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Tropical Marine Phytoplankton Assemblages and Water Quality Characteristics Associated with Thermal Discharge from a Coastal Power Station

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Abstract

A study of phytoplankton assemblages and water quality characteristics was conducted monthly from November 2009 to October 2010 at the coastal waters adjacent to the Sultan Azlan Shah Power Station (SASPS) in Manjung, Perak, Malaysia. Water quality parameters were measured and phytoplankton samples were collected at five sampling stations with different environmental conditions. The results showed a significant difference of total phytoplankton abundance, pH, salinity, dissolved oxygen, TSS, ammonium, nitrate, nitrite, BOD, chlorophyll-*a*, and water transparency among sampling stations ($P<0.05$). In this study, Bacillariophyta, Cyanophyta, Chlorophyta, and Dinophyta were the major phylum presented at all sampling stations, and the most dominant phytoplankton species was *Odontella sinensis* based on Importance Species Indices. The Principal Component Analysis recommended a combination of factors such as anthropogenic input, thermal discharge, and turbidity that influenced the phytoplankton abundance and water quality condition within the vicinity of SASPS.

Keywords: Phytoplankton, Thermal Stress, Manjung, Water Quality, Tropic, Bioindicator

1. Introduction

The Sultan Azlan Shah Power Station (SASPS) is located at the coastal waters of Manjung, Malaysia. The coal-fired coastal power station is constructed on a man-made island and entrains large volumes of seawater for cooling purpose in support of electric production. The power plant causes dreadful ecological effects to the nearby ecosystem because it discharges large volume of warm cooling water (as a product of steam condensation) and antifouling biocides which eventually upset the aquatic ecosystem health (Van Vliet, 1957; Poornima *et al*., 2006; Chuang *et al*., 2009). In tropical regions, the effect of thermal discharge is most prevalent because a slight increment of normal seawater temperature may affect the survival of a species either by hoisting a new group of stress-tolerant species or diminishing the present species. Krishnakumar *et al*. (1991) noted that certain forms of life might be threatened or killed due to behavioral changes as a result of a rapid exposure to high temperatures. Phytoplankton, a planktonic plant in an aquatic ecosystem, utilizes solar energy and nutrient to generate oxygen and organic food which in the end supports most of the rest of life in the seas. Phytoplankton, being the base of aquatic food web, is sensitive to anthropogenic environmental changes. The undesirable environmental conditions will indirectly influence the community structure of higher trophic levels in the marine ecosystem (Lo *et al*., 2004). The objectives of this study were to discover the impact of thermal stress on phytoplankton abundance and species composition and to determine the possible biological indicator of thermal stress based on phytoplankton community structure.

2. Materials and Methods

2.1 Study site

Sultan Azlan Shah Power Station (SASPS) is a coal-fired power station located at the coastal waters of Manjung in Perak and its coordinate is 4°09'44" North and 100°38'48" East. The power station consumes large volumes of seawater for cooling purposes and then discharges the thermal effluent into the adjacent coastal waters. During the study period, five sampling stations (Table 1; Fig. 1) with different environmental conditions were selected in the vicinity of SASPS. Station 1 was located between Katak Island and Teluk Rubiah Beach, represented as a controlled environment. Station 2 was located near the bottom inlet of the power station. SASPS

collects the adjacent seawater through the bottom inlet and discharges the warm cooling water into the outlet region at Station 3. Station 4 was located near the ash pond, a place where ash residues were stockpiled for further treatment. Station 5 was located near the mangrove forest, an area which also comprised of the intrusion of freshwater originated from a nearby village.

2.2 Sampling strategy and laboratory analysis

Sampling was conducted monthly from November 2009 to October 2010. Water and phytoplankton samples were collected at all sampling stations to determine the nutrients concentration and distribution and composition of phytoplankton around the SASPS. Water quality parameters such as water temperature, conductivity, salinity, dissolved oxygen, and pH were measured in-situ using YSI 85 DO-SCT meter and pH meter while water transparency was measured using Secchi disk. Surface water samples were collected and kept with ice in a cooler box for preservation. The collection of phytoplankton samples was done by filtering forty liters of seawater through 35µm mesh-sized plankton net. The phytoplankton samples were placed in polyethylene bottles and fixed with Lugol's solution for preservation (Sournia, 1978). In the laboratory, the phytoplankton samples were identified by referring to the taxonomic keys (Tomas, 1997; Shamsudin, 1990; Cupp, 1943; Newell & Newell, 1970; Smith & Johnson, 1996; Sournia, 1978) while phytoplankton composition and enumeration was based on the methods recommended by Lobban *et al*. (1988). Total suspended solids, biological oxygen demand (BOD), chlorophyll-*a* and inorganic nutrients such as ammonium, nitrite, nitrate, and phosphate concentrations were determined by referring to the Water and Wastewater Examination Manual (Dean, 1990).

2.3 Data analysis

One-way Analysis of Variance (ANOVA) was used to determine statistically significant difference of total phytoplankton abundance and water quality parameters among the sampling stations. The analysis was conducted using the Statistical Package of Social Science (SPSS) version 17. The dominant phytoplankton species at all sampling stations was determined by calculating the Importance Species Indices (ISI) (Wan Maznah & Mansor, 2000).

$$ISI = (fi)(Di)$$

Where: fi is the frequency of species i, while Di is the average relative density of species i.

