Causes of fish kills in Penang, Malaysia in year 2019, in conjunction to Typhoon Lekima

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Abstract

Mass fish mortalities was recorded, a day after the Typhoon Lekima passed the coastal areas at Penang, Malaysia in August 2019, which caused huge losses among the fish culturists. Being within the vicinity of a National Park, one would think that the water qualiy around a protected area should be of pristine quality but obviously it is not. Scientists and researchers from both Universiti Sains Malaysia and Department of Fisheries, with the help from NaFish have conducted several tests on the water and fish. The dead cultured fishes were mainly groupers, which prefer to stay at the bottom of the nets. The storm created by Typhoon Lekima had churned up all sediments in the shallow coastal areas. This had caused additional sediment and nutrients in the ecosystem, leading to algal bloom and also depletion of oxygen levels in the water, causing mass fish mortality. Water quality monitoring (physical, chemical and biological) was conducted along the coastal areas as well as extending towards the sea and at different depth to further understand the causes of fish kills over a period of three weeks after the incident. Sampling was done 3-days, 11-days and 26 days after the typhoon, Results had shown extremely low dissolved oxygen and high concentrations of nitrate, nitrite and chlorophyll a recorded after the typhoon. However, water quality slowly became normal and within the Malaysian Marine Water Quality Criteria & Standard for Class 2- Marine Life, Fisheries, Coral Reefs, Recreational & Mariculture.

Keywords: Mass mortality of fish, Hypoxia, Eutrophication, Algal bloom

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Introduction

Fisheries are an important sector in Malaysia, contributing to the economic growth, employment, and also as food source. In the year 2017, Penang was ranked as the third highest in the country for the wholesale value of fish production, 96,970.4 metric tonnes, values at RM1.4billion (DOF, 2017; Negin, 2019). The sector, particularly aquaculture industry in Penang has kept expending annually to meet both domestic and international demand.

Teluk Bahang, Penang, is a coastal town located off the north western coast of Peninsular Malaysia in Straits of Malacca. This area resided by fishing communities and about five villages with 244 households (Farhana *et al.*, 2012). Massive fish kills alarmed the area for the second time on 10th August 2019 after the first incident in April 2019. The occurrence and reoccurrence of fish kills has resulted in considerable public concern. In this incident all the six fish culturists in the vicinity of Teluk Bahang were badly impacted. This not only involved commercially important fishes such as groupers and snappers, but also wild fishes in the surrounding environment.

This massive fish kill event coincides with the storm brought on by Typhoon Lekima, which hit Penang Island on 9th August 2019. All the coastal areas of Penang Island experienced heavy rain, strong wind of 100 kph, and strong waves from around 9 p.m. till midnight (Loh, 2019). Storms brought by typhoons could cause environmental changes such as upwelling, terrestrial runoff particularly increase in nutrient concentration, and sediment resuspension, which affect marine ecosystems to some extents (Lim *et al.*, 2015; Aoki *et al.*, 2019).

An intensive field investigation in the area was conducted on the very next day, 11th August 2019 on the water quality and also fish samples by Centre for Marine and Coastal Studies (CEMACS), Universiti Sains Malaysia (USM). The present study investigates the connection between the substantial effects of typhoon, environmental changes in water quality, phytoplankton density and the massive fish kill event that took place in Teluk Bahang. We aim that our findings will provide basis in finding an adaptive solution to such incident in near future.

Materials and methods

Study stations

The water quality monitoring was done using a 2-dimensional approach i.e. along the coastal areas, towards the ocean from shore and the depth profile (Fig. 1a and Fig. 1b). The details of the sampling stations are shown in Table 1. Water samples were collected both from the surface and bottom. Results were presented as depth profile as well as distance from the shoreline.

Sampling methods

Both surface and bottom of seawater samples were collected on 13 August 2019, 21 August 2019 and 5 September 2019 respectively at a transect sites along the coastline and also perpendicular to the shore (Fig. 1b).

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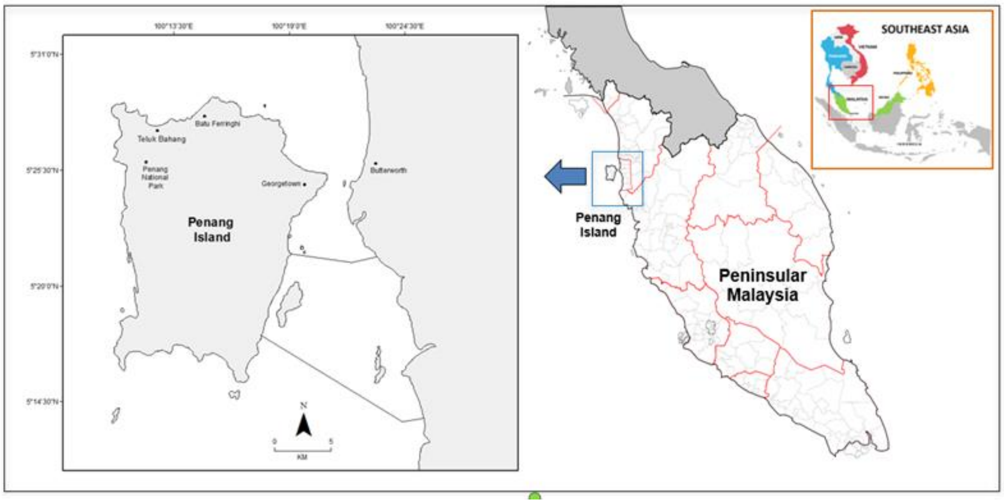

Figure 1a: Location of Penang, Malaysia.

