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A BASELINE STUDY OF TROPICAL PHYTOPLANKTON ABUNDANCE AND ITS RELATIONSHIPS TO THE ENVIRONMENTAL VARIABLES IN THE TERENGGANU RIVER ESTUARY, MALAYSIA

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Abstract: Phytoplankton is a vital and important organism as a producer of the primary food supply of the marine and freshwater food webs. This study is conducted to investigate the variability of phytoplankton abundance related to environmental variables in the Terengganu River Estuary, by using statistical analysis. Total of ten water samples were collected, of which three stations were in the estuary and seven stations were in the coastal water. A total of 124 taxa of 55 genera, belonging to six taxonomic classes were observed at the study area. The order of phytoplankton abundance was diatoms > blue-green algae > golden-brown algae > dinofalgellates > green algae > euglenoids. The phytoplankton abundance was higher in the coastal area compared to the estuary, with the maximum density 764.10 cells mL^{-1} and 157.40 cells mL^{-1} respectively. It was recorded that 10.96% of the total abundance from the data collection was registered in the estuary, while the remaining 89.04% were logged in the coastal region. The freshwater phytoplankton was dominated by golden-brown algae (Chrysophyceae), while marine phytoplankton was governed by diatoms and blue-green algae. It was observed that the water temperature and salinity were positively correlated with marine phytoplankton but negatively related to freshwater phytoplankton. High levels of water temperature and hypersalinity at the coastal region was observed to enhance the production rate in the coastal region. In contrast, the nutrients were positively related to freshwater phytoplankton, but negatively correlated to the marine phytoplankton, which results in low concentrations of nutrients in the coastal region that could be caused by intensive uptake by the abundance of marine phytoplankton. This study revealed that environmental variables are an important element in determining the phytoplankton community compositions in the tropical region.

Keywords: *Estuary, coastal water, environmental variables, nutrients, phytoplankton*

1.0 Introduction

Estuaries are the transition zones between fresh and marine water, engendering a nutrient enrichment food web system, resulting in one of the most biologically productive zones (Alsalahi *et al*., 2014; Leterme *et al*., 2011). Phytoplankton community is the basis of food web systems (Huertas *et al*., 2011), where the abundance, composition and biomass of phytoplankton communities are dependent on environmental conditions, such as temperature, salinity, light and nutrients (Shen *et al*., 2011). Generally, phytoplankton community composition as well as abundance differs along the salinity gradient with freshwater phytoplankton in low salinities whereas marine phytoplankton is in hypersaline conditions (Fambo *et al*., 2015). Changes in the sizes and species composition of phytoplankton contribute to major producers in the marine ecosystem, affecting the biogeochemical conditions (Sin *et al*., 2015). Therefore, hydro chemical studies are important for better understanding of the biological integrity of estuaries.

In the tropical regions where the magnitude of freshwater flows are higher during monsoon season, high volumes of surface runoff washed and transported out the surface nutrients and sediments from the upstream into the marine environment, which might have stimulated phytoplankton biomass (Burford *et al*., 2012; Alsalahi *et al*., 2014), leading to harmful algal blooms. It was documented that harmful algal blooms resulting in red discolorations of coastal water off South China Sea was observed in Sepanggar Bay off East Malaysia (06.00^{o}N, 114.04^{o}E), the incident occurs almost every year after the first report of the red tide in 1976 (Roy, 1977; Anton *et al*., 2000 & 2008). The study has identified the dinoflagellates as the main dominant phytoplankton group, with the highest abundance of 6,000 cells mL^{-1} and was recorded in March 2006.

Although a number of researchers have studied the phytoplankton characteristics of Malaysian estuaries and seas (Anton *et al*., 2008, Salleh *et al*., 2008; Nursuhayati *et al*., 2013), an investigation of the phytoplankton communities and their environment at the Terengganu River Estuary has not been done prior to this study. The main objective of the study was to determine possible correlations between the water quality parameters and the phytoplankton diversity and abundance. In additional, to identify any indicator between environmental variables associated with the phytoplankton community composition at the study area. The present study analyzes the physical and chemical variables such as water temperature, salinity, dissolved inorganic nitrogen (DIN) consisting of combination dissolved inorganic nitrogen (nitrite (NO_2)+nitrate (NO_3)+ammonia (NH_3)), dissolved inorganic phosphorus (DIP) and dissolved inorganic silicate (DISi). Analysis on phytoplankton community composition was also assessed to enhance future monitoring and mitigation programs. The output obtained in this study will provide baseline information on phytoplankton abundance and the relationships with environmental variables.