Principal Component Analysis (PCA) is a statistical analysis that is used to determine a few combinations of the original variables which is essential for summarizing the data. By using the analysis, the number of the uncorrelated variables is reduced with minimal loss of the original information (Sharma, 1995). It reduces a set of original variables and extracts a small number of factors (Principal Components) for analyzing relationships among the observed variables. The analysis had also been used in assessment of coastal eutrophication (Lundberg *et al*., 2005). Minitab version 14.13 was used to run the PCA.

According to Chatfield & Collins (1980), principal components with eigenvalue of less than 1.000 should be eliminated so that fewer main components could be focused and prioritized. In each principal component, a few groups containing some water quality parameters could be made based on their components values (the difference of component value among parameters must be small). Furthermore, a common hypothesis or inference could be assumed to explain the highlighted parameters clustered in a group in terms of their characteristics or influences (e.g. a group known as physical factor which included temperature, pH, and etc.). In this paper, PCA was done twice to determine the principal components from correlation matrix of phytoplankton abundance and water quality parameters, and also to determine the principal components from correlation matrix of dominant phytoplankton species and water quality parameters.

3. Results

3.1 Water quality parameters

In this study, the highest mean water temperature and conductivity were recorded at Station 3, which was located at the discharge outlet, but dissolved oxygen was the lowest at this sampling station. In addition, a stable range of water temperature and dissolved oxygen were recorded at other sampling stations (excluding Station 3) with 30.34 ± 0.62 ^{o}C to 31.03 ± 0.79 ^{o}C and 5.38 ± 1.48 mg/L to 5.67 ± 0.85 mg/L, respectively (Table 2).

Meanwhile, pH and salinity were at the range of 8.17 ± 0.31 to 8.29 ± 0.20 and 26.43 ± 2.04 to 29.63 ± 0.86 ppt, respectively. Besides, lower salinity and pH values were recorded at Station 5 and Station 3 respectively (Table 2). On the other hand, chlorophyll-*a*, BOD, TSS, ammonium, phosphate, nitrite, and nitrate were highest at Station 5. Lowest mean value of phytoplankton abundance and water transparency were recorded at the same sampling station (Table 2). In addition, the aforementioned parameters except phytoplankton abundance did not show a vast trend at Station 1 to Station 4. Based on one-way ANOVA, phytoplankton abundance, pH, water transparency, salinity, dissolved oxygen, TSS, ammonium, nitrate, nitrite, BOD, and chlorophyll-*a* were significantly different among sampling stations during the study period ($P<0.05$ at confidence level of 95%).

3.2 Relative abundance

In our study, Bacillariophyta was the most common phylum at all sampling stations followed by Chlorophyta, Cyanophyta, and Dinophyta (Fig. 2). The relative abundance of Bacillariophyta at all sampling stations was more than 80%. The relative abundance of Chlorophyta at Station 5, which accounted up to 10%, was much bigger compared to other sampling stations. On the other hand, Cyanophyta and Dinophyta showed a modest presence at all sampling stations by not exceeding 2% of relative abundance.

3.3 Importance Species Indices (ISI)

ISI yielded some predictable dominance of phytoplankton species within the vicinity of SASPS. Based on the ISI, *Pseudonitzschia heimii* was the most dominant phytoplankton at Station 1 whereas *Odontella sinensis* dominated Station 2 and Station 3 during the study period (Table 3). Other dominant phytoplankton species was *Oscillatoria corallinae* (Cyanophyta). As a whole, all sampling stations were dominated by Bacillariophyta (diatoms).

3.4 Principal Component Analysis (PCA)

According to the first PCA result (correlation matrix of phytoplankton abundance and water quality parameters), there were five significant principal components (Table 4). Furthermore, the components showed about 70% of the cumulative percent of total variance. However, only three principal components (showed up to 53% of the cumulative percent of total variance) were discussed because the cumulative percent of total variance represented by the components was sufficient (more than 50%) to explain the correlation among parameters. In the first principal component (PC1), conductivity (-0.258) and salinity (-0.251) could be drafted together in a group called as chemical factor and these parameters were considered as significant due to huge loading values (Table 4; Fig. 4). However, the group was assumed not to influence the phytoplankton abundance (-0.075) due to a huge difference of loading value between phytoplankton abundance, conductivity and salinity parameters.

The second group of PC1 included TSS (-0.353), ammonium (-0.389), nitrite (-0.354), nitrate (-0.309), and phosphate (-0.307) (Table 4; Fig. 4). Therefore, the second group in PC1 could be distinguished as anthropogenic factor. Meanwhile, in the second principal component (PC2), phytoplankton abundance (-0.163) could be grouped together with ammonium (-0.164), nitrite (-0.110), chlorophyll-*a* (-0.174), and BOD (-0.178) (Table 4; Fig. 4). The combination of biological and chemical factors in the group could potentially influence the phytoplankton abundance due to small difference of loading value among the parameters. On the other hand, two groups could be formed from the third principal component (PC3). The first group included pH (0.422) and water temperature (0.385) whereas the second group included conductivity (0.213), nitrate (0.214), and water transparency (0.294) (Table 4). Both groups were constituted by physical and chemical parameters. In this principal component, water transparency was a significant parameter influencing the phytoplankton abundance (0.329) as it showed the smallest difference of loading value between them.

