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Spatial and Temporal Distribution of Phytoplankton in Perak Estuary, Malaysia, During Monsoon Season

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ABSTRACT
Phytoplankton forms the essential base of the aquatic food web and plays a major role in aquatic productivity and ecosystem health. In the estuary and coastal waters, one of the major factors that controls phytoplankton community structure is the salinity changes along the river-sea continuum. The study was conducted to determine spatial and temporal distribution of phytoplankton along the salinity gradient in Perak river estuarine system during the northeast monsoon from November 2009 to February 2010. Four stations were established along the salinity gradient, from upstream where the salinity was 0.0 ppt to the marine area with salinity values of more than 25.0 ppt. The phytoplankton comprised of six main families namely, Bacillariophyceae (diatoms), Chlorophyceae (green algae), Cyanobacteria (blue-green algae), Chrysophyceae (golden-brown algae), Euglenophyceae (euglenoids) and Pyrrophyceae (dinoflagellates). A total of 93 species of phytoplankton were recorded from all the stations throughout the season, with green algae and diatoms dominating the upstream and the marine areas, respectively. On the other hand, the estuarine stations were dominated by both green algae and diatoms. The marine station had the highest ($p<0.05$) species density during the monsoon season compared to the other stations with a mean total density of 190.6±27.4 cells mL^{-1}, whereas, the lowest ($p<0.05$) density (73.8±11 cells mL^{-1}) was observed in the upstream station. Multidimensional scaling analysis based on the phytoplankton densities revealed two distinct groups. The first group consisted of the phytoplankton from the marine station, whereas, the other group consisted of the phytoplankton from the estuarine and upstream stations. In general phytoplankton distribution in Perak estuary was more similar to the freshwater rather than the marine plankton community due to a large flow of freshwater into the estuary during the northeast monsoon. This study revealed that salinity was an important factor in determining the phytoplankton distribution in this tropical ecotone.

Key words: Tropical estuarine ecosystem, phytoplankton distribution, species diversity, monsoon season, salinity gradient

INTRODUCTION
Perak river originates from the Titiwangsa mountain range and flows down its length of 402.0 km to its estuary located at Bagan Datoh (3°59'N-100° 46'E) to join the Straits of Malacca.

Its huge watershed of 14,700 km^2 (Yusoff *et al.*, 2006) greatly influenced the salinity fluctuation in the Perak estuarine system especially during the monsoon when the rainfall is high (76.1-311.9 mm during November to February). Perak estuary is unique in its own way because the wide range of salinity variations makes the estuary suitable as a breeding ground for a commercially important jellyfish, *Acromitus hardenbergi*, that is known to withstand the large fluctuations daily (tidal changes) or seasonally. Jellyfish fishery based on *Acromitus hardenbergi*, is the main fishery activity in that area (Yusoff *et al.*, 2010).

Phytoplankton is a very important primary producer for the aquatic ecosystem (Lalli and Parsons, 1993). Generally, most marine and freshwater organisms depend on phytoplankton which serves as a base for the aquatic food chain (Townsend *et al.*, 2000). Thus, the availability of phytoplankton influences the distribution of the consumer organisms, especially the immediate herbivory zooplankton. The high nutritional contents of phytoplankton make them valuable feed items in the aquatic food chain (Natrah *et al.*, 2007; Khatoon *et al.*, 2009, 2012; Banerjee *et al.*, 2010). On the other hand, the phytoplankton production is largely determined by the nutrient concentrations and light availability in the photic zone (Fogg and Thake, 1987; Yusoff, 1989).

In the estuary and coastal waters, salinity gradient was reported to be one of the major factors for the growth and diversity of phytoplankton communities (Macedo *et al.*, 2001; Khatoon *et al.*, 2010). Marine phytoplankton is adapted to high salinity and usually cannot survive in freshwater. Similarly, freshwater phytoplankton can hardly survive in seawater. However, some marine and freshwater species have evolved a tolerance to large salinity fluctuations and they can survive in the brackish water estuaries.

In Malaysia, there are two main monsoon seasons that greatly affected the weather, which are Southeast (SE) and Northeast (NE) monsoons. During the NE monsoon, the area in the east coast of Malaysia normally receives a large amount of rainfall starting from November until early March (Yoshida *et al.*, 2006). The high rainfall increases the amount of input water into the estuarine system, thus increases the dilution rate of the salinity in that particular area. The salinity of an estuary varies in time as well as in depth and distance from the freshwater source. This study aimed to illustrate the distribution of phytoplankton in a tropical estuary which undergoes drastic salinity fluctuations from freshwater state to marine water condition with salinity ranging from 0.0-25.4 ppt.