2.0 Materials and Methods

2.1 Study Area

The Terengganu River Estuary is created by the inflow of freshwater runoff from the Terengganu River to the South China Sea. The location of the study area was positioned at 5.34°N and 103.13°E. The study area was located at the tip of estuary breakwater (Fig. 1). A navigation channel was dredged through the river mouth with a width of 200 m and depth of 8 m. The tide at the study site is diurnal tide mixed with alternate semi-diurnal tide during the neap cycle, where the average tidal range during the spring and neap are approximately 2.50 m and 0.70 m respectively.

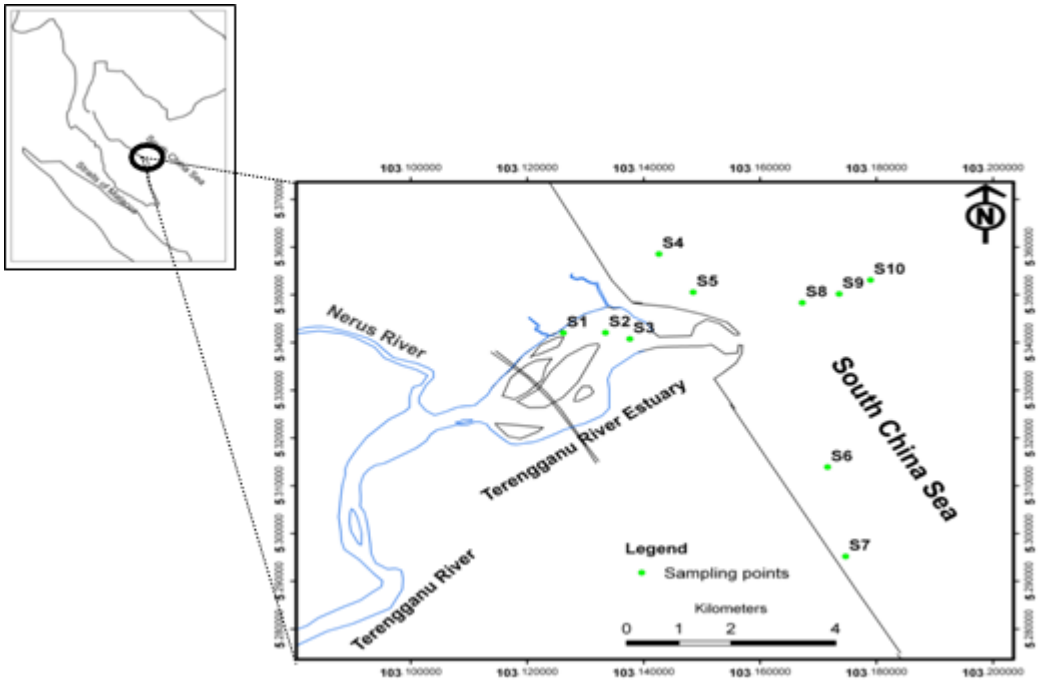

Figure 1 Sampling points at the study area

The Terengganu River basin is approximately 4,600 km^2. The study site is exposed to heavy rainfall during North-east Monsoon, with the average rainfall ranging from 200 mm to 600 mm, it occurs from the end (October) to early months (March) of the year (Suhaila and Jemain, 2009; Sultan and Shazili, 2010 and Tangang *et al*., 2012). From April to September, the average rainfall ranged from 100 mm to 125 mm and was classified as dry season. Annual fresh water discharge is approximately 10 X 10^9 m^3 year^{-1}, while the average daily discharge was 260 m^{3}s^{-1}. However, the daily freshwater

discharge at the estuary was controlled by the hydropower reservoir station located at the upstream catchment areas of the study site.

2.2 Sampling and Analytical Methods

A total of ten (10) water samples were collected, of which three were located in the estuary (S1 to S3), while the remaining seven stations (S4 to S10) were positioned in the coastal area as shown in Figure 1 and Table 1. In order to have a better explanation on the coastal area, stations S4 to S7 were categorized as nearshore stations, while S8 to S10 were named as offshore stations. The samples were drawn from the sub-surface (0.5 m below the surface) on 5 March 2012 during low water. The water samples were collected using a Van Dorn water sampler and stored in 1L pre-cleaned polyethylene bottles. Meanwhile, for the phytoplankton samples, 1L of water samples was kept in 1L pre-cleaned polyethylene and preserved with Lugol's solution. All water samples were stored in the Coleman ice-container box temperature below 4^{o}C at the time of collection and were brought to the laboratory and refrigerated in order to prevent significant changes before analysis. In situ parameters (temperature and salinity) were measured using YSI model 65. The probe was calibrated prior to sampling campaign. Nutrients like NO_2, NO_3, NH_3, DIP and DISi were measured according to the standard procedures (APHA, 2005; Grasshoff, 1999).