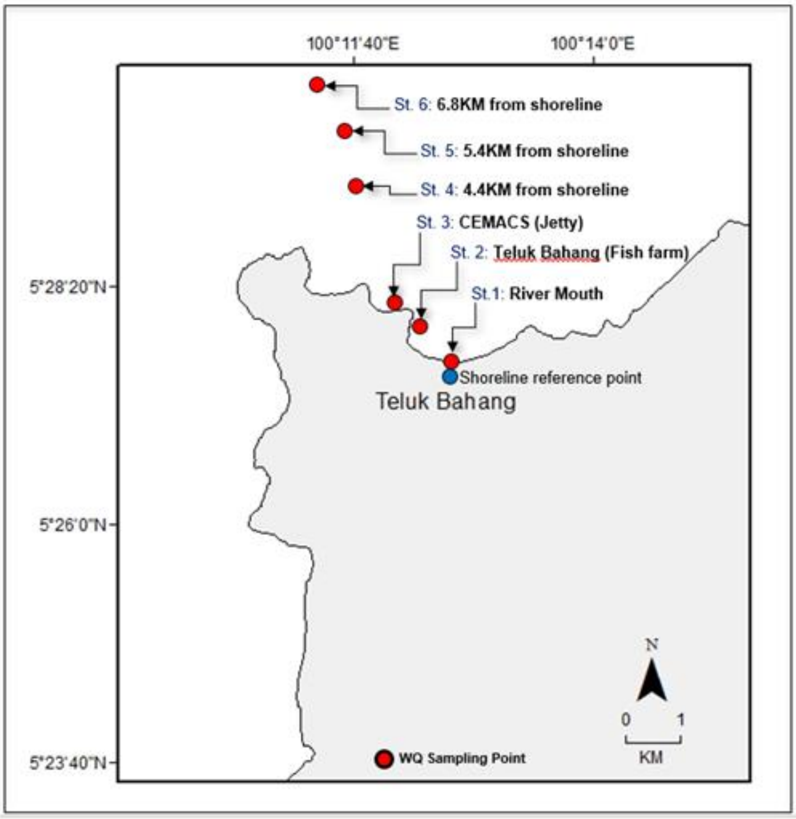

Figure 1b: Sampling points for water quality (13th Aug, 21st Aug & 05th Sep 2019; 0900am – 1200pm).

Table 1. Maximum depth (m) of each sampling station during sampling and periods.

	Maximum depth (m)		
Station	**13 August 2019**	**21 August 2019**	**05 September 2019**
River mouth	1.6	1.2	0.7
Teluk Bahang (fish farm)	4.2	3.1	2.9
CEMACS jetty	3.3	3.0	2.2
4.4KM from shoreline*	9.5	8.1	8.4
5.4KM from shoreline*	11.8	10.4	11.1
6.8Km from shoreline*	13.0	10.8	12.5

*Reference point for Shoreline located at Teluk Bahang with Lat: 05°27’34”N & Long: 100°12’32”E

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Triplicate samples were collected each for surface and bottom of seawater prior to water quality analysis. Water samples for bottom depth were collected using a Van Dorn water sampler. For both surface and bottom of seawater samples, 500 mL polyethylene bottles were rinsed with seawater prior to seawater collection (n=3). The bottles were labelled and stored in an ice box at 0°C to inactivate bacterial activities during the sampling occasion. All water samples for nutrient analysis were immediately filtered upon arrival at the laboratory and were stored in a deep freezer. All the samples were analyzed within a period of one month.

During the collection of water samples at the various sampling stations, the in-situ physical parameter readings such as dissolved oxygen (DO), salinity and temperature were taken using YSI ProPlus water quality meter. Measurements for dissolved oxygen (mg/L) were done with YSI ProPlus unit with Polarographic DO sensor; the probe was calibrated before every field sampling. The values taken for dissolved oxygen at 100% air saturation - 6.95mg/L. Meanwhile, measurements for pH reading were done in laboratory using calibrated Mettler Toledo pH meter.

Analysis of nitrite, nitrate, phosphate and ammonia were carried out using the standard titration method modified from Strickland and Parsons (1972) and Hing *et al.* (2012) in order to determine the nutrient conditions of the seawater. A spectrophotometer (UVmini-1240, Shimadzu, Japan) was used to measure the absorbance of the solution using a 1 cm quartz cuvette and distilled water as blank for all nutrient analysis.

All the readings were compared to the Malaysia Marine Water Quality Criteria & Standard (MMWQCS) for CLASS 2 - Marine Life, Fisheries, Coral Reefs, and Recreational & Mariculture (Ministry of Environment, 2005);

- Dissolved oxygen - 5.00 mg/L
- Water temperature - ≤ 2°C increase over maximum ambient
- Ammonia (unionized) - 0.07 mg/L
- Nitrate (NO_3) - 0.06 mg/L
- Nitrite (NO_2^-) - 0.055 mg/L
- Phosphate (PO_4^{3-}) - 0.075 mg/L

Surface and bottom seawater samples were collected to an aliquot of 1L volume using a Van Dorn sampler for phytoplankton analyses. Upon reaching to the laboratory, the seawater samples were pre-concentrated through 120-μm and 15-μm mesh sieves. The samples were then preserved with Lugol's iodine solution for phytoplankton density and composition analyses. Cell counts were performed using a Sedgewick-rafter chamber under a trinocular inverted light microscope (Motic AE2000). Identification was carried out until species levels whenever possible following Tomas (1997), Omura *et al*. (2012), and Tan *et al.* (2016).