MATERIALS AND METHODS

Study area: The study was carried out from during Northeast (NE) monsoon season from November 2009 until February 2010 in Perak river up to 1 km off the coastal area. Four sampling stations were established (Fig. 1, Table 1) based on the salinity gradient from freshwater area to the sea. Station 1 was situated at the upstream of the river where the salinity was almost zero. Stations 2 and 3 were located in the estuary, whereas station 4 was located slightly off the coast (1 km into the sea), to represent the marine station. All stations have similar depths with maximum depth of 5-6 m during high tide.

Sample collection: Sample collection was carried out during the four months of the NE monsoon season from November 2009 until February 2010. Water samples were collected at 1 m depth intervals using 5 L Niskin water sampler. Samples were preserved in Lugol's iodine for phytoplankton identification and quantification. Environmental parameters such as temperature,

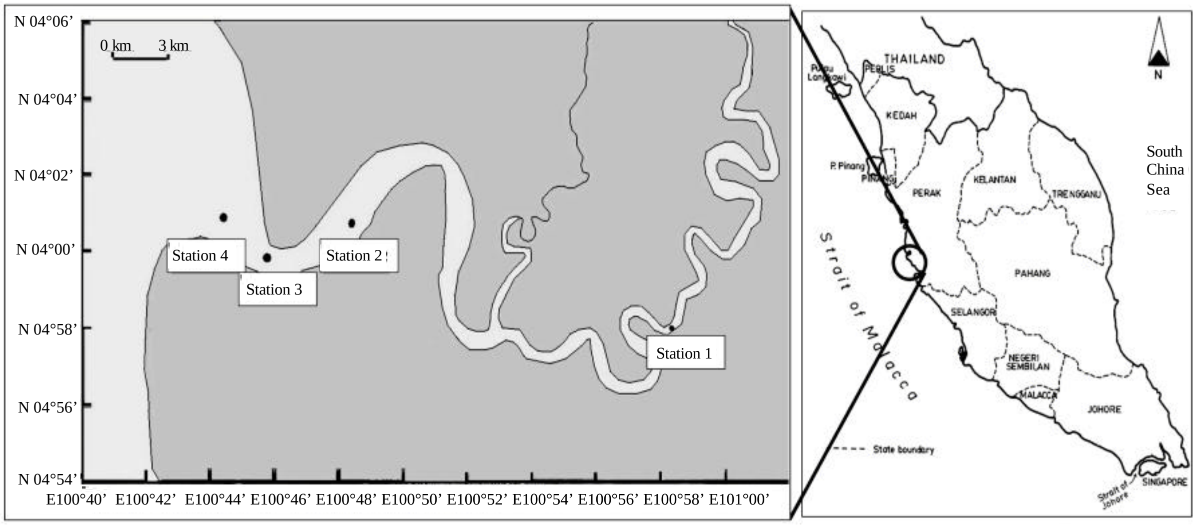

Fig. 1: Geographical location of the study area in Perak River, Peninsular Malaysia. (Map of Peninsular Malaysia taken from Fisheries and Aquaculture Department http://www.fao.org/docrep/field/009/ag160e/AG160E09.htm accessed on 5 October 2012)

Table 1: Coordinates of each sampling station

Station	Latitude (N)	Longitude (E)
1	3° 57.992'	100°58.476
2	3°59.758'	100°45.790'
3	4°00.700'	100°48.399'
4	4°00.446'	100°44.457'

salinity, pH, Dissolved Oxygen (DO), Total Dissolved Solid (TDS) and turbidity were measured *in situ* using the Hydrolab surveyor DS4 multiprobe. For nutrient analyses, 1-L water samples were collected in triplicates. The nutrient analyses including Total Ammonium Nitrogen (TAN), nitrate-nitrite (NO_2+NO_3) (Kitamura *et al.*, 1982) and Soluble Reactive Phosphorus (SRP) (Parsons *et al.*, 1984) were done using a spectrophotometric method.

Identification and enumeration: In the laboratory, samples were sedimented and concentrated to a working volume of 100 mL each. Enumeration of the phytoplankton was done under Leitz diavert inverted microscope following the method modified by Legendre and Watt (1972). A 2 mL subsample was placed into the cylindrical counting chamber and left to settle down. The counting chamber was transferred to the microscope stage for identification and enumeration. Random non-overlapping fields (Legendre and Watt, 1972) were examined until at least 150 units of the dominant species were counted (Lund *et al.*, 1958). The phytoplankton density was calculated in terms of number of cells per milliliter of water. Number per millilitre was calculated as follows:

$$\text{No. mL}^{-1} = C \times At/Af \times F \times V$$

Where:
C = Number of organisms counted
At = Total area of bottom of settling chamber (mm^2)
Af = Area of a field (mm^2)
F = Number of field counted
V = Volume of sample settled (mL)

The phytoplankton density was then calculated in terms of number of cells per millilitre of water by using correction factor to adjust the sample dilution or concentration.