Table 1: Coordinates of each sampling station

Station	Latitude (N)	Longitude (E)
S1	5.342	103.126
S2	5.342	103.133
S3	5.341	103.138
S4	5.359	103.143
S5	5.351	103.149
S6	5.314	103.172
S7	5.295	103.175
S8	5.348	103.167
S9	5.350	103.174
S10	5.353	103.179

Meanwhile, the phytoplankton samples were analyzed under microscope to identify the species and their abundance, following the method by Legendre and Watt (1972). A 2 mL subsample was placed in the cylindrical counting chamber and left to settle down for at least 24 hours prior to the counting process. Then, enumeration of the replicate areas took place at a magnification of not less than 500 times, until at least 150 units of

dominant species were counted (Lund *et al*. 1958). For enumeration of rare, large species, the entire chamber is subsequently scanned and counted at low magnification. Results obtained are expressed as cells mL^{-1} for all algal taxa.

2.3 Statistical Analysis

The statistical analyses were carried out by SPSS version 17.0 statistical package. The Mann-Whitney U was performed to evaluate the differences and correlation between two independent groups due to abnormal distribution of the variables. Meanwhile, the Spearman's rank correlation was used to measure the strength of relationship between two ranked variables.

3.0 Results and Discussion

3.1 Environmental Conditions

Environmental variables for the sampling points are listed in Table 2. The physical variables, water temperature and salinity were significantly lower ($p < 0.05$) in the estuary (S1 to and S3) compared to the coastal area (S4 to S10), with the mean for estuarine mouth concentrations were 27.64 ^{0}C and 0.40 ppt while for coastal area were 29.61^{o}C and 26.18 ppt, respectively. In contrast, the nutrients levels for DIN, DIP and DISi were significantly higher ($p < 0.05$) in the estuary compared to the coastal area, with mean levels of 13.17 µM, 0.39 µM and 179.44 µM, respectively, for the estuary and 3.22 µM, 0.24 µM and 99.50 µM, respectively, for the coastal area. In the tropical region, freshwater discharge is much cooler compared to seawater, probably due to the higher volume of surface runoff, discharged out most of the saline water back to the sea during low water, resulting in low salinity levels in the estuary (Vijith *et al*., 2009). Freshwater discharge from the upstream contains higher nutrients due to natural and untreated anthropogenic effluents outflow discharged into estuarine water (DID, 2010). In addition, pollution contaminant is usually higher in the estuarine compared to the coastal water. Additionally, a portion of the nutrients in the estuary was undelivered to the seawater due to the presence of the breakwater structures at the estuarine mouth (Sin *et al*., 2015). Low nutrients concentrations in the coastal water could be due to the intensive uptake by the phytoplankton community composition (Dorgham *et al*., 2004).

Table 2: Descriptive statistics of measured variables at different station during wet season

Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Temp (^{o}C)	27.73	27.49	27.70	30.66	30.35	29.74	30.35	28.47	28.81	28.87
Sal (ppt)	0.17	0.21	0.82	30.58	26.27	25.56	26.88	23.92	25.41	24.62
DIN (µM)	12.71	10.87	15.93	5.51	0.37	0.63	1.45	4.22	5.75	4.63
DIP (µM)	0.46	0.39	0.33	0.20	0.29	0.22	0.27	0.24	0.27	0.22
DISi (µM)	170.65	184.81	182.86	88.22	105.16	51.60	86.51	167.73	146.48	51.06

Temp= water temperature; Sal= salinity; DIN=dissolved inorganic nitrogen; DIP= dissolved inorganic phosphorus; DISi= dissolved inorganic silicate