The second PCA (correlation matrix of dominant phytoplankton species and water quality parameters) also generated five principal components with eigenvalue of more than 1.000 (Table 5). The first five principal components showed about 68% of the cumulative percent of total variance. However, only the first three principal components (cumulative percent of total variance was up to 50%) were discussed. In the first principal component (PC1), three dominant phytoplankton species consisted of *Chaetoceros curvisetus* (-0.043), *Odontella sinensis* (-0.083), *Pseudonitzschia heimii* (-0.076) were grouped together with pH (-0.090) and water temperature (-0.077) (Table 5; Fig. 5). Therefore, PC1 suggested that the abundance of *Chaetoceros curvisetus*,

Odontella sinensis, and *Pseudonitzschia heimii* were significantly influenced by physical and chemical factors. On the other hand, each of phytoplankton species in the second principal component (PC2) was influenced by different parameters. *Chaetoceros curvisetus* (-0.218) was affected by water temperature (-0.226) whereas *Odontella sinensis* (-0.173) was influenced by total suspended solids (-0.175). Meanwhile, there was a strong relationship between *Pseudonitzschia heimii* (0.131) and chlorophyll-*a* (0.100) (Table 5; Fig. 5). In the third principal component (PC3), water temperature (-0.299) and dissolved oxygen (-0.212) had the tendency to influence *Odontella sinensis* (-0.220).

4. Discussion

The thermal discharge within the outlet region played a significant influence on pH, water temperature, conductivity, salinity, and dissolved oxygen. The solubility of carbon dioxide in water increased with increment of water temperature and atmospheric pressure (Wiebe & Gaddy, 1940; Dodds *et al*., 1956; Ellis & Golding, 1963), thus forming more carbonic acids which then lowered the pH (Caldeira & Wickett, 2003). Usually, warm water is less viscous and has greater electrical conductance, therefore it facilitates the flowing of electric current. Light *et al*. (1995) reported that the conductivity of water depended on water temperature and showed a maximum conductance at 45^{o}C. Meanwhile, Hayashi (2004), in his temperature-electrical conductivity study, pointed out that the relationship between temperature and electrical conductivity of selected seawaters was proportional, yielding out a linear equation. Greater salinity within the outlet region did not reflect the impact of thermal discharge because it would barely change due to intrusion of freshwater in the marine environment. The presence as well as the flow of freshwater in the coastal environment also needed to be considered as it might affect the salinity at certain localities. During the study period, a murky water condition was observed particularly at Station 5 located near the shallow mangrove area. The greater water turbidity within the mangrove area indicated the presence of inland suspended solids and nutrients which were possibly brought by the coastal runoff originated from Kampung Permatang (a traditional village). Loading of suspended solids also increased the demand for oxygen to biologically decompose organic matter in the water. In addition, the continuous freshwater input within the vicinity of SASPS was certainly the major factor diluting the coastal waters salinity. Theoretically, chlorophyll a reflects the presence of phytoplankton in an aquatic environment but our study showed a contrary relationship between them particularly at Station 5 (Fig. 2). Phytoplankton abundance within the mangrove area was slightly lower compared to the abundance within the thermal plume. In essence, mangrove ecosystem is a nursery ground and refuge area for most zooplankton species and juvenile fish (Robertson *et al*., 1988; Holguin *et al*., 2001) due to high abundance of shelter (Nagelkerken *et al*., 2008) and played a significant influence in determining the abundance of phytoplankton (Buskey *et al*., 2004).

Bacillariophyta (diatoms) can be found vastly in marine environment (Simon *et al*., 2009) and were able to tolerate the unfavorable environmental conditions temporarily by evacuating the upper mixed layer and then sank to the deeper part of a water body (Smetacek, 1985). During the study, we discovered that the outlet region was fully dominated by diatoms compared to other sampling stations. Patrick (1971) noted that many species of diatoms tolerated the water temperature between 0^{o}C and 35^{o}C and classified diatoms based on their different temperature tolerance ranges (Stenotherms: withstand only a narrow temperature range; Meso-stenotherms: withstand 10^{o}C variation in temperature; Meso-eurytherms: withstand 15^{o}C variation in temperature; and Eu-eurytherms: withstand a variation of 20^{o}C or more in temperature). Based on our study, the relative abundance of Bacillariophyta (diatoms) was greater at Station 3 (Fig. 3) compared to other sampling stations and the mean water temperature at Station 3 was approximately 5^{o}C above the ambient water temperature. Therefore, the diatoms managed to tolerate the 5^{o}C variation in temperature and could be categorized as Stenotherms. Meanwhile, other phytoplankton groups surpassed their tolerance limit and probably facing mortality due to prolong exposure of thermal stress within the thermal plume. Krishnakumar *et al*. (1991) reported that a shift in population of organisms would occur when the heat-tolerant organisms increased whereas other organisms which thrive in cold water decreased.

Based on the Importance Species Indices, all the sampling stations were dominated by diatoms. *Odontella sinensis* dominated the areas including the inlet, outlet, and ash pond. It could be found frequently throughout the study period and contributed higher density particularly within the thermal discharge region. In addition, the species was not categorized as harmful algae or red tide agent and thus unlikely to threat other marine organisms within the ecosystem. In addition, under microscopic observation, the species occurred solitary and also in pairs. Unlike the brownish dinoflagellates, *Odontella sinensis* did not exemplify any vibrant color in its natural habitat during observation with naked eyes. Possibly, *Odontella sinensis* was suitable to be categorized as thermal indicator species based on its frequent occurrence and abundantly presented among other diatoms within the

stressful thermal outlet. Lo *et al*. (2004) reported that other diatom species, *Chaetoceros compressus*, was also known to be warm water and neritic species and its abundance increased with increasing water temperature. They also pointed out that *Skeletonema costatum*, a centric diatom, had euryhaline characteristic and regarded as an indicator species of pollution and eutrophication. Its abundance increased with increasing water temperature and usually bloomed in warmer inshore waters at the southwest region of Taiwan.

