

Case Study of Phytoplankton Blooms in Serangoon Harbor of Singapore

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Abstract—A recent algal bloom in the East Johor Strait has led to the damage of marine life in the water channel. This has led to heavy economic losses to the fish farms located along the water channel. There is a desire to study and be able to predict the occurrences of algal blooms so that their effects on the fish industry can be reduced. Many factors such as weather patterns, tidal conditions and nutrient content in the water contribute to the extent of the eutrophication.

This paper describes the design of experiments carried out in the East Johor Strait to study the dynamics of algal blooms. Physical and biogeochemical water column sampling were carried out using Acoustic Doppler Current Profilers (AD-CP) and a Conductivity, Temperature and Depth (CTD) probe that could measure various water quality parameters such as Turbidity, Salinity, pH level, Dissolved Oxygen (DO) and Chlorophyll-a concentration. Water samples from 1 m below the surface and 1 m above the channel floor were collected using Niskin Bottles. The water samples were sent to chemistry labs to test for the concentrations of various nutrients such as Ammonium, Nitrite, Nitrate and Phosphorus. Additional sampling was done using an Autonomous Underwater Vehicle (AUV) that was capable of measuring water quality parameters similar to those measured by the CTD.

The collection of the water sample data were meant to coincide with the spring and neap tides. The schedule is important to align with major phases of astronomic tide driving forces, such as flood tide, ebb tide and the transition between the two. Comparison can then be made to attempt to understand the various factors that contribute to algal blooms in the water body. Collected biogeochemical data can be used to improve water quality forecasts as well.

I. INTRODUCTION

As the urban area expands, the pollution content of urban discharge changes. This discharge may lead to inhospitable conditions around the coast or an excessive eutrophication which can lead to the asphyxiation of marine life or harmful algal blooms. In the later half of December 2009, fish farms located along the East Johor Strait, suffered severe economic losses due to fish mass kill [1]. The suffocation of marine life along the water channel was believed to have been caused by extensive algal blooms that occurred in that water channel. In order to prevent or control the damages caused by algal blooms, there is a growing interest in the study of the

causes and ability to predict algal blooms in coastal waters of Singapore itself.

For such a study, observations regarding the body of water are required. Surface observations are easy to make but the vertical structure of the water column is important. Therefore, an understanding of the variability of parameters along the depth of the water, or water column profile, at a certain location should be obtained.



Fig. 1. Dead tiger garoupas at a fish farm off Pulau Ubin, Singapore at the end of December 2009. The cause of death of a large number of fish in the area is suspected to be an algal bloom. Photo copyright Caroline Chia, Straits Times, 2 Jan 2010.

The chemical and biological content and their dispersion in a body of water is highly coupled with the hydrodynamic features of the estuary. Therefore, a water column sampling of the bio-geochemical content around the coastal waters of Singapore would allow for a more complete understanding of the effects of the changes in the chemical contents of the discharge, coupled with the tidal conditions of the Strait.

A literature review of the studies on the coastal waters of Singapore pertaining to algal bloom can be found in Section II. The detailed description and explanation of the design of the experiments conducted to collect data for the studies of algal blooms is located in Section III. Section IV gives a brief description of the equipment and measured parameters. The

presentation of the results and analysis is in the subsequent section and the paper will end with the conclusion, found in Section VI.

II. LITERATURE REVIEW

There were previous studies conducted by Gin *et al.* [2] to understand the structures of the phytoplankton in the tropical port waters of Singapore. The water samples were mainly collected from the Singapore Strait and the East Johor Strait. These data were collected from November 1997 to December 1998.

As phytoplankton depend on photosynthesis to survive, the presence of chlorophyll-a is a good indication of the presence of phytoplankton. Based on the results from Gin *et al.*, higher chlorophyll-a levels were detected during the South-West Monsoon season (June - August) than during the North-East Monsoon season (December - February). However, this phenomenon is only observed for the chlorophyll-a concentration in the Singapore Strait and *not* in the East Johor Strait. A high level of chlorophyll-a, which corresponds to an algal bloom, occurs frequently in the East Johor Strait and seemed to be independent of the seasons. They were likely to be a result of anthropogenic inputs and favorable climate and tidal conditions.