Statistical analysis: Species diversity of phytoplankton was determined using Shannon-weiner index. The data were analyzed using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 6.1.9 PRIMER-E Ltd. (Clarke and Warwick, 2001). For each diversity index, significant differences in terms of spatial and temporal were tested using one-way ANOVA test in the Statistical Package for the Social Sciences (SPSS) software version 17.

RESULTS

Environmental conditions: During the NE monsoon season, water temperature in Perak estuary ranged from 27.7-31.7°C along freshwater zone to the marine station. The salinity varied between 0.0-25.4 ppt while total dissolved solid ranged from 0.0-25.2 g L^{-1} (Table 2). The minimum salinity and total dissolved solid values were observed at the upstream station while the maximum levels were observed at the marine station. As for the dissolved oxygen, the upstream station recorded the highest value followed by the marine and estuarine stations. Turbidity in Perak estuary was highest at the estuarine station followed by the upstream and marine stations with mean values of 505.2±247.5, 50.8±20.4 and 0.3±0.1 NTU, respectively. The highest rainfall during sampling occasion was recorded in November 2009 (311.9 mm) and eventually decreased towards the end of the sampling period (Fig. 2).

During the sampling period, nutrient concentrations were not significantly different amongst all the stations (Table 3). The upstream station showed the highest concentration of TAN and NO_2+NO_3 followed by estuarine stations and the lowest concentration was recorded in the marine station. On the other hand, the highest concentration of SRP was recorded at the marine station followed by estuarine and upstream station.

Table 2: Physical and chemical parameters of Perak river at different stations

	Stations					
	Upstream		Estuarine		Marine	
Physical parameter	Mean	Range	Mean	Range	Mean	Range
Salinity (ppt)	0.0±0.0	0.0-0.0	10.9±4.9	1.2-20.6	20.1±2.8	14.8-25.4
Temperature (°C)	29.7±1.0	27.7-31.7	29.6±0.8	28.0-31.2	29.7±1.0	28.3-30.7
Dissolved oxygen (mg L^{-1})	5.5±0.0	5.4-5.5	4.3±0.4	3.5-5.0	4.8±0.3	4.2-5.4
Total dissolved solid (g L^{-1})	0.0±0.0	0.0-0.0	11.3±4.9	1.5-21.1	14.7±5.3	4.2-25.2
Turbidity (NTU)	50.8±20.4	0.0-100.5	505.2±247.5	10.3-1000++	0.3±0.1	0.2-2.4

Mean values are Mean±SE

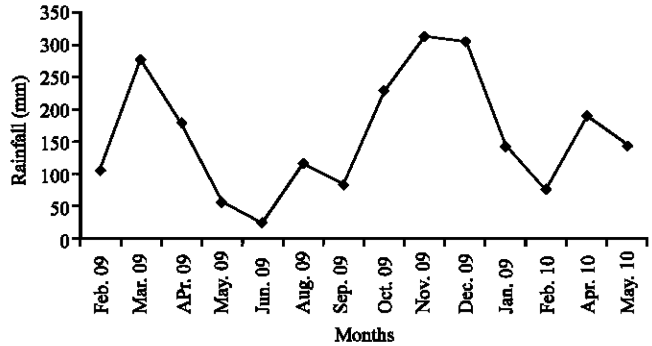

Fig. 2: Rainfall data for Perak river during November 2009 to February 2010 (Malaysian Meteorological Department, 2011)

Table 3: Nitrogen and phosphorus concentrations in Perak river at different stations

	Stations					
	Upstream		Estuarine		Marine	
Nutrients	Mean	Range	Mean	Range	Mean	Range
TAN (mg L^{-1})	0.04±0.01	0.02-0.06	0.03±0.01	0.02-0.06	0.02±0.01	0.01-0.03
NO_2+NO_3 (mg L^{-1})	0.23±0.04	0.16-0.30	0.11±0.05	0.05-0.28	0.03±0.01	0.02-0.04
SRP (mg L^{-1})	0.03±0.00	0.02-0.03	0.02±0.00	0.02-0.06	0.03±0.01	0.02-0.04

Mean values are Mean±SE

Table 4: Mean density (Cells mL^{-1}±SE) and percentages (%) of phytoplankton genera at different stations in Perak river