Results from the water samples taken on 13 August (3 days after event of fish kills), 21 August (11 days after the event) and 5 September 2019 (26 days after the event) were presented.

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More detail sampling sites were conducted and a projection of 2-D results (distance from shoreline and depth profile) was presented.

Notes to the sampling dates:

13th August 2019 (3 days after typhoon): Close to spring tide/ Flooding tide

21st August 2019 (11 days after typhoon): Close to neap tide / Flooding tide

05th September 2019 (26 days after typhoon): Close to neap tide / Ebbing tide

Results

Temperature and salinity

Average water temperature recorded from range 30.20 - 30.70 °C (Surface - 4.0m depending on depth of station) on 13 August 2020 and 30.30 - 30.70 °C (Surface - 4.0m depending on depth of station) on 21 August 2020. Average water temperature slightly low on 5 September 2019 from range 30.00 - 30.20 °C (Surface - 4.0m depending on depth of station) compare to previous sampling dates. Salinity was consistent throughout the sampling period range from 29.89 - 30.52 ppt (13 August 2020); 29.32 - 30.40 ppt (21 August 2020) and 29.28 - 30.34 ppt (5 September 2019). Salinity recorded from river mouth slightly low (29.28 - 30.33 ppt) compare to other stations.

Dissolved oxygen

Figure 2 shows the dissolved oxygen levels recorded during the water quality monitoring. On 13 August 2019 (3 days after Typhoon Lekima), the dissolved oxygen levels were extremely low (below 5 mg/L) from the river mouth till about 5.4km offshore, especially at the bottom on 21 August 2019 (11 days after Typhoon Lekima), the dissolved oxygen levels recorded were mainly above the MMWQCS (Class 2) of 5mg/L. On 5 September 2019 (26 days after Typhoon Lekima), the dissolved oxygen levels recorded were all above the MMWQCS (Class 2) of 5mg/L.

Turbidity

Figure 3 shows the results of turbidity measurements at the sampling stations. On 13 August 2019, the turbidity levels were higher at the distance of 4.4.km till 6.8km offshore (above 20 NTU), especially at the bottom. On 21 August 2019, the turbidity levels recorded were generally below 20 NTU. On 5 September 2019, the turbidity levels were low at the surface but were around 3-40 NTU around the bottom at the distance of 2 km till 5.5 km offshore.

pH

Figure 4 shows the pH levels at all the sampling stations during the three sampling events. On 13 August 2019, the pH levels were more towards acidic especially near the river mouth, both surface and bottom. This is not surprising due to the heavy rainfall a couple of days before the sampling date. On 21 August 2019, the pH level has shown signs of approaching the normal seawater pH, which is slightly alkaline. On 5 September 2019, the pH levels seemed to be at normal level.

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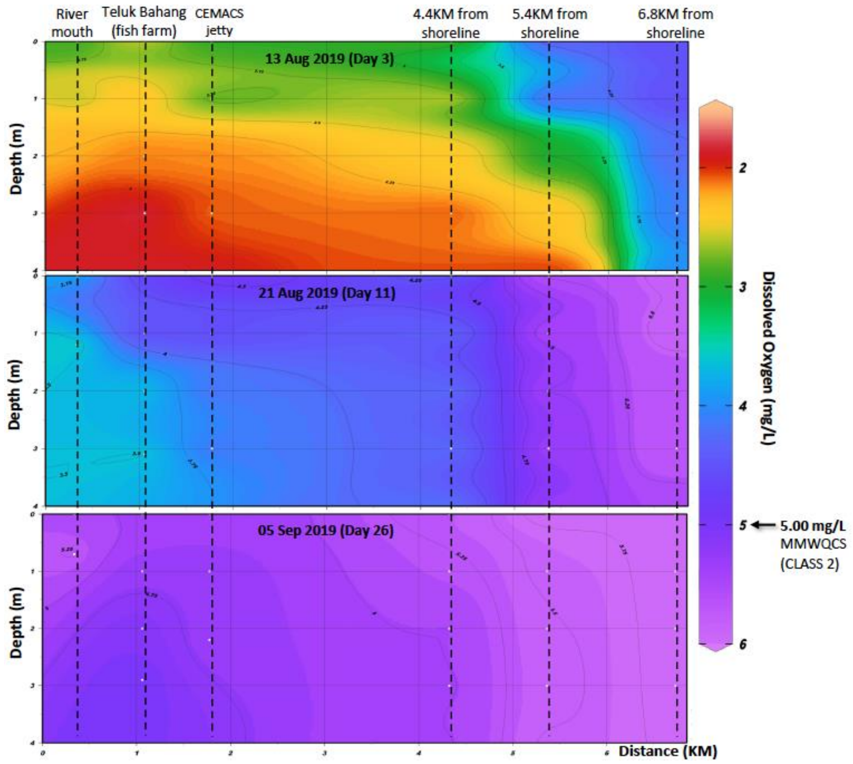

Figure 2: Concentration of Dissolved Oxygen (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27'34"N/Long: 100°12'32"E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples measured on 13th Aug, 21st Aug & 05th Sep 2019.