An eutrophication model for Singapore waters, known as NEUTRO, was developed by the Tropical Marine Science Institute (TMSI) [3, 4]. The model utilizes the proficient kinetics of the Water Quality Analysis Simulation Program (WASP) model and combines the three dimensional advection-diffusion contaminant transport module to more accurately resolve the effects caused by spatial and temporal ocean dynamics. In the NEUTRO model, there are 13 state variables: Ammonia, Nitrate, Phosphate, Phytoplankton, Carbonaceous Biochemical Oxygen Demand, Dissolved Oxygen, Organic Nitrogen, Organic Phosphorous, Zooplankton, Bacteria, Total Suspended Solids, Available Dissolved Silica and Particulate Biogenic Silica. Simulation of the concentration of phytoplankton requires recent data to calibrate the model.

III. DESIGN OF EXPERIMENTS

A. Selection of Location

As mentioned in the previous Section, it was observed that algal blooms occur occasionally in the East Johor Strait. Therefore, it is ideal to carry out experiments in the entire width of the Strait. However, due to the presence of heavy traffic within the center of the channel, Serangoon Harbor, only two areas, Box #1 and #2 as shown in Figure 2, were allocated for experimentations by the Maritime Port Authority of Singapore (MPA).

Algal blooms are likely a result of a combination of factors such as an excessive amount of certain nutrients and favorable climate and tidal conditions. Therefore, water samples were collected, using a Niskin Bottle, at points A, B and C as in Figure 2. Point A is located closer to the causeway which connects the island of Singapore to the Malaysian Peninsula. There is no flow of water between the two bodies of water

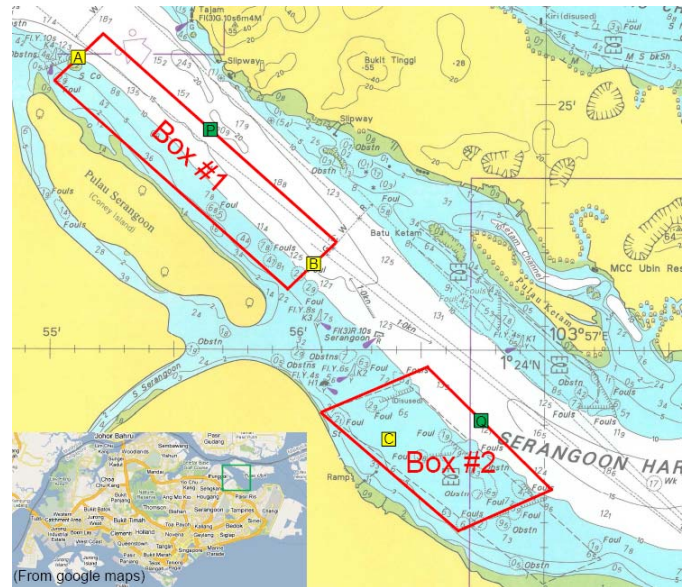


Fig. 2. A map of East Johor Strait. Boxes #1 and #2 were the allocated locations from Maritime Port Authority. Point A, B and C were the points where water samples and water column profiles were sampled. Point P and Q were the locations of where the AD-CPs were placed.

separated by the causeway and results in an estuary like area near the causeway itself. Point C is located closer to the Singapore Strait. The flow in the strait is relatively uniform based on the simulation forecast of the currents in the channel. To obtain a full range of extremes, points A and B are ideal to study the effects when the currents are strong while point C is suitable for the condition when the magnitude of the current is at its smallest. Water samples were collected 1 m from the surface of the water and 1 m from the floor of the channel.

Acoustic Doppler Current Profilers (AD-CPs) were mounted on the floor of the channel to record the direction and magnitude of the currents at point P and Q. Point P and Q were chosen to be in the deepest part of the channel and as near as possible to the mid-point between the main island of Singapore (the land mass to the bottom left in Figure 2) and the island Pulau Ubin (the land mass to the top right in Figure 2).