3.2 Phytoplankton composition and distribution

A total of 124 species were identified in the study area (Table 3) that were categorized into six (6) groups with eighty-two (82) species belonging to diatoms (Bacillariophyceae), sixteen (16) green algae (Chlorophyceae), twelve (12) blue-green algae (Cyanobateria), eight (8) dinoflagellates (Pyrrophyceae), five (5) euglenoids (Euglenophyceae) and one (1) golden-brown algae (Chrysophycease). The species composite for each sampling station is tabulated in Table 4a. Descriptive statistics on the number of species within the estuary (S1 to S3) and coastal water (S4 to S10) showed that euglenoids was only recorded in the estuary but was not registered in the coastal water. Maximum number of euglenoids recorded at S1 was four species. In addition, green algae, blue-green algae and golden-brown algae were significantly higher ($p < 0.05$) in the estuary compared to the coastal water, with maximum green algae (eight species) was observed at S1 and S3, while blue-green algae (nine species) at S3 and golden-brown algae (one species) at S1, S2, S3 and S6. The diatom species in the estuary and coastal water were almost similar ($p > 0.05$); however the maximum diatom (forty one species) was identified at S7. Significantly higher ($p < 0.05$) number of dinoflagellate species was recorded in the coastal water compared to the estuary with maximum dinoflagellates (six species) registered at S6. Percentage distribution of species in the respective sampling station showed that diatoms species dominated all the sampling stations in the estuary and coastal water (Fig. 2a), where 83% of the species were diatom in the nearshore (S4 to S7) and the offshore (S8 to S10) water respectively and 46% of species in the estuary water (S1 to S3). Nursuhayati *et al*. (2013) reported similar phytoplankton groups (six groups) with a total of 93 species, and diatoms (52 species) registered the most number of species in a muddy estuary in the Straits of Malacca, west coast of Peninsular Malaysia.

Table 3: Abundance of phytoplankton species (cells mL^{-1}) recorded in Terengganu River estuary

	Sampling Stations									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Bacillariophyceae										
Amphora sp.	0.7	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asterionella sp.	0.0	0.0	0.0	0.0	0.0	0.0	29.6	2.8	0.0	0.0
Asteromphalus sp.	0.0	0.0	0.0	0.0	2.3	1.2	4.9	0.1	0.8	0.0
Bacteriastrum sp.a	0.0	0.0	0.4	15.6	1.1	5.9	2.5	1.8	0.0	1.1
Bacteriastrum sp.b	0.0	0.0	0.4	24.4	7.9	2.3	9.9	2.8	4.8	1.3
Bacteriastrum sp.c	0.0	0.0	0.0	4.4	2.3	4.7	0.0	0.2	4.0	0.0
Bacteriastrum sp.d	0.0	0.0	0.0	20	1.1	2.3	7.4	0.2	1.6	0.0
Bacteriastrum sp.e	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	5.7	0.0
Chaetoceros sp.a	1.4	0.8	0.0	6.7	17.0	2.3	22.2	6.4	8.1	2.3
Chaetoceros sp.b	0.0	2.3	0.6	0.0	0.0	15.2	0.0	0.0	0.0	3.6
Chaetoceros sp.c	0.7	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chaetoceros sp.d	1.4	0.0	1.2	4.4	10.2	11.7	4.9	1.9	8.1	2.8
Chaetoceros sp.e	0.0	0.0	1.6	0.0	9.1	0.0	2.5	2.8	4.0	0.0
Chaetoceros sp.f	0.0	0.0	0.4	13.3	17	12.9	4.9	5.5	0.0	1.5
Chaetoceros sp.g	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chaetoceros sp.h	0.0	0.0	0.0	0.0	0.0	2.3	0.0	2.2	4.0	1.9
Chaetoceros sp.i	0.0	0.0	0.0	31.1	27.2	24.6	14.8	6.4	12.9	0.0
Chaetoceros sp.j	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Chaetoceros sp.k	0.0	0.0	0.0	2.2	0.0	1.2	2.5	0.0	0.0	0.0
Chaetoceros sp.l	0.0	0.0	0.0	0.0	0.0	4.7	4.9	0.0	0.0	0.0
Chaetoceros sp.m	0.0	0.0	0.0	0.0	0.0	0.0	61.7	0.0	0.0	0.0
Climacodium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0
Corethron sp.	0.0	0.0	0.0	13.3	1.1	0.0	2.5	0.0	0.0	0.0
Coscinodiscus sp.	0.0	0.0	0.0	0.0	1.1	2.3	9.9	0.2	0.0	0.0
Coscinodiscus sp.	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.1	0.0	0.0
Coscinodiscus sp.	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Coscinodiscus sp.	0.0	0.0	0.0	6.7	0.0	2.3	0.0	0.0	0.0	0.0
Cyclotella sp.	0.7	3.0	1.4	0.0	4.5	3.5	24.7	0.0	3.2	0.0
Cyclotella sp.	0.0	0.0	0.0	2.2	0.0	1.2	4.9	0.0	0.0	0.0
Cymbella sp.	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ditylum sp.	0.0	0.0	0.0	4.4	2.3	2.3	4.9	0.0	0.0	0.2
Ditylum sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Eucampia sp.	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0
Fragilaria sp.	0.0	0.0	0.6	6.7	0.0	2.3	0.0	0.0	0.0	0.0
Fragilaria sp.	0.0	0.0	0.0	17.8	0.0	0.0	0.0	0.0	0.0	0.0
Fragilaria sp.	0.0	0.0	0.0	0.0	0.0	0.0	64.2	0.0	0.0	0.0
Fragilaria sp.	0.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0
Gramatophora sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Guinardia sp.	0.0	0.0	0.0	28.9	9.1	19.9	12.3	2.8	4.8	1.5
Guinardia sp.	0.0	0.0	0.0	0.0	0.0	7	4.9	0.0	0.0	0.0
Guinardia sp.	0.0	0.0	0.0	2.2	6.8	1.2	2.5	0.0	0.8	0.0
Guinardia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0
Guinardia sp.	0.0	0.0	0.0	0.0	10.2	0.0	0.0	0.0	0.0	0.0
Guinardia sp.	0.0	0.0	0.0	2.2	0.0	0.0	2.5	0.0	0.0	0.0
Guinardia sp.	0.0	0.0	0.0	8.9	0.0	1.2	0.0	0.0	0.0	0.0