		Upstream		Estuarine		Marine	
	No. of species	Mean density	%	Mean density	%	Mean density	%
Bacillariophyceae							
Bacteriastrum	2	0.0±0.0	0.00	0.0±0.0	0.00	1.4±0.9	0.78
Biddulphia	1	0.0±0.0	0.00	0.0±0.0	0.00	2.4±1.0	1.33
Chaetoceros	5	0.0±0.0	0.00	1.3±1.3	2.19	15.0±4.6	8.32
Corethron	1	0.0±0.0	0.00	0.0±0.0	0.00	7.5±2.5	4.16
Coscinodiscus	6	0.2±0.2	0.72	0.0±0.0	0.00	28.2±9.9	15.64
Cyclotella	5	1.3±0.9	4.37	15.1±10.7	26.00	38.4±11.7	21.26
Diatoma	1	3.4±1.1	11.06	3.9±0.6	6.64	4.4±1.6	2.43
Diploneis	1	0.0±0.0	0.00	0.0±0.0	0.00	0.8±0.3	0.44
Dithylium	1	0.0±0.0	0.00	0.0±0.0	0.00	1.6±0.4	0.86
Fragilaria	1	0.0±0.0	0.00	5.2±5.2	8.89	1.6±0.7	0.89
Hemiaulus	1	0.0±0.0	0.00	0.0±0.0	0.00	0.8±0.3	0.42
Licmophora	1	0.0±0.0	0.00	0.7±0.7	1.27	0.0±0.0	0.00
Melosira	2	0.3±0.2	0.90	0.0±0.0	0.00	0.0±0.0	0.00
Meuniera	1	0.0±0.0	0.00	0.0±0.0	0.00	0.2±0.2	0.11
Navicula	7	15.6±4.3	49.99	21.4±6.6	36.92	12.0±3.2	6.68
Nitzschia	3	5.6±2.7	17.88	4.6±1.6	7.85	12.2±3.6	6.74
Pleurosigma	2	0.4±0.1	1.26	1.3±1.3	2.24	17.4±4.5	9.66
Pseudonitzschia	1	0.0±0.0	0.00	0.0±0.0	0.00	1.1±0.4	0.62
Rhizosolenia	1	0.0±0.0	0.00	0.0±0.0	0.00	1.5±0.5	0.83
Skeletonema	1	0.0±0.0	0.00	0.0±0.0	0.00	1.6±0.7	0.89

Table 4: Continue

		Upstream		Estuarine		Marine	
	No. of species	Mean density	%	Mean density	%	Mean density	%
Surirella	1	2.8±1.2	9.09	0.7±0.7	1.27	6.8±2.6	3.77
Tabellaria	2	1.0±0.4	3.24	0.0±0.0	0.00	0.8±0.3	0.44
Thallasionema	1	0.0±0.0	0.00	0.0±0.0	0.00	0.4±0.1	0.21
Thallasiosira	2	0.3±0.3	1.08	3.9±3.9	6.73	20.4±7.0	11.32
Thalassiotrix	1	0.0±0.0	0.00	0.0±0.0	0.00	0.8±0.3	0.42
Triceratium	1	0.0±0.0	0.00	0.0±0.0	0.00	3.2±1.3	1.78
Chlorophyceae							
Actinastrum	1	0.3±0.2	1.19	0.0±0.0	0.00	0.0±0.0	0.00
Ankistrodesmus	1	0.6±0.3	2.61	4.3±1.6	10.79	0.0±0.0	0.00
Chodatella	2	5.9±3.6	24.97	2.9±2.9	7.43	0.0±0.0	0.00
Closteriopsis	1	0.9±0.9	3.81	0.0±0.0	0.00	0.0±0.0	0.00
Closterium	1	0.9±0.4	3.75	0.4±0.4	1.12	0.0±0.0	0.00
Coelastrum	1	0.0±0.0	0.00	0.7±0.7	1.86	0.0±0.0	0.00
Cosmarium	2	3.6±1.4	15.26	3.7±3.7	9.29	0.0±0.0	0.00
Crucigenia	2	1.6±0.9	6.78	6.0±4.3	15.24	0.0±0.0	0.00
Oocystis	1	0.0±0.0	0.00	2.2±2.2	5.57	0.0±0.0	0.00
Scenedesmus	10	9.5±3.8	40.44	18.6±7.9	46.86	0.0±0.0	0.00
Staurastrum	1	0.3±0.2	1.19	0.0±0.0	0.00	0.0±0.0	0.00
Tetraedron	1	0.0±0.0	0.00	0.7±0.7	1.86	0.0±0.0	0.00
Cyanobacteria							
Chroococcus	2	2.6±1.0	22.50	5.2±5.2	30.15	0.8±0.3	61.62
Merismopedia	1	1.8±0.6	15.81	0.4±0.4	2.59	0.0±0.0	0.00
Oscillatoria	3	7.2±2.2	61.69	11.5±6.2	67.25	0.4±0.1	28.79
Spirulina	1	0.0±0.0	0.00	0.0±0.0	0.00	0.1±0.1	9.60
Chrysophyceae							
Dinobryon	1	0.6±0.3	100.00	0.7±0.7	100.00	0.0±0.0	0.00
Pyrrophyceae							
Ceratium	1	0.0±0.0	0.00	0.0±0.0	0.00	0.4±0.4	31.84
Peridinium	2	1.8±0.9	100.00	0.2±0.2	100.00	0.8±0.3	68.16
Euglenophyceae							
Euglena	4	5.3±1.5	66.54	4.3±1.6	36.22	0.0±0.0	0.00
Strombomonas	1	0.0±0.0	0.00	2.4±2.4	20.05	1.9±0.5	100.00
Trachelomonas	1	2.7±0.7	33.46	5.2±0.7	43.73	0.0±0.0	0.00