B. Selection of Dates and Timings

The occurrence of an algal bloom is affected by the climate and tidal conditions. The dates that the experiments were conducted were chosen such that a variety of tidal conditions were present. It was generally observed that the algal blooms occur more frequently during neap tides when tidal-driven mixing is minimum and less frequently during spring tides.

Various dates throughout the month of June 2009 were picked based on a forecast of the tidal elevation in Serangoon Harbor as shown in Figure 3. The experiments were chosen to coincide with the spring and neap tides. The dates selected were June 9, 11, 15, 17 and 25. June 9, 11 and 25 are days when it is spring tide while June 15 and 17 are the days that neap tides occur.

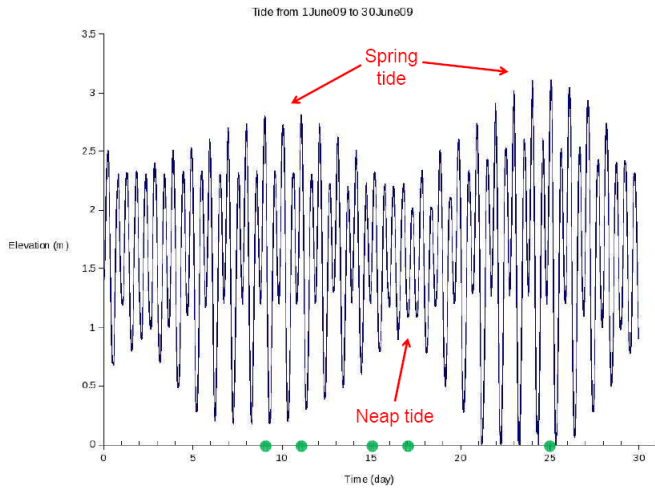


Fig. 3. A prediction of the tidal elevation at Serangoon Harbor for June 2009. The green dots mark the dates the experiments were conducted to collect water samples.

TABLE I
THE DATE, TIME AND LOCATION FOR DATA COLLECTION.

Tide Types	Dates	Point(s)	Time interval	Tide condition
Spring	Jun 9	A & B	1400-1600	Ebb
	Jun 9	C	1200-1400	Phase change
Spring	Jun 11	A & B	1500-1700	Ebb
	Jun 11	C	1300-1500	Phase change
Neap	Jun 15	C	1530-1700	Phase change
Neap	Jun 17	C	1030-1230	Phase change
Spring	Jun 25	A & B	1500-1700	Ebb
	Jun 25	C	1300-1500	Phase change
	Jun 25	A & B	1000-1300	Flood

Throughout the course of the day, there are flood and ebb tides. These flooding/ebbing conditions determine the direction of the flow in the channel. The currents flow from South-East to North-West during the flood tide while the currents flow from North-West to South-East during the ebb tide. When the tidal phase changes from flooding to ebbing and vice versa, there is a period of lowest current magnitude known as ‘phase change’. The exact times were selected to occur with the flood tide, ebb tide and phase change. Table I summarizes the timings and dates that were selected to take the measurements and collect the water samples.

IV. EQUIPMENT AND MEASURED PARAMETERS

A range of equipment were used to study the various parameters of the body of water along its depth. Water column sampling was carried out using a Conductivity, Temperature and Depth (CTD) probe which had additional probes that could measure other water quality parameters such as Turbidity, Salinity, pH level, Dissolved Oxygen (DO) and Chlorophyll-a (Chl-a) concentration. The sampling rate of the probe was set to 1 Hz.

Past literatures [4, 5] indicate that Nitrogen and Phosphorus based nutrients were the most crucial nutrients that would affect the occurrences of algal blooms. Therefore, nutrients

that were of great interest in this study were Ammonia (NH_3), Nitrite (NO_2), Nitrate (NO_3), Total Nitrogen (Total N), Phosphate (PO_4), and Total Phosphorus (Total P).