Hemiaulus sp.	0.0	0.0	0.0	31.1	9.1	2.3	4.9	0.2	1.6	0.6
Hemiaulus sp.	0.0	0.0	0.0	4.4	0.0	0.0	7.4	0.0	0.0	0.0
Hemiaulus sp.	0.0	0.0	0.0	4.4	0.0	2.3	0.0	0.0	0.0	0.0
Hemiaulus sp.	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Hemiaulus sp.	0.0	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0
Hemidiscus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Leptocylindrus sp.	0.0	0.0	0.0	28.9	13.6	12.9	0.0	0.0	0.0	0.0
Meuniera sp.	0.0	0.0	0.0	6.7	4.5	0.0	12.3	0.0	0.0	0.0
Navicula sp.	2.1	7.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Navicula sp.	0.0	0.8	1.4	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Navicula sp.	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia sp.	2.1	0.0	0.0	0.0	6.8	2.3	4.9	0.0	0.0	0.6
Nitzschia sp.	0.0	0.0	0.4	15.6	4.5	5.9	2.5	2.8	0.8	0.0
Odontella sp.	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.1	0.8	0.0
Odontella sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Odontella sp.	0.0	0.0	0.0	2.2	1.1	0.0	2.5	0.0	0.0	0.0
Odontella sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Odontella sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Odontella sp.	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Pinnularia sp.	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleurosigma sp.	0.7	0.8	0.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Pleurosigma sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Rhizosolenia sp.	2.8	1.5	0.0	0.0	0.0	2.3	2.5	0.0	0.0	0.0
Rhizosolenia sp.	0.0	0.0	0.4	0.0	4.5	3.5	7.4	2.8	8.1	2.6
Rhizosolenia sp.	0.0	0.0	0.2	6.7	2.3	1.2	0.0	0.1	0.0	0.0
Rhizosolenia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Rhizosolenia sp.	0.0	0.0	0.0	4.4	3.4	0.0	7.4	0.0	0.0	0.0
Rhizosolenia sp.	0.0	0.0	0.0	0.0	4.5	0.0	17.3	0.0	0.0	0.0
Skeletonema sp.	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surirella sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra sp.	2.1	1.5	0.6	0.0	0.0	7	12.3	1.8	0.0	0.0
Tabellariafenestrata	5.6	6.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tabellaria sp.	0.0	2.3	0.6	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Thalassionema sp.	0.0	0.0	0.0	31.1	5.7	0.0	59.3	2.5	5.7	0.4
Thalassionema sp.	0.0	0.0	0.0	13.3	31.8	19.9	27.2	0.0	0.0	0.0
Thalassiothrix sp.	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	7.3	0.0
Chlorophyceae										
Ankistrodesmus sp.	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Closterium sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Closterium sp.	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crucigeniatetrapedia	2.8	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eudorina sp.	0.7	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gonatozygon sp.	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Penium sp.	0.0	0.8	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Pleurotaenium sp.	1.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus sp.	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus sp.	1.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus sp.	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Selenastrum sp.	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spondylosium sp.	2.8	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurastrum sp.	0.7	3.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurastrum sp.	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurastrum sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyanobacteria										
Anabaena sp.	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aphanocapsa sp.	1.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chroococcus sp.	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chroococcus sp.	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oscillatoria sp.	14.6	9.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oscillatoria sp.	5.6	8.3	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oscillatoria sp.	2.8	9.1	0.8	366.7	138.5	187.6	108.7	102.8	164.7	50.0
Oscillatoria sp.	1.4	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Oscillatoria sp.	6.9	0.0	0.0	20.0	3.4	0.0	9.9	8.3	2.4	0.0
Oscillatoria sp.	2.8	2.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oscillatoria sp.	0.0	0.0	0.0	2.2	0.0	0.0	2.5	0.0	0.0	0.0
Spirulina sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrrophyceae										
Ceratium sp.	0.0	0.0	0.0	4.4	2.3	1.2	2.5	1.1	3.2	0.2
Ceratium sp.	0.0	0.0	0.0	0.0	0.0	4.7	0.0	2.2	2.4	0.4
Ceratium sp.	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.7	0.8	0.0
Ceratium sp.	0.0	0.0	0.0	2.2	7.9	12.9	12.3	2.2	2.4	0.9
Peridinium sp.	0.0	0.0	0.4	0.0	0.0	2.3	0.0	0.0	0.0	0.0
Peridinium sp.	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0
Protoperidinium sp.	0.0	0.0	0.0	2.2	0.0	0.0	2.5	0.0	1.6	0.0
Protoperidinium sp.	0.0	0.0	0.0	0.0	1.1	0.0	2.5	0.0	0.0	0.0
Chrysophyceae										
Dinobryon sertularia sp.	61.1	62.8	11.3	11.3	0.0	14.1	0.0	0.0	0.0	0.0
Euglenophyceae										
Euglena sp.	1.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Euglena sp.	0.0	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Euglena sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phacus sp.	0.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trachelomonas sp.	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The grand total of phytoplankton abundances for the sampling stations ranged from 40.10 to 764.10 cells mL^{-1} (Table 4b). The population density varied with different regions, 40.10 to 157.40 cells mL^{-1} in the estuary, 387.70 to 764.10 cells mL^{-1} in the nearshore and 72.70 to 166.80 cells mL^{-1} in the offshore regions. The study by Nursuhayati *et al*. (2013) documented that the mean density of phytoplankton in the Straits of Malacca, Malaysia varied from 73.8 to 218.0 cells mL^{-1}. Meanwhile, Thangaradjou *et al*. (2012) reported that at the southwest Bay of Bengal the population of phytoplankton at the coastal water ranged from 39.00 to 82.80 cells mL^{-1}. Comparatively, Terengganu River Estuary seemed to be more productive compared to