According to Mazlum (1999), in each principal component, a variable is considered to be most significant when it represents high loading value and larger variance, thus necessary to be evaluated. Based on the first PCA result, three principal components which represented more than 50% of the cumulative percent of total variance were evaluated to explain the correlation among parameters. However, only the second (PC2) and the third (PC3) principal components were further evaluated because the difference of loading value between phytoplankton and other parameters in them was small compared to the first principal component (PC1). The two principal components yield out a desirable combination of physical, biological, and anthropogenic factors in determining the phytoplankton assemblages during the study period. Based on the second PCA, three principal components which also represented more than 50% of the cumulative percent of total variance were further evaluated. Similar to the first PCA, a small difference of loading value between the three most dominant phytoplankton species and other parameters was likely to be further evaluated. The three principal components indicated that physical factors such as water temperature, dissolved oxygen, and total suspended solids were the major parameters to influence the occurrence of *Chaetoceros curvisetus*, *Odontella sinensis*, and *Pseudonitzschia heimii* during the study period.

5. Conclusion

A significant different of water quality condition and phytoplankton abundance were discovered among the sampling stations within the vicinity of SASPS. Other factors such as anthropogenic sources and upwelling of coastal waters near the power station should also be accounted to understand further about the changing water quality characteristics and phytoplankton distribution. A phytoplankton community structure dominated by diatoms occurred particularly within the outlet region of the SASPS, making it suitable to be the biological indicator of thermal pollution and water quality degradation due to its robust tolerance towards environmental stressor.

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References

Buskey, E.J., Hyatt, C.J. & Speekman, C. (2004). Trophic Interactions Within the Planktonic Food Web in Mangrove Channels of Twin Cays, Belize, Central America. *Atoll Research Buletin*.

Caldeira, K. & Wickett, M.E. (2003). Anthropogenic Carbon and Ocean pH. Nature, 425 (6956), 365-365.

Chatfield, C. & Collins, A.J. (1980). *Introduction to Multivariate Analysis*. Chapman and Hall in Association with Methuen, Inc. 733 Third Avenue, New York NY.

Chuang, Y.L., Yang, H.H. & Lin, H.J. (2009). Effects of a Thermal Discharge from a Nuclear Power Plant on Phytoplankton and Periphyton in Subtropical Coastal Waters. *Journal of Sea Research*, 6, 197 – 205.

Cupp, E.E. (1943). Marine Plankton Diatoms of the West Coast of North America. *Bulletin of the Scripps Institution of Oceanography*. University of California Press, Berkeley, California, 5 (1), 1-238.

Dean, V. 1990. *Water and Wastewater Examination Manual. Lewis Publishers*, Chelsea, Mich, USA.

Dodds, W., Stutzman, L. & Sollami, B. (1956). Carbon Dioxide Solubility in Water. Industrial & Engineering Chemistry Chemical & Engineering Data Series, 1 (1), 92-95.

E.H. Poornima, M. Rajadurai, V.N.R. Rao, S.V. Narasimhan, & V.P. Venugopalan, (2006). Use of Coastal Waters as Condenser Coolant in Electric Power Plants: Impact on Phytoplankton and Primary Productivity. *Journal of Thermal Biology*, 31, 556-564.

Ellis, A. & Golding, R. (1963). The Solubility of Carbon Dioxide above 100 Degrees C in Water and in Sodium