Ammonia is often used as a fertilizer and when nitrifying bacteria is present, it can be converted into Nitrate. Phytoplanktons can consume NH_3 and NO_2 and NO_3 for the Nitrogen based demands but typically prefer NH_3 . When the concentration of NH_3 is low, the phytoplankton will utilize NO_3 to grow [4]. Ammonia is an end product of decomposition when the phytoplankton dies.

Nitrate is a salt of nitric acid which is very soluble in water. As mentioned earlier, it is available for phytoplankton uptake when the concentration of NH_3 is low. Nitrite is a salt of nitrous acid and can be converted into nitrate through a process called nitrification. Both NO_2 and NO_3 are derived from NH_3 when it is broken down by certain bacteria. Ammonia, Nitrite and Nitrate are all part of the Nitrogen cycle. The Total Nitrogen is a summation of all the Organic and Inorganic Nitrogen present. As NH_3 , NO_2 and NO_3 are Inorganic Nitrogen compounds, the Organic Nitrogen can be calculated based on the difference between the Total Nitrogen and the summation of NH_3 , NO_2 and NO_3 present.

Phosphate is the inorganic form of Phosphorus and is one of the key elements necessary in the growth of plants. Phytoplanktons consume Phosphate to grow and its subsequent death produces Organic Phosphorus. Other sources of Phosphate may be human and animal waste, phosphorus rich bedrock, industrial effluents and fertilizer runoff [5]. Organic Phosphorus can be computed by taking the difference between Total Phosphorus and Phosphate, which is the Inorganic Phosphorus.

As in-situ probes for most of these nutrient concentrations are not available, a Niskin bottle was used to collect water samples from the locations mentioned in Section III-A. The water samples were collected at 1 m from the surface and 1 m from the floor of the channel. The samples were sent to chemistry labs to evaluate the level of concentration of the nutrients mentioned above.

The methods used to test the level of the nutrients follow those found in [6]. For nutrients such as NH_3 , PO_4 and Total N, the concentration measured were lower than the detection limit of the methods used to test them. In such cases, these values were assigned the value of the lowest detectable limit by the method. These values are not removed as they are not errors in the equipment. They are very small values and would contribute to the overall analysis. The detection limit of NH_3 , PO_4 and Total N are 0.01 mg/L, 0.025 mg/L and 0.025 mg/L respectively.

The chlorophyll level in the water is represented by the measurement of Chl-a present. This quantity was measured in-situ using a multi-parameter probe. The probe uses a Chl-a sensor (YSI 6025) that has a resolution of 0.1 $\mu\text{g/L}$ and can measure in a range of 0 - 400 $\mu\text{g/L}$. Based on the measured results of Chl-a from the 26 samples, the mean value of the Chl-a recorded is 5.1 $\mu\text{g/L}$ with a standard deviation of 3.0 $\mu\text{g/L}$.

An Autonomous Underwater Vehicle (AUV) that had water quality probes mounted on the nose of the AUV was deployed as well. The probes found on the nose were the same as those found on the CTD. The advantage the AUV had over the CTD was that it could take measurements that could give an idea of the properties in not only temporal but spacial resolution as well. The results from the AUV, however, were not used in the current studies as it required further analysis.

V. RESULTS

In total, 26 water samples were collected from three locations, points A, B and C as shown in Figure 2. The samples collected at 1 m from the water surface and 1 m from the seabed will be termed as ‘shallow’ and ‘deep’ respectively in this study.

For all the days, locations and tide types, the Chl-a level at the shallow points are higher than the deeper points as shown by Figure 4. The reason for this phenomenon is likely because more sunlight can reach the surface of the sea than the deeper part of the sea. This would allow for more photosynthetic activities near the surface, hence more phytoplanktons would thrive there than at the deeper part of the sea. This was also observed from the positive correlation between the water column temperature and chlorophyll-a concentration [9].