Phytoplankton composition and distribution: Generally, there were six main families of phytoplankton in Perak estuary which were Bacillariophyceae (diatoms), Chlorophyceae (green algae), Cyanobacteria (blue-green algae), Chrysophyceae (golden-brown algae) Euglenophyceae (euglenoids) and Pyrrophyceae (dinoflagellates). A total of 93 species of phytoplankton from 48 genera were recorded from all the stations throughout the season, whereas, 50 species were found at the marine station, 52 species found at the estuarine station and 48 species recorded in the upstream station (Table 4). Among the phytoplankton, diatoms have the most number of species (52) followed by green algae (24), blue-green algae (7), euglenoids (6), dinoflagellates (3) and chrysophytes (1). Throughout the season, at the upstream station, green algae were the most dominant group, contributing 40.5% of the total phytoplankton populations, followed by diatoms (30.8%), blue-green algae (15.1%), euglenoids (10.5%), dinoflagellates (2.3%)

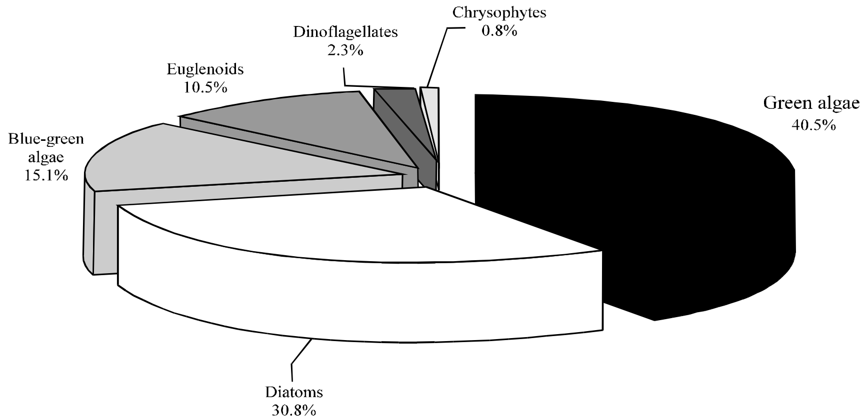

Fig. 3: Mean percentages of different phytoplankton groups in the upstream station (Station 1)

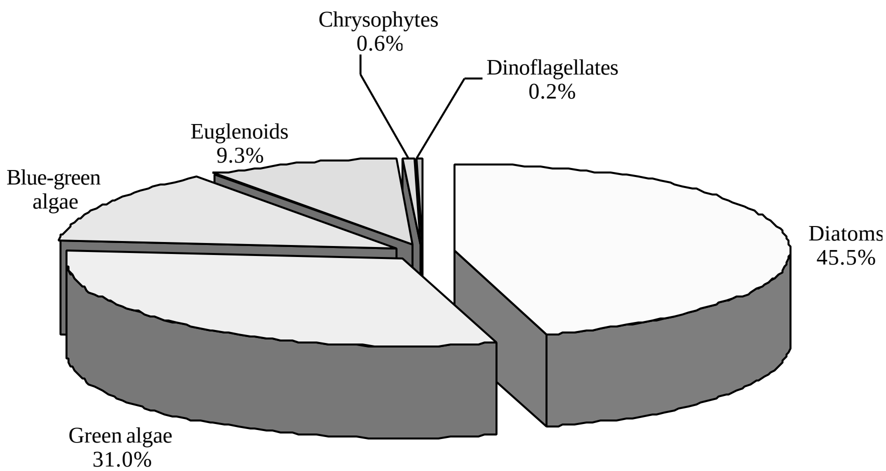

Fig. 4: Mean percentages of different phytoplankton groups estuarine station (Stations 2 and 3)

and chrysophytes (0.8%) (Fig. 3). For the estuarine station, diatoms contributed 45.5% of the total phytoplankton populations, closely followed by green algae (31.0%), blue-green algae (13.4%), euglenoids (9.3%), chrysophytes (0.6%) and dinoflagellates (0.2%) (Fig. 4). As for the marine station, only four groups of phytoplankton were found during the season with diatoms taking up 97.6% of the total phytoplankton populations, followed by euglenoids, blue-green and dinoflagellates with 1.1, 0.7 and 0.6, respectively (Fig. 5).

Among the stations, marine station had the highest total mean density ($p<0.05$) of phytoplankton (190.6±27.4 cells mL^{-1}) followed by estuarine station (128.8±14.0 cells mL^{-1}) and upstream station (73.8±11.0 cells mL^{-1}) (Fig. 6). Phytoplankton density was highest during the month of January with mean total density of 154.3±24.7 cells mL^{-1}, whereas the lowest density was recorded in December with mean total density of 106.2±16.1 cells mL^{-1}. However, there was no significant difference ($p>0.05$) in densities amongst the sampling months during this wet season (Fig. 7).