Chloride Solutions. *American Journal of Science*, 261 (1), 47-60.
Hayashi, M. (2004). Temperature-Electrical Conductivity Relation of Water for Environmental Monitoring and Geophysical Data Inversion. Environmental monitoring and assessment, 96 (1), 119-128.
Krishnakumar, V., Sastry, J. & Swamy, G.N. (1991). Implication of Thermal Discharges into the Sea – A Review. *Indian Journal of Environmental Protection*, 11, 525-527.
Light, T.S., Kingman, B. & Bevilacqua, A.C. (1995). *The Conductivity of Low Concentrations of CO_2 Dissolved in Ultrapure Water from 0-100°C*. The 209th American Chemical Society National Meeting, Anaheim, California, April 2-6.
Lo, W.T., Hwang, J.J., Hsu, P.K., Hsieh, H.Y., Tu, Y.Y., Fang, T.H. & Hwang, J.S. (2004). Seasonal and Spatial Distribution of Phytoplankton in the Waters of Nuclear Power Plants, North of Taiwan. *Journal of Marine Science and Technology*, 12, 372 - 379.
Lobban, C.S., Chapman, D.J. & Kremer, B.P. (1988). Experimental Phycology: A laboratory Manual. Press Syndicate 1998. University of Cambridge, 47-55.
Ludwig, J.A. & Reynolds, J.F. (1988). Diversity Indices. In J.A. Ludwig and J.F. Reynolds (eds.), Statistical Ecology: A primer on Methods and Computing. John Wiley and Sons, New York, 85-103.
Lundberg, C., Lonnroth, M., Numers, V. M. & Bonsdorff, E. (2005). A Multivariate Assessment of Coastal Eutrophication. Examples from the Gulf of Finland, Northern Baltic Sea. *Marine Pollution Bulletin*, 50, 1185-1196.
Mazlum, N., Ozer, A. & Mazlum, S. (1999). Interpretation of Water Quality Data by Principal Component Analysis. *Turkish Journal of Engineering & Environmental Sciences/Turk Muhendislik ve Cevre Bilimleri Dergisi*, 23 (1), 19-26.
Nagelkerken, I., Blaber, S., Bouillon, S., Green, P., Haywood, M., Kirton, L., Meynecke, J.O., Pawlik, J., Penrose, H. & Sasekumar, A. (2008). The Habitat Function of Mangroves for Terrestrial and Marine Fauna: A Review. *Aquatic Botany*, 89 (2), 155-185.
Newell, G.E. & Newell, R.C. (1979). *Marine Plankton: A Practical Guide*. 5th Edition. Hutchinson & Co. London.
Patrick, R. (1971). The Effects of Increasing Light and Temperature on the Structure of Diatom Communities. *Limnology and Oceanography*, 405-421.
Robertson, A., P. Dixon, & P. Daniel. (1988). Zooplankton Dynamics in Mangrove and other Nearshore Habitats in Tropical Australia. *Marine Ecology progress series*. Oldendorf, 43(1), 139-150.
Shamsudin, L. (1990). *Diatom Marin di Perairan Malaysia*. Dewan Bahasa dan Pustaka. Kementerian Pendidikan Malaysia. Kuala Lumpur.
Sharma, S. (1995). *Applied Multivariate Techniques*. John Wiley and Sons, Inc.
Simon, N., Cras, A.L., Foulon, E. & Lemée, R. (2009). Diversity and Evolution of Marine Phytoplankton. *Comptes Rendus Biologies*, 332, 159-170.
Smetacek, V. (1985). Role of Sinking in Diatom Life-History Cycles: Ecological, Evolutionary, and Geological Significance. *Marine Biology*, 84 (3), 239-251.
Smith, D.B.L. & K.B. Johnson. (1996). *A Guide to Marine Coastal Plankton and Marine Invertebrate Larvae*. 2nd Edition. Kendall/Hunt Publishing Company. Dubuque, Iowa.
Sournia, A. (1978). *Phytoplankton Manual*. United Nations Educational, Scientific and Cultural Organization, Paris.
Straughan, D. (1980). *Impact of Southern California Edison's Operations on Intertidal Harbor*. Southern California Development Series.
Tomas, C.R. (1997). Identifying Marine Phytoplankton. Academic press, 10-18.
Van Vliet, V. (1957). Effect of Heated Condenser Discharge Water upon Aquatic Life. *American Society of Mechanical Engineering*, 57, 1-10.
Wan Maznah, W.O. & Mansor, M. (2000). Periphytic Algal Composition in Pinang River Basin, A Case Study on One of the Most Polluted Rivers in Malaysia. *Journal of Bioscience*, 1, 53 – 67.
Wiebe, R. & Gaddy, V. (1940). The Solubility of Carbon Dioxide in Water at Various Temperatures from 12 to 40 and at Pressures to 500 Atmospheres. Critical Phenomena*. *Journal of the American Chemical Society*, 62, 815-817.

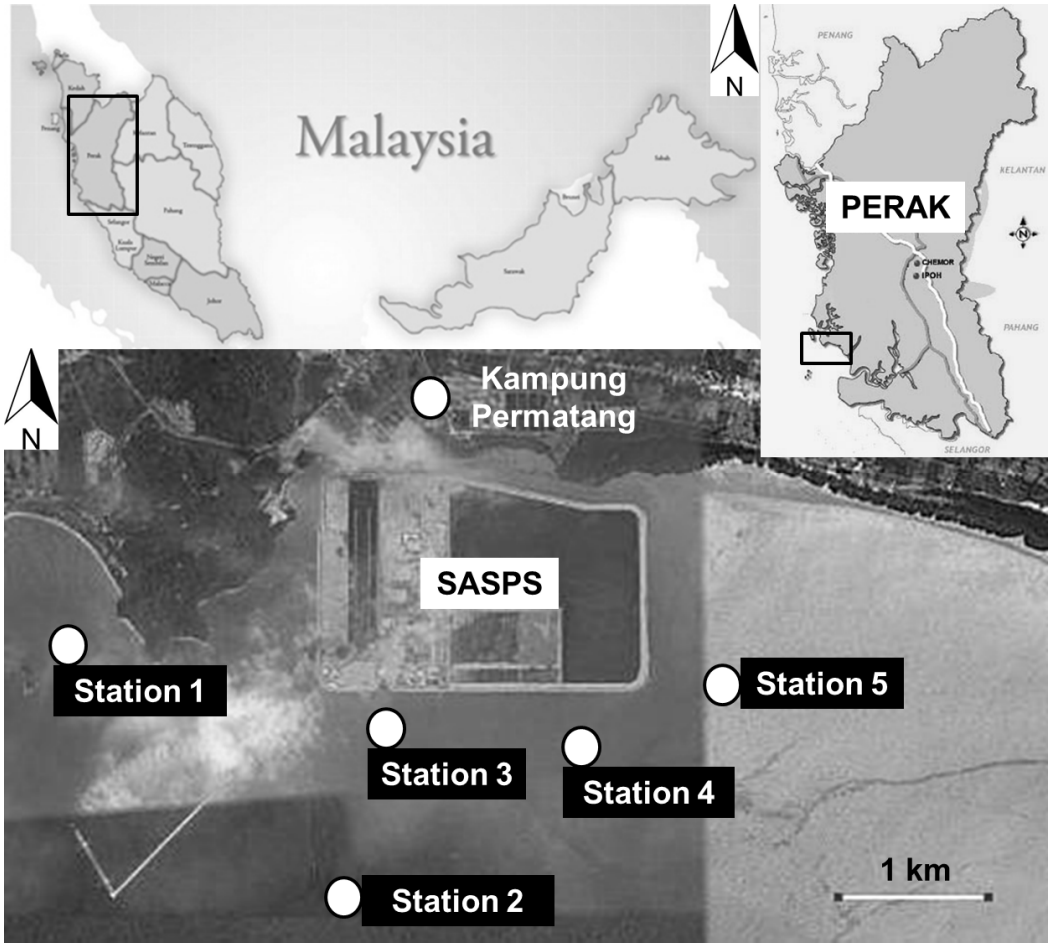

Figure 1. Location of all sampling stations (Station 1 – Station 5) within the vicinity of SASPS (Source: http://maps.google.com.my).