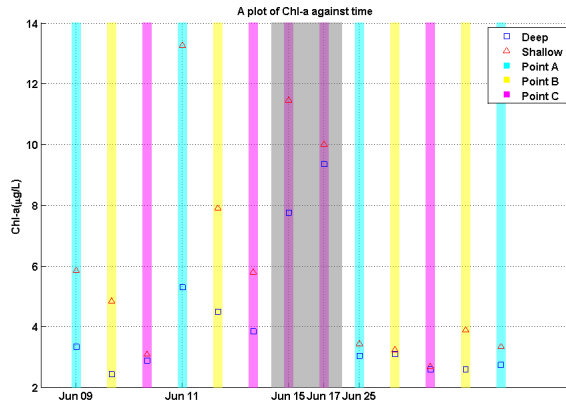


Fig. 4. A plot of Chl-a against time. The various colours represent the point that the sample were taken from. Cyan represents the samples that were taken from point A, yellow represents the samples that were taken from point B and Magenta represents the samples taken from point C. The gray shaded area is the period of neap tide. The red line with triangles is the Chl-a level for the shallow points and the blue line with squares is the Chl-a level for the deep points.

In order to plot the various nutrients on the same chart as that of Chl-a, the values of the nutrients and Chl-a were normalized by dividing the entire time series by the maximum value in the time series. Equation (1) summarizes how the normalization is done. In this paper, any normalization is done using (1). The vector $\vec{x}$ can represent any of the time series for the nutrients or Chl-a.

$$\vec{x}_{norm} = \frac{\vec{x}}{\max(\vec{x})} \quad (1)$$

As expected in Section III-B, the concentration of chlorophyll-a is much higher during neap tide as shown in Figure 5. This is because as the neap tide approaches, the diminished mixing and tidal flushing helps nutrient levels to build up, hence resulting in more algal blooms. It was also observed that the level of Chl-a concentration decreases from point A to point C on June 9 and June 11, as shown in Figure 4. This is quite possibly due to the proximity of the points from the estuary located to the West of the allocated area of experiments. This trend is still observed for June 25, but it is not as evident as that on June 9 and 11 – a heavy rain that occurred in the morning of June 25 could introduce freshwater and increased mixing to the body of water, hence lowering a chance of nutrients to build up [9].

Past literature indicates that Nitrogen-based nutrients are usually the limiting nutrients in coastal marine eco-systems [7]. Therefore, studies of the levels of Chl-a with respect to the levels of Nitrogen-based nutrients should be considered.

Since the level of Chl-a is generally higher during the neap tide and water samples were only taken from point C during the neap tide period, in order to make a comparison that excludes the effects of tidal conditions and location, a plot of the normalized Chl-a and NH_3 against time for point C, as shown in Figure 5, is used to study the trends of Chl-a with NH_3 .

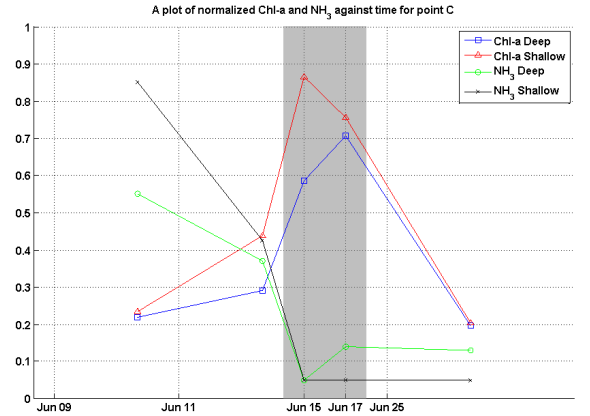


Fig. 5. A plot of normalized Chl-a and NH_3 against time from samples taken from point C. The gray shaded area is the period of neap tide. The red line with triangles and the blue line with squares are the Chl-a level for the shallow points and the Chl-a level for the deep points respectively. The black line with 'x's' and the green line with circles are the NH_3 level for the shallow points and the NH_3 level for the deep points respectively.

From Figure 5, on June 9 and 11, when Chl-a is low, NH_3 is relatively high. During the neap tide period, June 15 and 17, Chl-a is relatively higher while NH_3 is lower than before. On June 25, however, Chl-a is low and NH_3 is low as well. Therefore, apart from June 25, Chl-a seems to vary inversely with NH_3 and it is likely that NH_3 is the nutrient that limits the growth of phytoplankton in that region. The nutrient that limits the growth of phytoplankton is also known as the ‘limiting nutrient’.