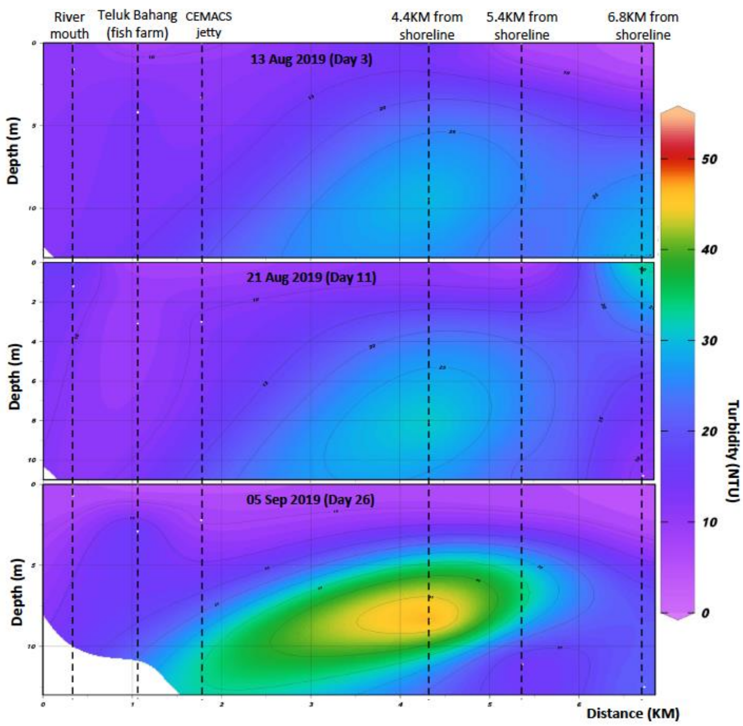

Figure 3: Turbidity (NTU) level at different depths from 0-7KM distance from shoreline (Lat: 05°27'34"N/Long: 100°12'32"E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples measured on 13th Aug, 21st Aug & 05th Sep 2019.

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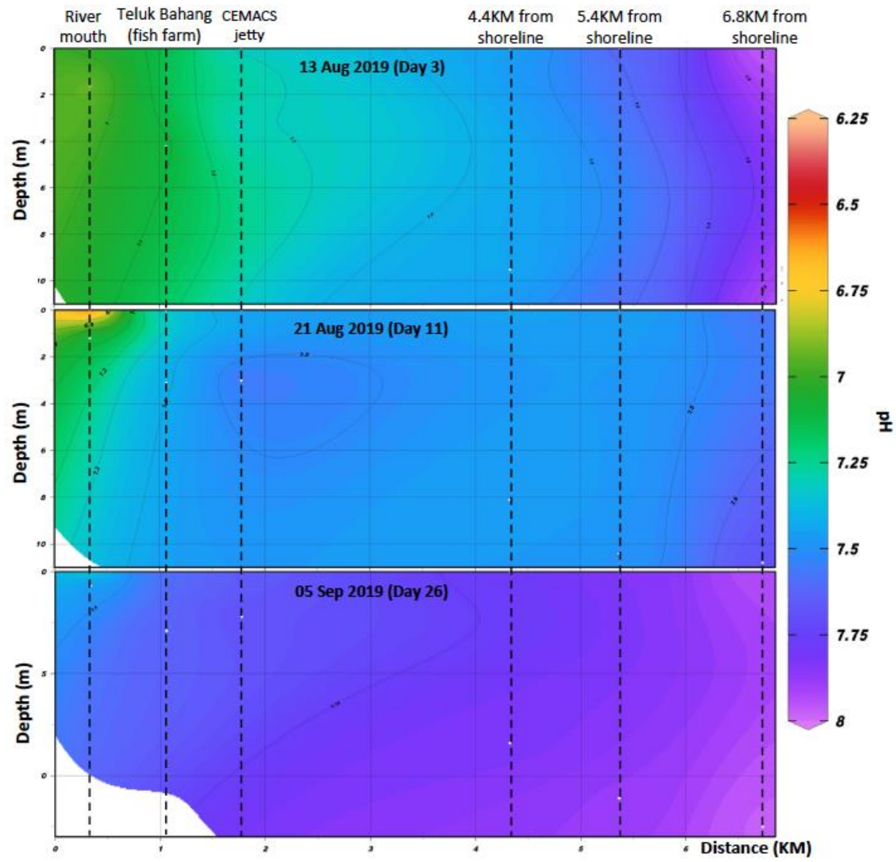

Figure 4: The pH level at different depths from 0-7KM distance from shoreline (Lat: 05°27'34"N/Long: 100°12'32"E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples measured on 13th Aug, 21st Aug & 05th Sep 2019.

Ammonia

Figure 5 shows the ammonia levels at all the sampling stations during the monitoring duration. On 13 August 2019, the ammonia levels were above the 0.07mg/L MMWQCS standard for Class 2 water quality. Higher levels of ammonia were recorded beyond 6km offshore (both surface and bottom). On 21 August 2019, the ammonia level has shown signs of approaching the normal seawater ammonia. On 5 September 2019, the ammonia levels were very high and the concentration had increased starting from the fish farm towards offshore (both bottom and surface samples).

Nitrate

Figure 6 shows the nitrate levels recorded at all the sampling sites during the three sampling events. On 13 August 2019, the nitrate levels were overall above the 0.06mg/L MMWQCS standard for Class 2 water quality. On 21 August 2019, the nitrate levels were within the Class 2 MMWQCS Standards except for samples taken from the river mouth. On 5 September 2019, the nitrate levels seemed to be at normal level.