Table 1. Coordinate of sampling stations within the vicinity of SASPS.

Sampling station	Latitude	Longitude	Remarks
Station 1	4º09’20.09”N	100º37’08.69”E	Controlled
Station 2	4º08’27.83”N	100º38’07.44”E	Inlet point
Station 3	4º09’14.28”N	100º38’22.28”E	Outlet point
Station 4	4º09’28’’N	100º38’52”E	Ash pond
Station 5	4º10’23”N	100º 39’ 6”E	Mangrove area

Table 2. Mean (± s.d) of water quality parameters and phytoplankton abundance (Cells/m^3 ± s.e) at all sampling stations around the SASPS from November 2009 to October 2010.

Variables	**Sampling stations**				
	St. 1	**St. 2**	**St. 3**	**St. 4**	**St. 5**
Water temperature (^oC)	30.43 ± 0.62	30.40 ± 0.77	34.75 ± 1.51	30.98 ± 0.95	31.03 ± 0.79
pH	8.29 ± 0.20	8.29 ± 0.18	8.17 ± 0.31	8.24 ± 0.23	8.27 ± 0.23
Conductivity (µS/cm)	49.32 ± 1.84	48.10 ± 2.89	54.53 ± 2.92	48.10 ± 3.06	46.05 ± 3.46
Salinity (ppt)	28.70 ± 1.17	27.98 ± 1.92	29.63 ± 0.86	27.57 ± 1.86	26.43 ± 2.04
DO (mg/L)	5.523 ± 0.671	5.507 ± 0.922	4.973 ± 0.621	5.673 ± 0.854	5.381 ± 1.479
BOD (mg/L)	1.706 ± 1.177	1.384 ± 0.850	1.437 ± 0.980	1.525 ± 0.937	2.141 ± 1.283
TSS (mg/L)	35.974 ± 6.696	36.180 ± 9.057	39.528 ± 6.631	37.246 ± 7.970	55.603 ± 22.886
Chlorophyll-*a* (µg/L)	0.416 ± 0.304	0.531 ± 0.392	0.618 ± 0.480	0.631 ± 0.495	0.958 ± 0.533
Ammonium (mg/L)	0.009 ± 0.011	0.009 ± 0.017	0.015 ± 0.022	0.012 ± 0.012	0.018 ± 0.016
Nitrite (mg/L)	0.003 ± 0.005	0.004 ± 0.006	0.005 ± 0.008	0.003 ± 0.007	0.005 ± 0.013
Nitrate (mg/L)	0.015 ± 0.014	0.015 ± 0.024	0.015 ± 0.010	0.015 ± 0.009	0.019 ± 0.014
Phosphate (mg/L)	0.000 ± 0.001	0.000 ± 0.001	0.002 ± 0.003	0.001 ± 0.003	0.006 ± 0.009
Water transparency (m)	1.44 ± 0.61	1.42 ± 0.62	1.40 ± 0.72	1.29 ± 0.64	1.16 ± 0.65
Phytoplankton abundance (Cells/m^3)	48066.00 ± 57426.09	82398.53 ± 113140.87	48313.25 ± 74524.96	58218.38 ± 65264.39	44946.61 ± 50871.45

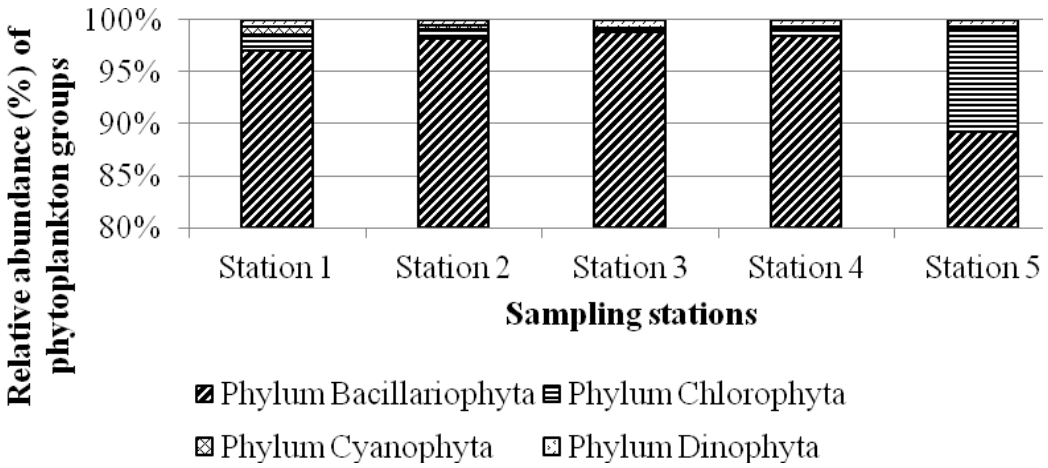

Figure 2. Relative abundance (%) of phytoplankton groups at all sampling stations within the vicinity of SASPS from November 2009 to October 2010.

Table 3. Dominant species of phytoplankton at all sampling stations with their Importance Species Indices (ISI>2.00).