Apart from NH_3 , the other Nitrogen-based nutrient that is utilized by phytoplankton for Nitrogen uptake is NO_3 . Figure 6 shows a plot of the normalized Chl-a and NO_3 against time for the water samples collected at point C.

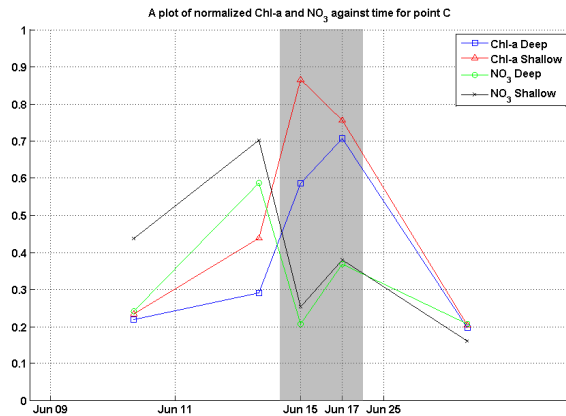


Fig. 6. A plot of normalized Chl-a and NO_3 against time from samples taken from point C. The gray shaded area is the period of neap tide. The red line with triangles and the blue line with squares are the Chl-a level for the shallow points and the Chl-a level for the deep points respectively. The black line with 'x's and the green line with circles are the NO_3 level for the shallow points and the NO_3 level for the deep points respectively.

The trends of the levels of Chl-a and NO_3 are generally similar during the spring tide but are different during the neap tide. For the samples from the shallow points, an increase in the level of Chl-a results in a decrease in the level NO_3 . On the other hand, for the samples from the deep points, the level of NO_3 increased when the level of Chl-a increased.

From Figure 7, it is obvious that there is a difference in the level of NH_3 in June 9 and 11 and June 15 and 17. The levels of NH_3 for June 9 and 11 are significantly higher than those in June 15 and 17. As mentioned earlier, phytoplankton has a preference for utilizing NH_3 as the Nitrogen uptake but when the concentration of NH_3 is low, phytoplankton would utilize NO_3 . This is most likely the case for the phytoplankton obtained in the samples from the shallow points. The low concentration of NH_3 results in the consumption of NO_3 , hence, when there is an increase in the number of phytoplankton (as indicated by a higher level of Chl-a), there is less NO_3 . For samples from the deep points, as the size of phytoplankton present is smaller compared to the shallow points, it is possible that the level of NH_3 present is still sufficient for the phytoplankton and hence there is not a need to consume NO_3 for the Nitrogen uptake.

Referring to Figure 8, it is observed that for June 25, the trends of Chl-a and NO_3 are opposite. The level of NH_3 on June 25 is much lower than on June 9 and 11. It is likely that in this case, the low concentration of NH_3 causes phytoplankton to utilize NO_3 as their Nitrogen uptake, hence resulting in the opposing trends observed.

The level of NO_3 is higher for the samples collected from the shallow points than the deeper points on June 25 as shown

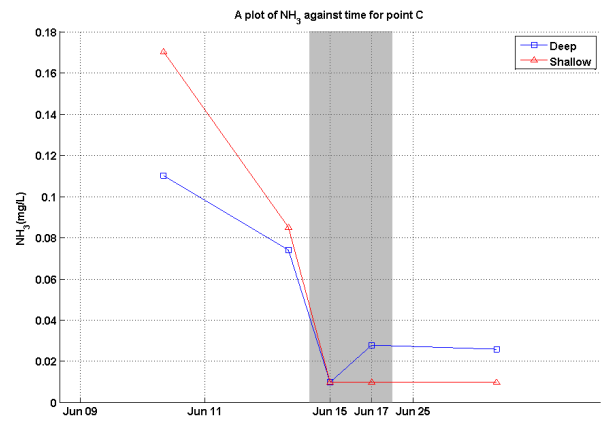


Fig. 7. A plot of NH_3 against time from samples taken from point C. The gray shaded area is the period of neap tide. The red line with triangles and the blue line with squares are the NH_3 level for the shallow and deep points respectively.