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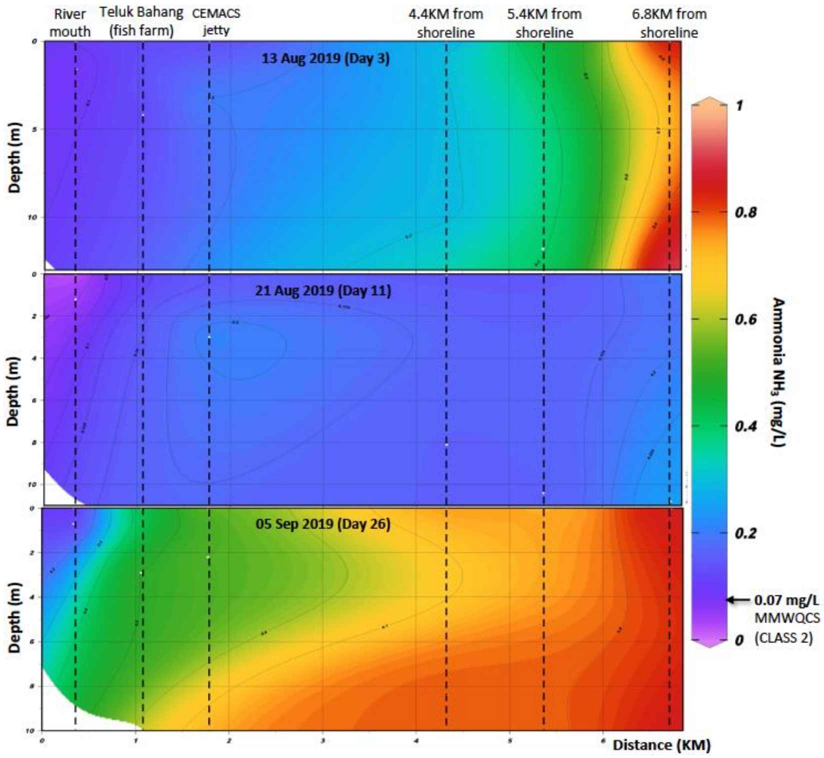

Figure 5: Concentration of Ammonia NH_3 (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27’34”N/Long: 100°12’32”E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples collected on 13th Aug, 21st Aug & 05th Sep 2019.

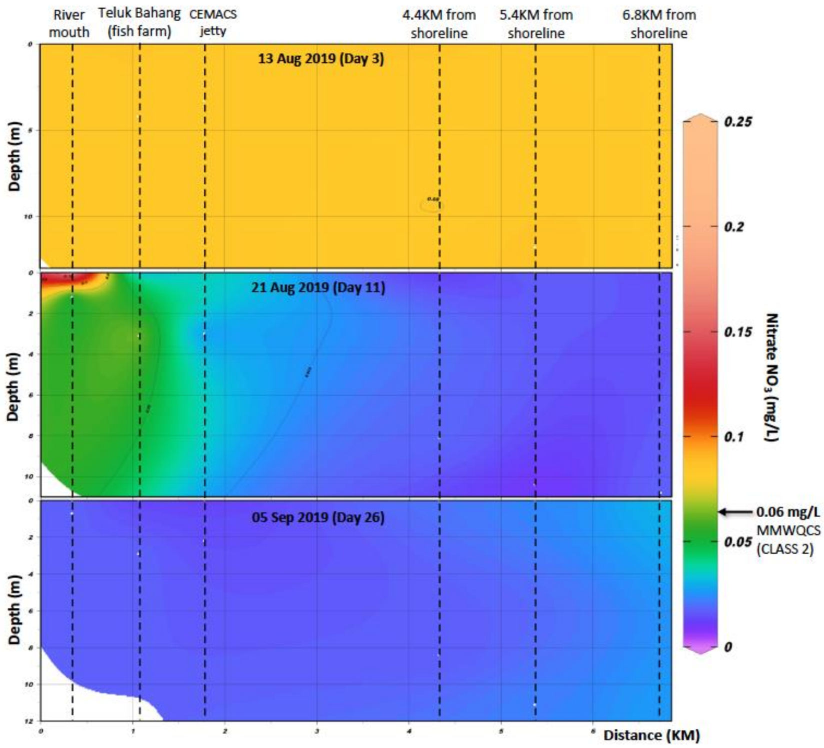

Figure 6: Concentration of Nitrate NO_3 (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27’34”N/Long: 100°12’32”E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples collected on 13th Aug, 21st Aug & 05th Sep 2019.

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Nitrite

Figure 7 shows the results of nitrite concentrations at all sampling stations throughout the monitoring period. On 13 August 2019, the nitrite levels were overall above the 0.055mg/L MMWQCS standard for Class 2 water quality. On 21 August 2019, the nitrite levels for all sampling sites and depth were within the Class 2 MMWQCS Standards. On 5 September 2019, the nitrate levels seemed to be at normal level but the levels bottom samples of offshore sites were slightly higher.