the southwest Bay of Bengal and muddy estuary located at the west coast of Peninsular Malaysia. It was observed that diatoms were the most abundant phytoplankton populations, constituting of 50.38% of total density in the study area, followed by blue-green algae with 40.66%, golden-brown algae with 4.89%, dinoflagellates with 2.79%, green algae with 0.96% while euglenoids formed only 0.32% of total phytoplankton density. It was recorded that 10.96% of the total abundance collected from the data campaign was registered in the estuary (S1 to S3), while the remaining 89.04% were logged in the coastal region (S4 to S10). Distribution of population densities for each sampling stations showed that diatoms and blue-green algae were the dominant groups at the study area (Fig. 2b). The result indicated that the freshwater zone was dominated by golden-brown algae with abundance decreased downstream, while coastal zone was governed by diatoms and blue-green algae (Table 4b). At the west coast of Peninsular Malaysia, Nursuhayati *et al*. (2013) stated that green algae were found to be dominant in the freshwater zone while diatoms were mostly found in the marine area. Lassen *et al*. (2004) also reported that in the Langat estuary, the dominant marine phytoplankton associated with high salinity concentrations were diatoms. Anton *et al*. (2008) documented that dinoflagellates dominated the Sepanggar Bay, off East Malaysia. While at the southwest Bay of Bengal, it was reported that diatoms species dominated the nearshore area in all the seasons (Thangaradjou *et al*., 2012). Diatoms significantly regulated the silicate for biological process and reduced the silicate levels in the water column (Satpathy *et al*., 2010; Heneash *et al*., 2015). High silicate-phosphate ratios in the study area (Table 2) probably supported the diatom domination in the marine ecosystem (Bethoux *et al*., 2002).

Table 4: Descriptive statistics of 4a: species composition and 4b: population densities (cells mL^{-1})

Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	R
DT	16.00	11.00	21.00	31.00	34.00	38.00	41.00	28.00	21.00	14.00	4a
GA	8.00	7.00	8.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	
BGA	8.00	5.00	9.00	3.00	2.00	1.00	3.00	2.00	2.00	2.00	
DIN	0.00	0.00	2.00	3.00	3.00	6.00	4.00	4.00	5.00	3.00	
GBA	1.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	
Eug	4.00	3.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
DT	44.00	28.20	14.70	366.40	234.50	200.10	496.20	49.50	85.40	20.80	4b
GA	11.20	11.40	5.40	0.00	0.00	1.20	0.00	0.00	0.00	0.00	
BGA	36.20	30.30	8.10	388.90	141.90	187.60	121.10	111.10	167.10	50.40	
DIN	0.00	0.00	0.40	8.80	11.30	27.00	19.80	6.20	10.40	1.50	
GBA	61.10	62.80	11.30	0.00	0.00	14.10	0.00	0.00	0.00	0.00	
Eug	4.90	4.60	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

