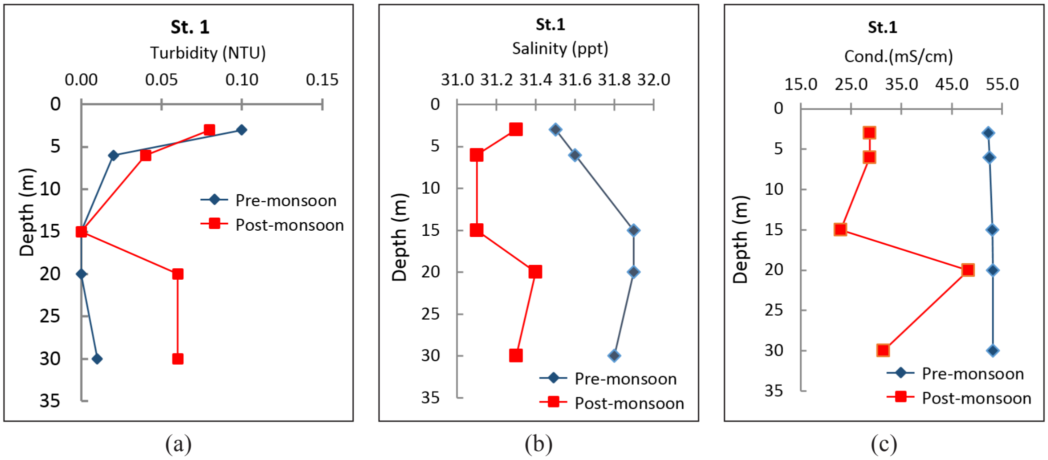


Figure 5. Profile of (a) turbidity (NTU), (b) salinity (ppt) and (c) conductivity (mS/cm) throughout the water column in October 2014 and in April 2015 at St.1 Pulau Perhentian. An unstable profile of turbidity, salinity and conductivity was observed throughout the water column during the post-monsoon event

These results suggested that the influence of the Northeast monsoon into Pulau Perhentian not only affected the distribution of dissolved nutrients in surface water but also throughout the water column. The distribution of dissolved nutrients during the pre-monsoon period was affected by an uptake process at surface layer and remineralization in a deeper layer. However, during the post-monsoon period, their concentration was more affected by vertical mixing in the water column. Consequently, an input of nutrients to the surface water at St. 1 and St. 2 during the post-monsoon event might be the result of mixing and forcing arge-scale resuspension of surface sediment rich in N and P, as suggested by Broecker and Peng (1982). A huge input of nutrients into surface water might be issued with a limiting factor (Capone et al., 1997; Falkowski, 1997) that controls primary production. The effect of input to the production is an essential study in order to understand the condition of nutrients between both seasons.

Nutrients' Condition

The ratio of N:P at surface layer (3 m depth) showed the different pattern of ratio distribution between the pre-monsoon and post-monsoon events as highlighted in Figure 6(a). During the pre-monsoon event, the wide range of N:P ratio was observed, between 3 recorded at St. 5 and 76 recorded at St. 1. This means the ratio increased as distance from the island increased. However, during the post-monsoon event, the ratio was more consistent where its ratio ranged only between 3 recorded at St. 1 and 16 recorded at St. 4, which was the highest ratio recorded.

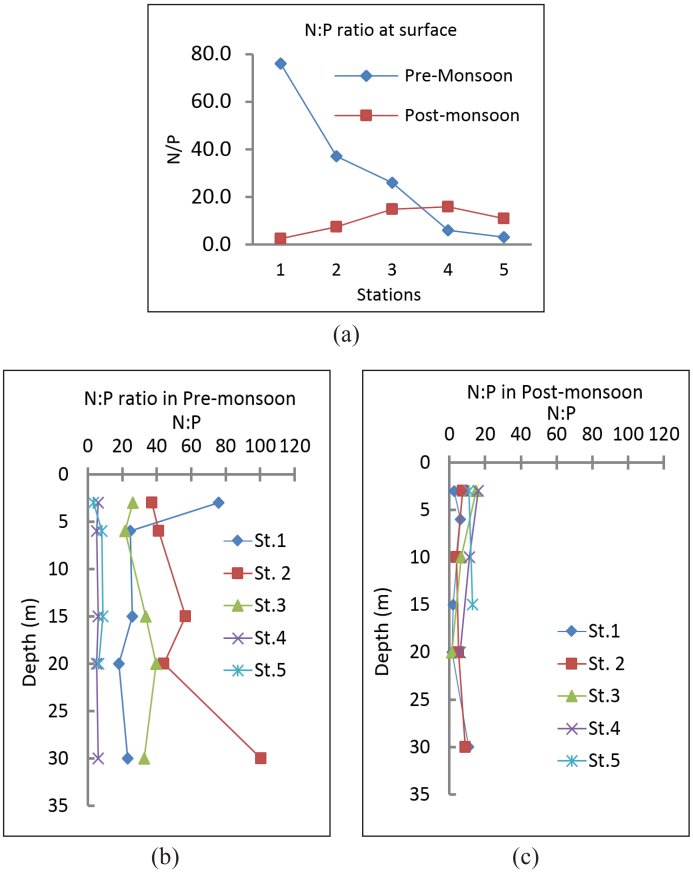


Figure 6. The horizontal (a) and vertical distribution of N:P ratio at our stations during (b) pre-monsoon and (c) post-monsoon events