Species	Sampling Stations				
	St. 1	St. 2	St. 3	St. 4	St. 5
Phylum Bacilariophyta					
Pseudonitzschia heimii	4.54	1.18	2.20	3.88	2.19
Odontella sinensis	3.58	6.82	5.18	6.91	6.40
Chaetoceros curvisetum	1.19	1.60	2.45	1.86	1.28
Chaetoceros curvisetus	4.31	5.49	3.48	4.53	6.90
Chaetoceros lorenzianus	0.34	1.36	0.42	2.09	1.12
Cylindrotheca closterium	2.26	1.94	0.92	0.78	2.66
Ditylum brightwellii	2.68	2.85	3.25	3.30	2.99
Navicula transitans	0.34	1.70	0.51	2.65	2.88
Pleurosigma sp.	0.17	2.76	2.17	0.73	0.12
Phylum Cyanophyta					
Oscillatoria corallinae	3.67	0.55	0.27	0.23	0.01

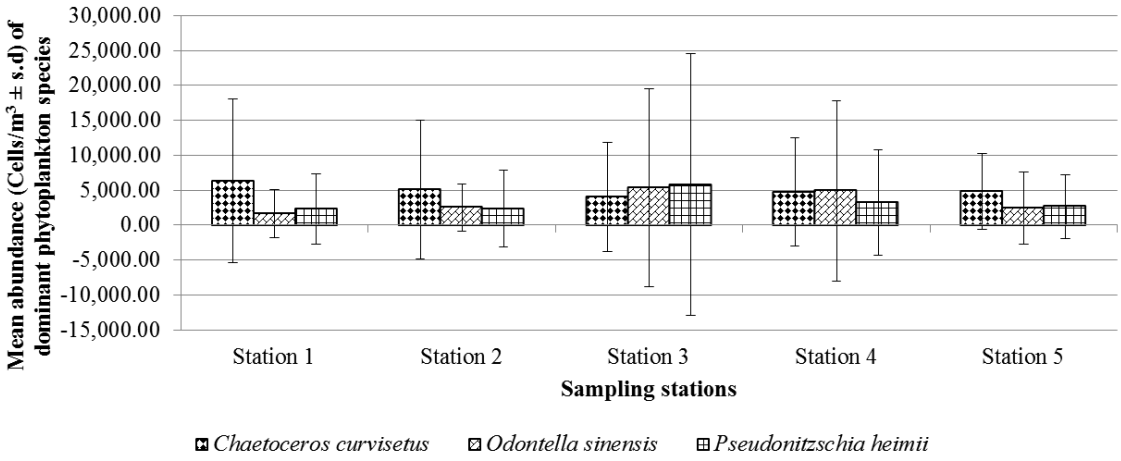

Figure 3. Mean abundance (Cells/m^3 ± s.d) of three most dominant phytoplankton species at all sampling stations within the vicinity of SASPS from November 2009 to October 2010.

Table 4. Principal components from correlation matrix of phytoplankton abundance and water quality parameters.

Eigenvalues Explained by Principal Components				
PC1	PC2	PC3	PC4	PC5
3.2136	2.6238	1.6603	1.2814	1.0789
Percent of Total Variance Explained				
PC1	PC2	PC3	PC4	PC5
0.230	0.187	0.119	0.092	0.077
Cumulative Percent of Total Variance Explained				
PC1	PC2	PC3	PC4	PC5
0.230	0.417	0.536	0.627	0.704
Variables	**Component Loadings**			
	PC1	PC2	PC3	PC4	PC5
Phytoplankton abundance	-0.075	-0.163	0.329	-0.551	-0.102
pH	-0.047	-0.209	0.422	0.468	-0.144
Water temperature	-0.153	0.320	0.385	-0.200	0.160
Conductivity	-0.258	0.486	0.213	-0.133	0.107
Salinity	-0.251	0.464	0.020	-0.027	0.005
Dissolved oxygen	0.193	-0.363	-0.397	-0.074	0.167
TSS	-0.353	-0.010	-0.206	0.337	-0.056
Ammonium	-0.389	-0.164	-0.018	0.044	0.308
Nitrite	-0.354	-0.110	-0.299	-0.173	-0.043
Nitrate	-0.309	-0.292	0.214	-0.171	0.080
Phosphate	-0.307	-0.081	0.059	0.288	0.197
Water transparency	0.048	0.228	0.294	0.197	-0.642
Chlorophyll-*a*	-0.415	-0.174	0.183	0.095	-0.255
BOD	-0.192	-0.178	-0.247	-0.330	-0.531