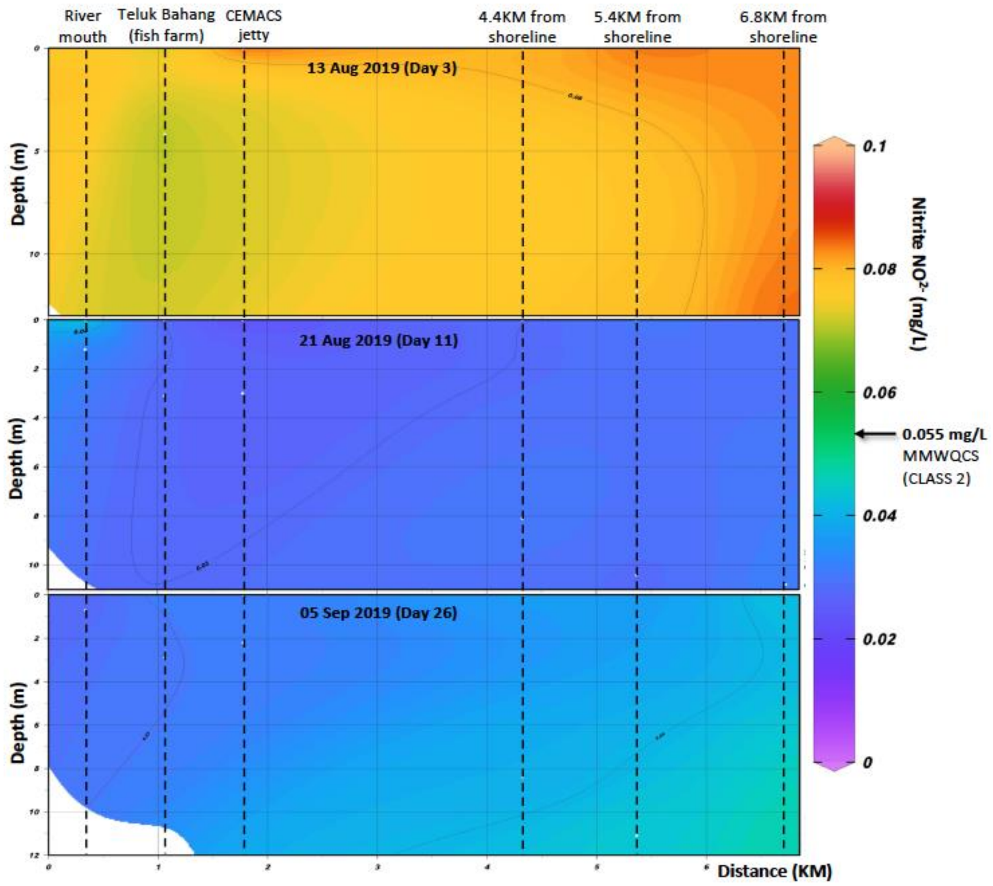

Figure 7: Concentration of Nitrite NO^{2-} (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27'34"N/Long: 100°12'32"E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples collected on 13th Aug, 21st Aug & 05th Sep 2019.

Phosphate

Figure 8 shows the phosphate levels at all sampling stations. On 13 August 2019, the phosphate levels were overall above the 0.075mg/L MMWQCS standard for Class 2 water quality. On 21 August 2019, the phosphate levels were higher compared to results on date 13 August and exceeded the Class 2 MMWQCS Standards. Highest concentration was recoded near surface till 4 m for samples taken from the river mouth. On 5 September 2019, the phosphate levels seemed to be below the 0.075mg/L MMWQCS Standard Class 2.

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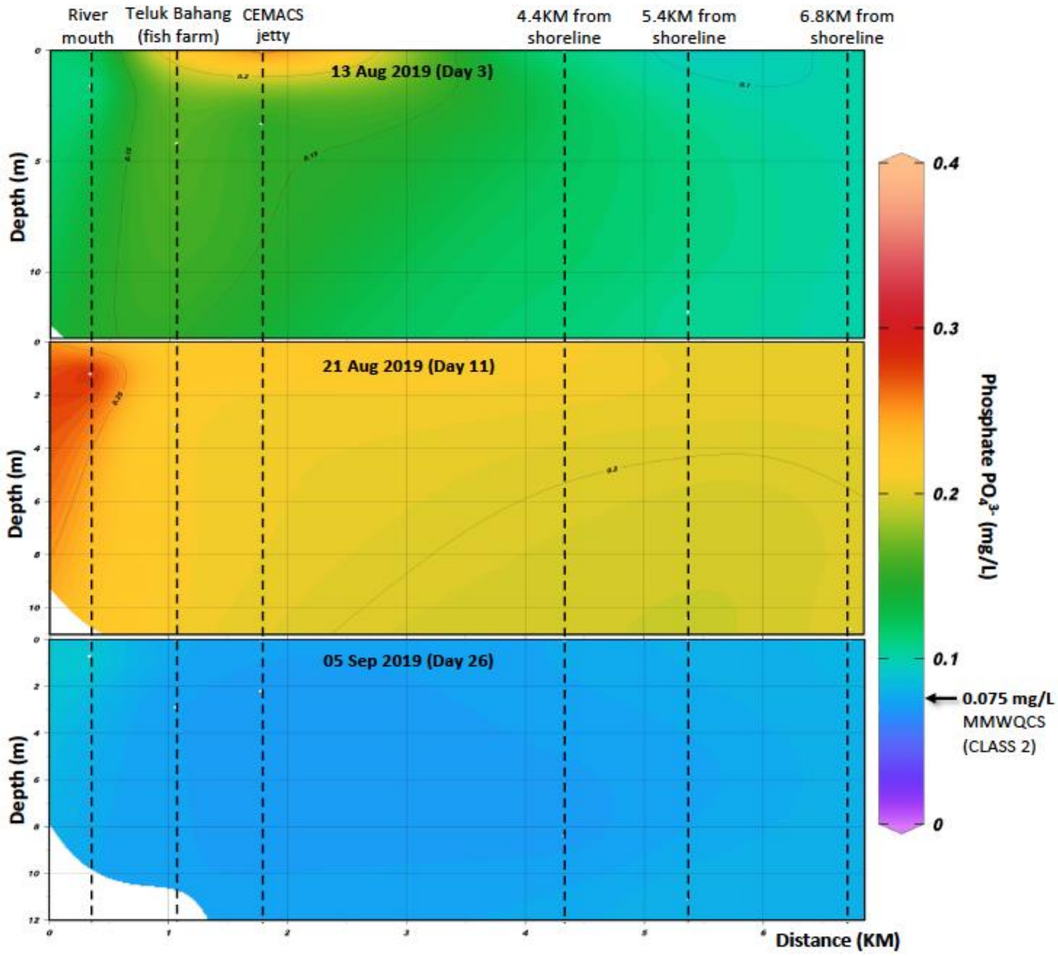