According to Hecky and Kilham (1988), ecosystems with N:P molar ratios less than the average required cellular ratio of 16:1 were generally N-limited and those with ratios >16:1 were P-limited. Therefore, it could be suggested that, during the pre-monsoon event, low concentrations of dissolved PO_4^{3-} and NO_3^- in surface water resulted in the existence of P-limitation condition at stations further away from Pulau Perhentian, St. 1, 2 and 3. Conversely, N-limitation condition was recorded at stations nearer to the island (St. 4 and 5) during the pre-monsoon period and at all of the stations during the post-monsoon period. This indicated that St. 1, 2 and 3 were in P-limitation condition during the pre-monsoon period and changed to N-limitation condition during the post-monsoon period. The transformation between both conditions was reported previously by McComb et al. (1981) in Western Australia.

The presence of P-limitation condition (N:P >16) at St. 1, 2 and 3 during the pre-monsoon event might be explained by low concentrations of dissolved PO_4^{3-} due to active biological uptake by phytoplankton. In fact, P-limitation has also been observed along:

the upper Chesapeake Bay (Boynton et al., 1982); the Peel-Harvey estuaries (McComb et al., 1981); the Mediterranean Sea (Bonin et al., 1989); and in Norwegian waters (Paasche & Erga, 1988). According to Harrison et al. (1986), the P-limitation could be attributed to the growth of phytoplankton (mainly diatoms) which caused phosphate concentrations to drop, before nitrate concentration in seawater. In addition, due to the mode of PO_4^{3-} input into stations St. 1 to St. 5 (most likely from the island) it might be sedimented more rapidly in closer proximity to the island (Smith & Veeh, 1989). The condition could lead to frequent limitation of production by P than N, which was similarly noted in Howarth et al. (1995). P supply rate was equally limiting during this period (pre-monsoon) and the addition of P to this environment condition will elicit phytoplankton biomass stimulation (Fisher et al., 1992).

The vertical profile of N:P ratio was also less than 16 throughout the water column at St. 4 and 5 during the pre-monsoon period as shown in Figure 6(b). Its ratio was ranged between 5 and 6, and between 3 and 9 at St. 4 and 5, respectively. Moreover, the high N:P ratio (>16) was recorded throughout the water column at St. 1, 2 and 3 during the pre-monsoon period. This vertical profile of N:P ratio (>16) could indicate the existence of P-limitation not only at surface water, but also throughout the water column at St. 1, 2 and 3 during the pre-monsoon event. On the other hand, there was an N-limitation condition at most of the stations during the post-monsoon event, due to less N:P ratio (<16) at surface water and throughout the water column resulting from a huge input of PO_4^{3-}.

The existence of a P-limitation condition at St. 1, 2 and 3 during the pre-monsoon period was converted to N-limitation condition during the post-monsoon event. This conversion was also observed in previous studies (D'Elia et al., 1986; Fisher et al., 1992) that could explain the strong influence of the Northeast monsoon on PO_4^{3-} distribution rather than NO_3^- distribution at these stations. The addition input of nutrients (with a high concentration of PO_4^{3-}) during the post-monsoon period was brought up from bottom water to surface layer by water mixing due to high turbulence throughout the water column. This additional supply especially for dissolved PO_4^{3-} was lower down the N:P ratio at surface layer and throughout the water column.

In this study, the seasonal Northeast monsoon has shifted the nutrient condition from P to N limitation condition at St.1, St.2 and St.3 in Pulau Perhentian. In fact, most scientists have put their efforts into determining why this apparent shift from P limitation to N limitation occurs. Some of the more obvious reasons include: the widely-observed more efficient recycling of P; the high losses of fixed N to the atmosphere due to denitrification in coastal waters (Nixon, 1981); and the role of sulfate in recycling P in coastal sediments (Caraco et al., 1989). Based on our present data, we would suggest that this transformation of P limitation to N limitation was more likely to have been influenced by the recycling of P. This included biological uptake by phtoplankton (diatom) at surface water and water mixing throughout the water column.

CONCLUSION

This study was an initial study on nutrient condition at Pulau Perhentian, Terengganu. Our present data has suggested the existence of P limitation condition (N:P ratio >16) during the pre-monsoon period due to active biological uptake by phytoplankton. However, during the post-monsoon period, this nutrient condition was converted to the N limitation condition (N:P ratio <16) due to a huge input of dissolved nutrients, especially dissolved PO_4^{3-} from bottom water resulting from water mixing. However, future comprehensive studies are needed in order to understand the spatial and temporal nutrient condition around Pulau Perhentian, as well as to formulate the long-term strategic plan for Marine Park sustainability.

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