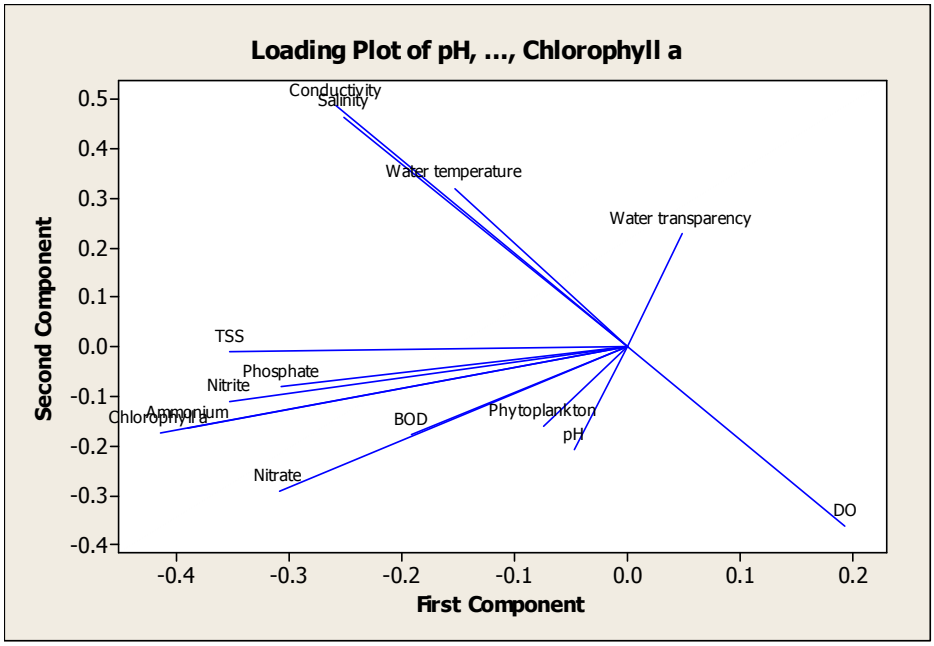

Figure 4. Principal Component Analysis (PCA) made on the loadings of water quality parameters and phytoplankton abundance.

Table 5. Principal components from correlation matrix of water quality parameters and dominant phytoplankton species abundance.

Eigenvalues Explained by Principal Components				
PC1	PC2	PC3	PC4	PC5
3.1013	2.0697	1.8331	1.3796	1.1731
Percent of Total Variance Explained				
PC1	PC2	PC3	PC4	PC5
0.222	0.148	0.131	0.099	0.084
Cumulative Percent of Total Variance Explained				
PC1	PC2	PC3	PC4	PC5
0.222	0.369	0.5	0.599	0.683

Variables	**Component Loadings**				
	PC1	PC2	PC3	PC4	PC5
Chaetoceros curvisetus	-0.043	-0.218	-0.499	-0.364	0.058
Odontella sinensis	-0.083	-0.173	-0.22	0.488	-0.451
Pseudonitzschia heimii	-0.076	0.131	-0.608	-0.184	-0.219
pH	-0.09	0.405	0.008	0.469	0.192
Water temperature	-0.077	-0.226	-0.299	0.21	0.232
Salinity	-0.149	-0.477	-0.081	0.141	0.127
Dissolved oxygen	0.131	0.557	-0.212	0.109	-0.073
TSS	-0.368	-0.175	0.074	0.248	-0.114
Ammonium	-0.414	0.091	-0.01	-0.244	0.314
Nitrite	-0.36	-0.043	0.331	-0.226	-0.072
Nitrate	-0.358	0.311	-0.089	-0.184	0.111
Phosphate	-0.322	0.028	0.039	0.193	0.284
Chlorophyll-*a*	-0.461	0.1	-0.164	0.136	-0.132
BOD	-0.227	0.064	0.201	-0.195	-0.637

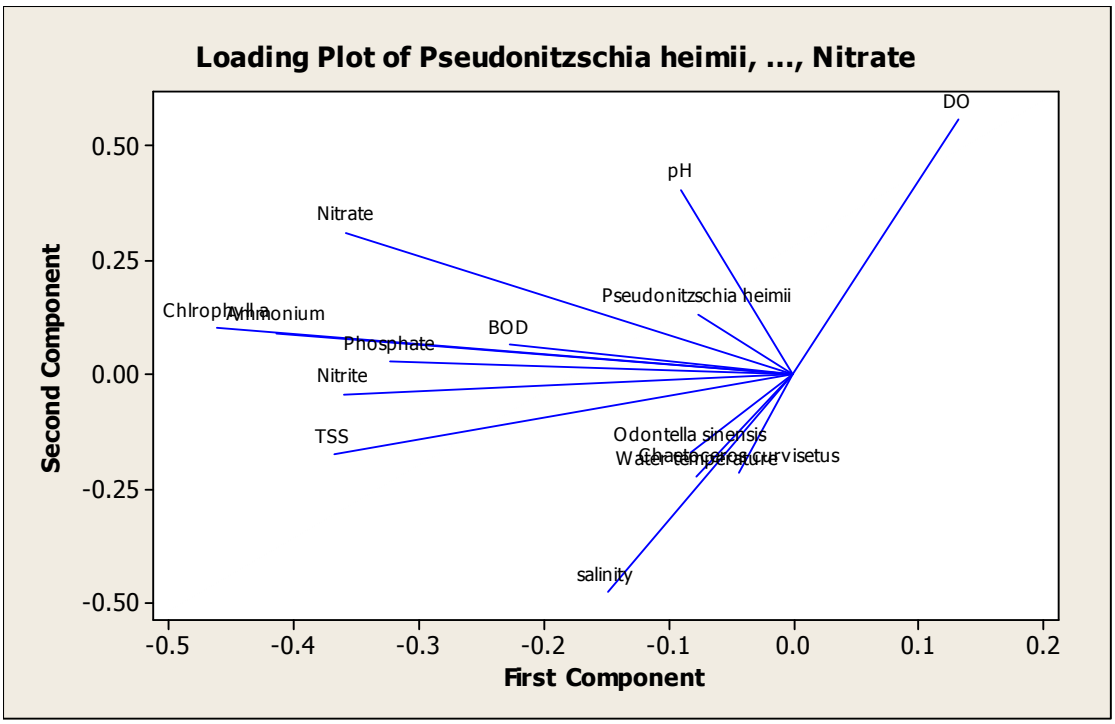

Figure 5. Principal Component Analysis (PCA) made on the loadings of water quality parameters and dominant phytoplankton species abundance.