DT=Diatoms, GA= green algae, BGA= blue green algae, DIN=dinoflagellates, GBA=golden-brown algae, Eug= euglenoids and R=remark

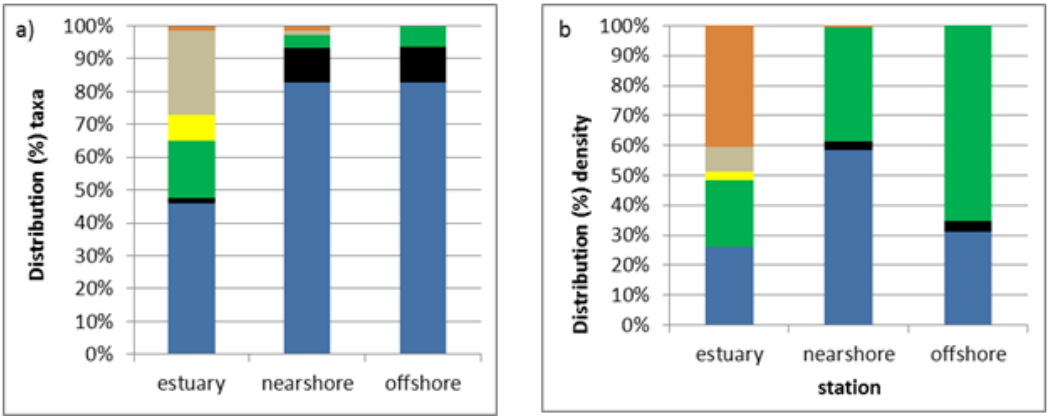

Figure 2a: percentage of species distribution & 2b: percentage of phytoplankton group distribution in each station. Blue (diatoms), black (dinoflagellates), green (blue-green algae), yellow (euglenoids), gray (green algae) and orange (golden-brown algae)

3.3 Relationship Between Phytoplankton and Environmental Parameters

Analysis through Shapiro Wilk test (Praveena *et al*., 2013) showed that salinity, diatoms, green algae, golden-brown algae and euglenoids were not normally distributed ($p<0.05$). Therefore, the Spearman's rho correlation coefficient test was performed to understand the relationship among the variables (Table 5). Surface water temperature was significantly and positively correlated with surface salinity ($r=0.95$, $p<0.01$), but negatively related to all the nutrients, namely nitrogen ($r=-0.71$, $p<0.05$), phosphorus ($r=-0.68$, $p<0.05$) and silicate ($r=-0.78$, $p<0.01$). Salinity was negatively related with nitrogen ($r=-0.67$, $p<0.01$), phosphorus ($r=-0.68$, $p<0.05$) and silicate ($r=-0.70$, $p<0.01$), indicating the importance of surface runoff nutrients into the marine water (Sin *et al*., 2015).

The water temperature was positively correlated with the marine phytoplankton, namely diatoms ($r=0.83$, $p<0.01$), blue-green algae ($r=0.83$, $p<0.01$) and dinoflagellates ($r=0.77$, $p<0.01$) but negatively related to the freshwater phytoplankton, namely green algae ($r=-0.73$, $p<0.05$), golden-brown algae ($r=-0.66$, $p<0.05$) and euglenoids ($r=-0.77$, $p<0.01$). Meanwhile, the salinity was significantly positively correlated with diatoms ($r=0.84$, $p<0.01$), blue-green algae ($r=0.83$, $p<0.01$) and dinoflagellates ($r=0.83$, $p<0.01$), while negatively correlated to green algae ($r=-0.73$, $p<0.05$), golden-brown algae ($r=-0.68$, $p<0.05$) and euglenoids ($r=-0.81$, $p<0.01$). It was observed that freshwater phytoplankton was negatively correlated to temperature and salinity, in contrast to the marine phytoplankton which was positively correlated to water temperature and salinity. The coastal region was hotter and more hypersaline compared to the river mouth (Table 2). Water temperature has the ability to enhance the phytoplankton production rates,

according to Shah *et al*. (2008), with the critical range for good productivity is 18.30 to 37.80^{o}C. Meanwhile, Kim *et al*. (2004) suggested 15 to 30^{o}C water temperature associated with saline levels of 20 to 36 ppt are the tolerances rations for dinoflagellates growth. Thus, the study site has the surface water temperature varying from 27.73 to 30.66^{o}C, indicated a good site for the phytoplankton communities to growth. However, Henesh *et al*.(2015) stated that the water temperature's fluctuations in the water column do not have great impacts on the phytoplankton groups, while salinity is the main physical variable affecting the biodiversity, and suggested that a sudden drop in salinity could incur stresses on the phytoplankton, resulting in biodiversity losses. However, the current study illustrated that water temperature and salinity are the significant factors in the formation of the phytoplankton community composition at the study site (Table 5).