The MDS analysis based on phytoplankton composition and density revealed two distinct groups at 35% of similarity. The first group consisted of phytoplankton from marine station while the

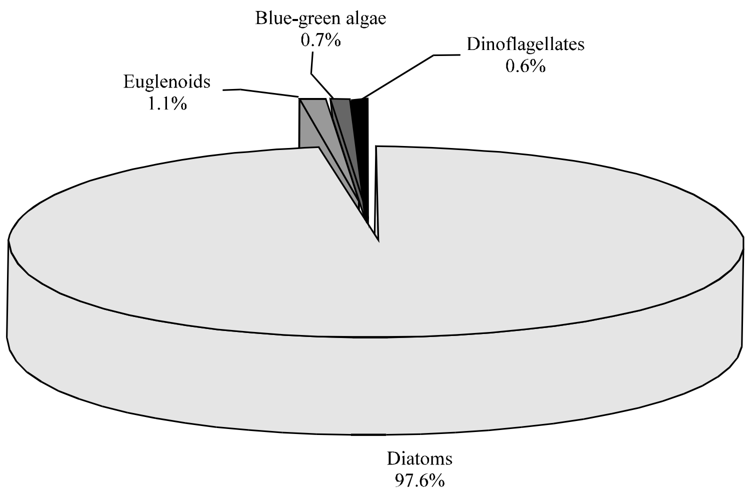

Fig. 5: Mean percentages of different phytoplankton groups in the marine station (Station 4)

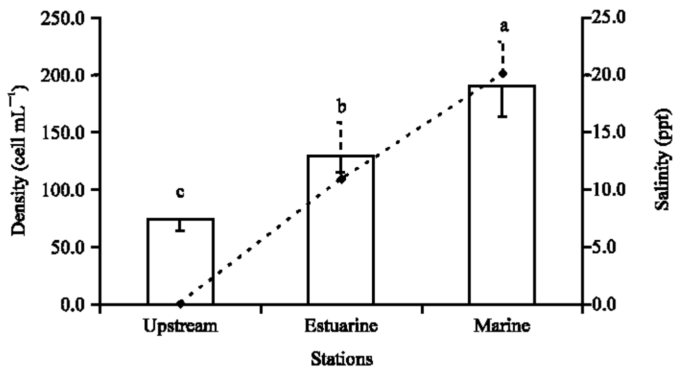

Fig. 6: Mean phytoplankton density (cells mL^{-1}) and salinity levels (ppt) in different sampling stations during the northeast monsoon season in Perak river, Malaysia, vertical bars are standard error of the means

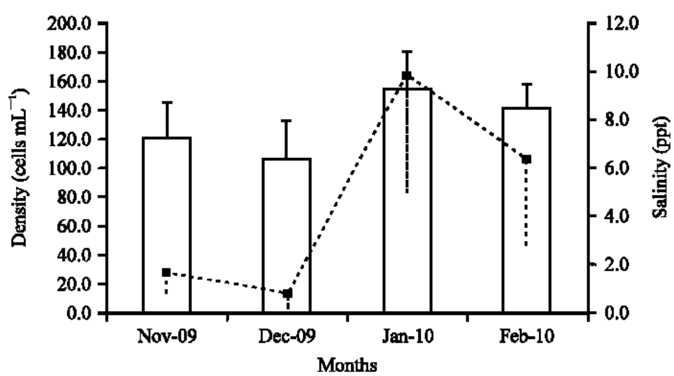

Fig. 7: Mean phytoplankton densities and salinity levels in different months during the northeast monsoon season in Perak river, Malaysia, vertical bars are standard error of the means

other group consisted of phytoplankton from the estuarine and upstream stations (Fig. 8). Species diversity index (H') of phytoplankton populations during this monsoon ranged from

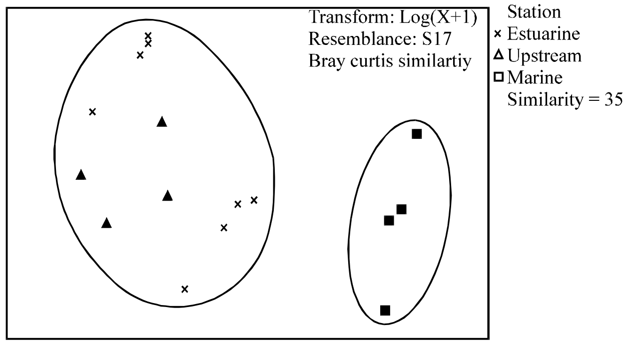

Fig. 8: Multi-dimensional scale (MDS) ordination of phytoplankton composition and densities in Perak river, Malaysia, vertical bars are standard error of the means