Figure 8: Concentration of Phosphate PO_4^{3-} (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27'34"N/Long: 100°12'32"E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples collected on 13th Aug, 21st Aug & 05th Sep 2019.

Chlorophyll a concentration

Chlorophyll-a is a measure indicating the present of phytoplankton in the water. Figure 9 shows the concentrations of chlorophyll a at all the sampling stations during all the sampling events. On 13 August 2019, the chlorophyll-a levels were overall high especially from surface to bottom at the sites of river mouth, fish farm until about 2.5km from shoreline. On 21 August 2019, the chlorophyll-a levels were overall high, with the highest concentration recorded around the river mouth towards the fish farm. However, the coverage of high density of chlorophyll-a was lower on 21 August compared to samples collected on 13 August. On 5 September 2019, the chlorophyll-a levels seemed to be reduced in concentrations.

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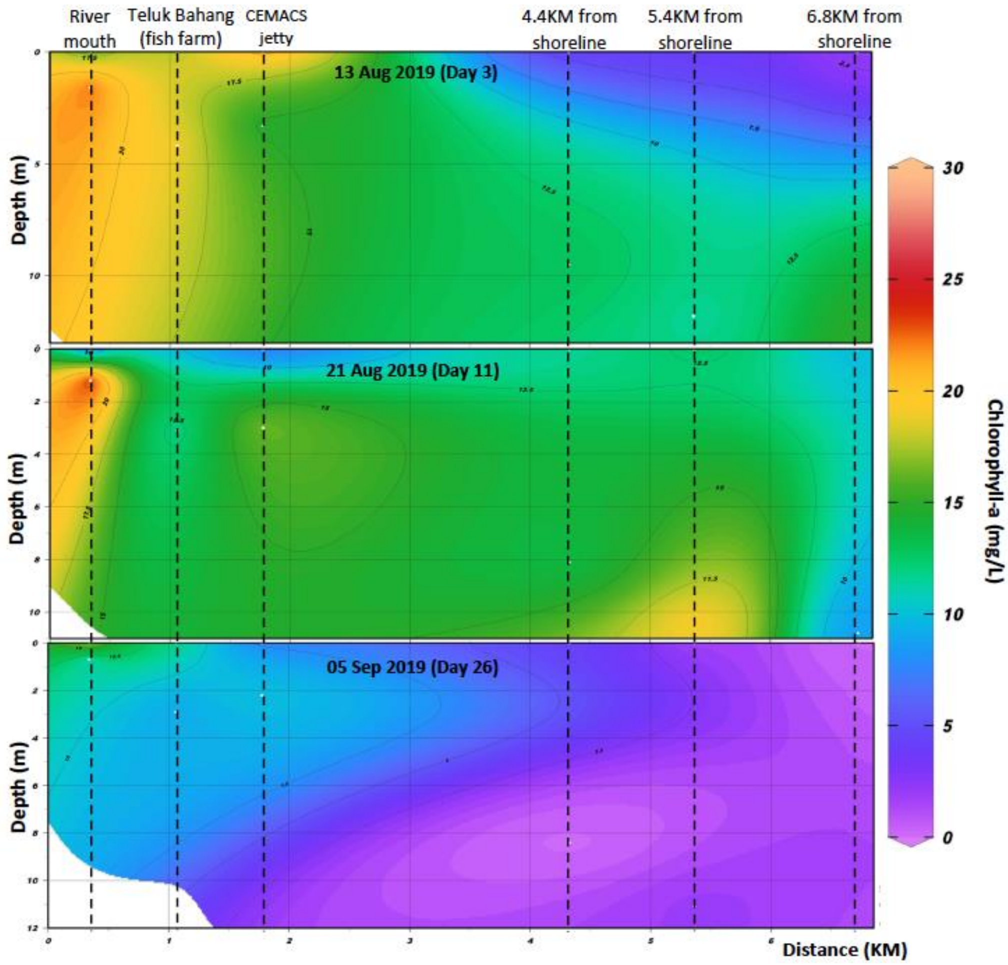

Figure 9: Concentration of Chlorophyll-a (mg/L) at different depths from 0-7KM distance from shoreline (Lat: 05°27’34”N/Long: 100°12’32”E). Graph generated using Ocean Data View ODV 5.1.7 from coordinates and water samples collected on 13th, 21st Aug and 5 September 2019.