Table 5: Correlations Spearman's rho between environmental variables and phytoplankton

Variables	Temp	Sal	DIN	DIP	DISi	DT	BGA	DIN	GA	GBA	Eug
Temp	1.00										
Sal	***0.95***	1.00									
DIN	***-0.71****	***-0.67****	1.00								
DIP	***-0.68****	***-0.68****	0.50	1.00							
DISi	**-0.78**	***-0.70****	***0.69****	**0.77**	1.00						
DT	**0.83**	**0.84**	***-0.66****	-0.39	-0.47	1.00					
BGA	**0.83**	**0.83**	-0.61	***-0.71****	-0.62	**0.81**	1.00				
DIN	**0.77**	**0.83**	**-0.82**	-0.55	-0.69*	**0.78**	**0.79**	1.00			
GA	***-0.73****	***-0.73****	0.59	***0.66****	***0.64****	-0.54	-0.61	-0.60	1.00		
GBA	***-0.66****	***-0.68****	0.49	0.59	0.54	-0.46	-0.50	-0.50	**0.99**	1.00	
Eug	**-0.77**	**-0.81**	**0.77**	**0.82**	**0.77**	-0.59	***-0.75****	**-0.81**	**0.90**	**0.83**	1.00

__. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Temp=water temperature, Sal=salinity, DIN=dissolved inorganic nitrogen, DIP=dissolved inorganic phosphorus, DISi=dissolved inorganic silicate, DT=Diatoms, BGA= blue green algae, DIN=dinoflagellates, GA= green algae, GBA=golden-brown algae and Eug= euglenoids

The relationship between nutrients namely, DIN, DIP and DISi with phytoplankton groups displayed that the freshwater phytoplankton was positively correlated to nutrients, but the marine phytoplankton was negatively correlated to nutrients (Table 5). The euglenoids were significantly related to all the nutrients namely DIN ($r=0.77$, $p<0.01$), DIP ($r=0.82$, $p<0.01$) and DISi ($r=0.77$, $p<0.01$). Green algae were correlated to DIP ($r=0.66$, $p<0.05$) and DISi ($r=0.64$, $p<0.05$). Diatoms were negatively correlated to DIN ($r=-0.66$, $p<0.05$), while blue-green algae were correlated to DIP ($r=-0.71$, $p<0.05$) and

dinoflagellates were significantly and negatively correlated to DIN ($r=-0.82$, $p<0.01$) and DISi ($r=-0.69$, $p<0.05$). Nutrients, particularly phosphate, can alter the phytoplankton community composition and structure in the tropical water (Cole and Sanford, 1989, Anton *et al*., 2008). Negative relationship between marine phytoplankton with nutrients might be due to intensive uptake by the denser phytoplankton community compositions (Table 4b) at the coastal water that reduced the nutrient concentrations in the water column (Table 2). This finding is consistent with that of Heneash *et al*. (2015), who observed that low levels of silicate are accompanied by dense bloom of euglenoids. This study also showed that golden-brown algae had no correlation with any nutrients (Table 5) and normally golden brown algae are found in nutrient poor waters, which is probably because most of the nutrients were utilized by other phytoplankton (Sin *et al*., 2015).

4.0 Conclusion

This study illustrated that phytoplankton can be a reliable indicator of ecological changes because its community composition is closely related to environmental characteristics A relationship among physical and local water quality characteristics with phytoplankton community was observed in the Terengganu River Estuary. The order of phytoplankton abundance was diatoms > blue-green algae > golden-brown algae > dinofalgellates > green algae > euglenoids. The phytoplankton species composition was comparatively higher in the coastal region than in other areas, and it was largely influenced by the temperature, salinity and nutrient concentrations. Higher population density of phytoplankton was largely associated with increased diatom and blue-green algae, accounting for 50.38% and 40.66% of the total species respectively. The results of the analysis suggested that freshwater phytoplankton was dominated by golden-brown algae, while marine phytoplankton was dominated by diatoms and blue-green algae in the Terengganu River Estuary. The study also showed significant correlations between environmental variables with phytoplankton community structure.

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