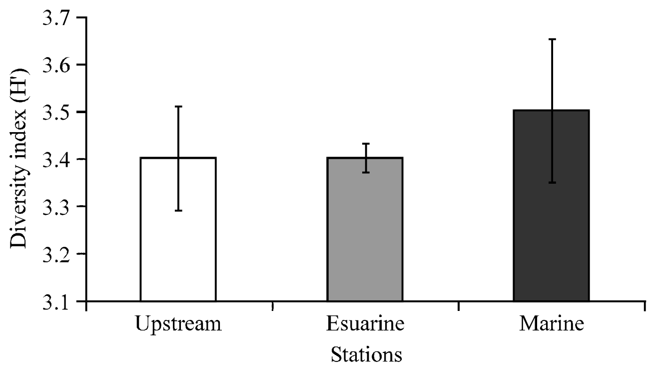

Fig. 9: Shannon-weiner diversity index (H') of phytoplankton populations at different stations in Perak river, Malaysia, vertical bars are standard error of the means

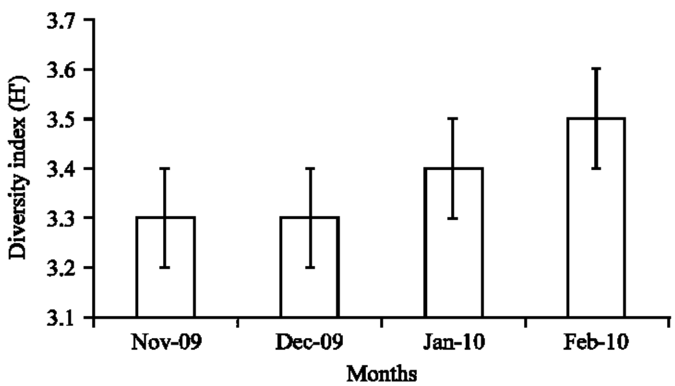

Fig. 10: Shannon-weiner diversity index (H') of phytoplankton populations in different sampling months in Perak river, Malaysia, vertical bars are standard error of the means

3.4 (upstream and estuarine) to 3.5 (marine) (Fig. 9). No significant difference in terms of phytoplankton biodiversity was observed amongst freshwater, brackish and marine waters. Similarly, phytoplankton species diversity index (H') did not differ significantly amongst the months, although it was observed that the diversity index was lower during the periods of heavy precipitation (November and December with H' values of 3.3-3.5) compared to those months (Janury and February) with lesser rainfall (Fig. 2, 10).

DISCUSSION

Large watershed size of the Perak river resulted in drastic salinity fluctuations in its river mouth compared to the estuaries of the nearby rivers with smaller watersheds. During the NE monsoon with high rainfall, the salinity in the estuarine station was very low, probably due to the huge flushing of water from the upstream during the high tidal interchanges. Since, the river mouth size is big (from 0.5 up to 2.3 km across) (Maizatul Asnida *et al*., 2011), the freshwater remains longer in the estuary in the wet season. Therefore, the salinity of the estuarine station was low even during the high tide during the monsoon season with heavy rainfall.

Similar to many other freshwater ecosystems, green algae was found to dominate the upstream station in the present study where salinity was 0.0 ppt during both low and high tides. Similar dominance in the tropical freshwater ecosystem was reported by Figueredo and Giani (2001). On the other hand, diatoms dominated the estuarine and marine areas. Previously, same diatom dominance among phytoplankton groups has been reported by Ananthan *et al*. (2008), Muylaert *et al*. (2009),Onyema (2008) and Shah *et al*. (2008). Lassen *et al*. (2004) also stated that in the Langat estuary, diatoms also formed the major phytoplankton group in the station with high salinity values. In the present study, out of 24 diatom genera recorded at the marine station, the main five genera were *Cyclotella*, *Coscinodiscus*, *Thalassiosira*, *Pleurosigma* and *Chaetoceros*. The most dominant form was the centric diatoms. Moving upstream, the domination of centric diatoms in the marine station changed to *Navicula* and *Cyclotella* in estuarine station while in the upstream station *Navicula* and *Nitzschia* were dominant. Trigueros and Orive (2000) also reported that *Cyclotella* dominated the phytoplankton species in a microtidal estuary. In Rupert Bay, it was reported that diatoms were dominant in the upstream, but in the estuarine and coastal areas, flagellates algae were dominant. However, within the group, *Cyclotella* was recorded as dominant diatom in estuarine and coastal waters (De Seve, 1993).