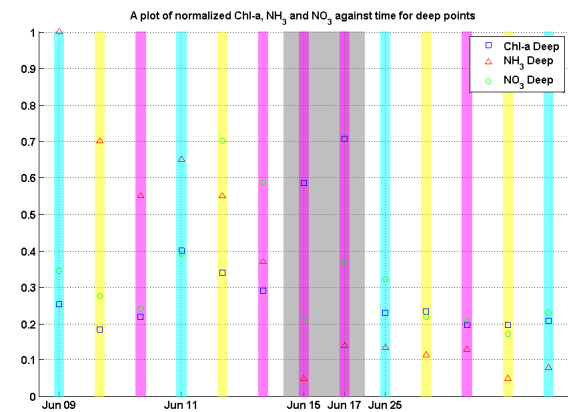


Fig. 8. A plot of normalized Chl-a, NH_3 and NO_3 against time for samples from the deep points. The various colours represent the point that the sample were taken from. Cyan represents the samples that were taken from point A, yellow represents the samples that were taken from point B and Magenta represents the samples taken from point C. The gray shaded area is the period of neap tide. The blue line with squares is the level of Chl-a, the red line with triangles is the level of NH_3 and the green line with circles is the level of NO_3 .

in Figures 8 and 9. The trend of the level of NO_3 follows the level of Chl-a. However, it cannot be concluded that NH_3 was used as the Nitrogen uptake for the phytoplankton as the trend of the level of NH_3 and Chl-a is not obvious.

The average level of NH_3 found at the shallow points is higher than the average level found at the deep points on June 25. The higher levels of NO_3 and NH_3 found in the shallow points could be due to a heavy rain that occurred in the morning of June 25. The rain could possibly bring in NO_3 due to slightly acidic rain or wash fertilizers off the grass area around the Singapore island and is transported and deposited into the Strait of Johor through the storm drains that is present throughout the Singapore island.

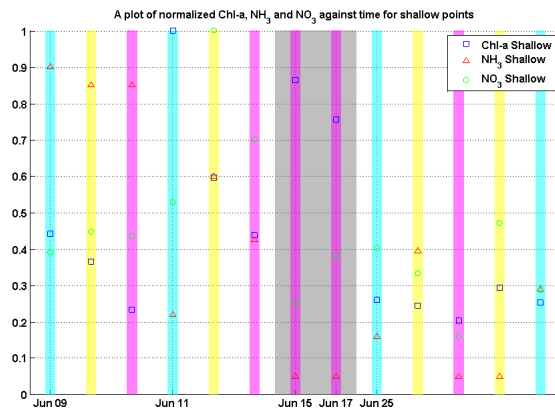


Fig. 9. A plot of normalized Chl-a, NH_3 and NO_3 against time for samples from the shallow points. The various colours represent the point that the sample were taken from. Cyan represents the samples that were taken from point A, yellow represents the samples that were taken from point B and Magenta represents the samples taken from point C. The gray shaded area is the period of neap tide. The blue line with squares is the level of Chl-a, the red line with triangles is the level of NH_3 and the green line with circles is the level of NO_3 .

VI. CONCLUSION

The design of an experiment conducted to measure parameters that would enable the study of algal blooms in the Serangoon Harbor has been described. The concentration of phytoplankton is greater near the surface of the water than in the deeper part of the water. It is also noted that the amount of phytoplankton seems to be higher during neap tide than spring tide.

Further analysis of the concentration of chlorophyll-a, NH_3 and NO_3 reveals that Nitrogen is likely the limiting nutrient in Serangoon Harbor. The phytoplankton has a preference to uptake NH_3 for their Nitrogen demand and will then consume NO_3 when the presence of NH_3 is low.

Multi-layer model simulation and data assimilation have been carried out [8] to improve the forecast using the velocity, salinity and temperature profiles measured at the various locations.

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