The present study revealed a total of 94 species of phytoplankton from all the stations throughout the season, where the highest species number was recorded in the estuarine station with 52 species followed by marine and upstream station with 50 and 49 species, respectively. However, in terms of density, marine station recorded the highest phytoplankton density compared to the estuarine and upstream zones perhaps due the lower turbidity levels in the marine waters, compared to the estuary and in the upstream. Palleyi *et al*. (2008) reported that in the Brahmani estuary of Orissa, India, phytoplankton abundance increased with the increasing salinity level. Estuarine stations recorded the highest turbidity (505.2±247.5 NTU) compared to other stations due to the higher water disturbance caused by daily tidal currents. Under this condition, light availability became a limiting factor that could affect the phytoplankton growth. Cloern (1987) also reported that phytoplankton production was controlled by limitations of light where productivity was low near the riverine source of sediments and increased toward the estuary mouth where turbidity decreased. Experiment on the effects of turbidity on phytoplankton biomass conducted by May *et al*. (2003) showed that the increase in turbidity was primarily responsible for the muted bloom of phytoplankton, thus decreasing the phytoplankton productivity.

The present study showed mix populations of freshwater and marine phytoplankton in the estuarine area. Due to frequent flushing and mixing of freshwater and marine waters in the estuarine area, many species from upstream and marine zones must have adapted to the daily and seasonal fluctuating environmental conditions. According to Kimmerer (2002), Sin *et al*. (2006) and Reaugh *et al*. (2007), freshwater flow was considered as the major factor that affect the phytoplankton growth because it influences the capacity of phytoplankton species to grow faster.

In addition, nutrient concentrations, which tend to be high in the upstream and marine stations, might have contributed to the phytoplankton growth (Spies and Parsons, 1985). Tanaka and Choo (2000) also reported that phytoplankton growth was higher in water bodies with high nutrient levels, provided that light was not limiting.

In terms of temporal distribution, phytoplankton abundance was low in the wet months probably due to dilution as a result of heavy precipitation. In addition, increased turbidity level during the wet months might have also caused a decline in phytoplankton populations. Studies done by Hoffman (1952) in Lake Fort Smith showed similar trends where phytoplankton was greatly reduced in numbers and abundance following heavy precipitation.

The phytoplankton diversity of the estuarine and upstream stations were similar probably due to the fact that the estuarine environment was comparable to the upstream station during the monsoon when there was large inflow of freshwater. Likewise, previous studies also reported that some estuaries had low biodiversity compared to the coastal waters due to the high frequency of disturbance in the physical and chemical features of the former (Nybakken, 1997). In terms of temporal variation, phytoplankton diversity was low in November and December which could be due to the heavy precipitation received during the early monsoon (Fig. 2). Bapjai and Agarker (1997) in their study attributed the low phytoplankton biodiversity to hydrological disturbance such as flooding. Adesalu and Nwankwo (2008) and Rajagopal *et al.* (2010) also stated that the low values of Shannon's index for phytoplankton population were due to the estuary dilution during rainy season. Similar inferences was reported by Onyema (2008) and Ananthan *et al.* (2008) who stated that phytoplankton diversity was reduced in the wet season due to the decreased amount of light for phytoplankton photosynthesis caused by low water clarity.

Multi dimensional scaling analysis based on phytoplankton composition and abundance showed that the phytoplankton community in Perak river was distinctly different ($p<0.05$) in the marine station compared to the estuarine and upstream station. This can be explained by the fact that the salinity level at the marine station remained relatively constant regardless of the tidal and seasonal fluctuations. Thus, only marine phytoplankton could be found in this area. In most cases, estuarine biological communities are more similar to the marine area than those in the freshwater zone (Cloern *et al.*, 1983; Jackson *et al.*, 1987; Schuchardt and Schirmer, 1991; Cloern and Dufford, 2005; Muylaert *et al.*, 2009). However, in this study, phytoplankton composition at the estuarine stations was more similar to the upstream station because of the low salinity waters in the estuary during low tides, especially during monsoon season (Fig. 7). Another factor that could cause similarity in phytoplankton community between the upstream and the estuarine stations was the advective transport between these zones during tidal changes.

CONCLUSION

In conclusion, salinity seemed to be an important factor in determining phytoplankton composition and distribution in the Perak river-marine continuum. Salinity gradient along the river, on the other hand, was mainly dictated by the seasonal changes of precipitation which influenced the dilution and turbidity levels of the ecosystem. During the NE monsoon, phytoplankton community structure in the estuary was comparable that in the freshwater area due to low salinity during the period of heavy precipitation. However, phytoplankton composition and density at the marine station remained more or less constant as the salinity in this area was not significantly affected by the tidal and monsoonal flushings of the river-estuarine area. Multi dimensional scaling analysis also illustrated that the phytoplankton community in the study area consisted of two distinct groups. The marine phytoplankton community is characterized by high density dominated by diatoms and high species biodiversity. The first group consisted of phytoplankton from marine station while the other group consisted of phytoplankton from the estuarine and upstream stations. The second group consisted of a mixture of fresh and brackish water species with drastic fluctions in composition and density due to changes in salinity and turbidity associated with the tidal cycles and monsoonal rainfall.

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