Phytoplankton density and observation

The phytoplankton was predominantly centric diatom and some pennate diatom. No known harmful or ichthyotoxic dinoflagellate or raphidophytes species were observed in the samples collected on 13 August 2019. Figure 10 shows the phytoplankton samples were observed under compound light microscope.

Centric diatoms, *Coscinodiscus* spp. dominated with cell density of 32,243 cells/L. On 21 August 2019, the dominance of phytoplankton shift towards *Chaetoceros* spp. with high cell density of 950,000 cells/L, followed by *Eucampia* sp. with 314,286 cells/L. Raphidophyte *Chattonella* sp. was observed but in acceptable amount of 1,471 cells/L. On 5 September 2019, phytoplankton were dominated by *Guinardia* sp. with cell density of 61,945 cells//L. Raphidophyte, *Chattonella* sp. was observed but in acceptable amount of 2,728 cells/L.

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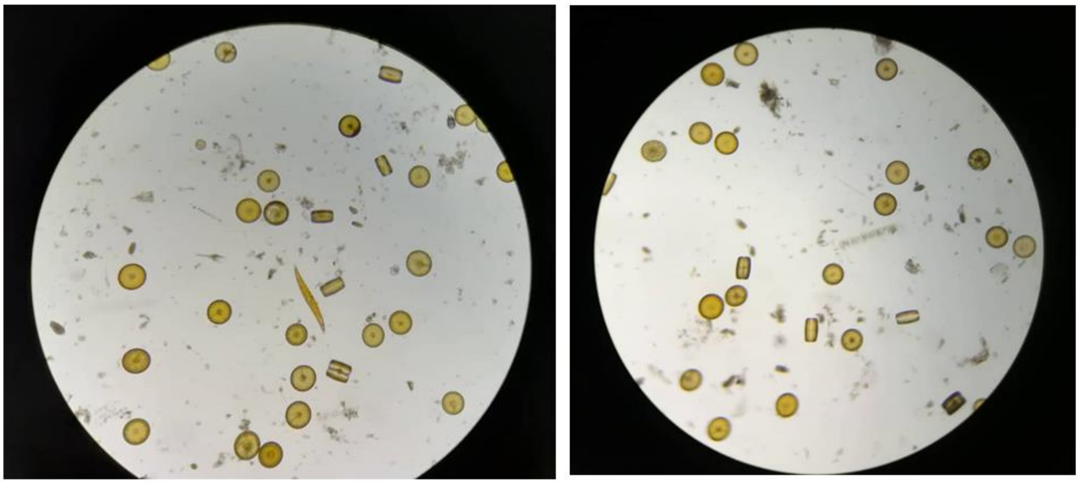

Figure 10: Phytoplankton composition collected on 13 August 2019, reflecting a dominance of centric diatoms, *Coscinodiscus* spp.

Discussion

The results of the event and after the event (11 days and 26 days after the event) had been compared and a clearer picture to address the issues of fish kills at Teluk Bahang had been generated. The results had shown that the water quality at the studied locations are mostly exceeded the recommended limits of MMWQCS standard for Class 2 water quality (for aquaculture and recreation), especially for dissolved oxygen and the nutrients (ammonia, nitrate, nitrite and phosphate) at 3 days sampling after the typhoon. Chlorophyll levels were also high.

The dissolved oxygen concentrations were found to be extremely low at both the surface and bottom profiles at the coastal areas but had extended to a distance as far as 5km away from the shoreline for surface profile and 6km away from the shoreline for bottom profile. This is a reflection that the entire coastal areas to as far as 5-6km from shoreline were experiencing low dissolved oxygen at 3 days after the fish kills been reported in the study area. However, the dissolved oxygen concentrations were shown to be recovering (DO between 3.5-4.5 mg/L) during the sampling at 11 days after the fish kills been reported and became stable or return to permissible values (DO between 5-6 mg/L) by day 26. DO is important to marine life and to primary productivity. DO affect primarily the composition and decomposition of organic matter, the dynamic processes in seawater and air sea interaction. In first three day after typhoon, the drastic decrease in DO is followed by increased concentration of chlorophyll-a show the representative of phytoplankton abundance and organic matter in seawater. Kress *et al.* (2002) reported that when oxygen required for oxidation of organic matter exceeds the oxygen produced by photosynthesis, the dissolve oxygen level in the water might ultimately decrease. Then, the increase of DO after the 11- day typhoon could contribute by reduction of chlorophyll-a and nutrient

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rich water. It may have an impact in improving primary productivity, resulting in increased oxygen production. Another reason that increases DO return to normal is the effect of lowering water temperature that increases oxygen solubility in water.

The pH had been detected at a lower range at the shoreline for both surface and bottom profiles, especially during the sampling of 3 days after the fish kill incident. The pH levels has shown signs of recovering on the sampling at 11 days after the fish kill incident and returned to normal condition after then. It was found that the source of pH reduction was land-based. The drop in pH during early typhoon may be caused by current induced strong winds that could carry open sea oceanic water with high salinity into coastal areas and lead to increased salinity coastal waters. The heavy rainfall and associated run-off, however, could balance the changes and decrease the salinity, also leading to decrease in seawater pH (Li *et al*., 2009). Moreover, as the associated chemoautotrophic nitrification process started, the process uses oxygen and releases hydrogen ions that can cause pH and DO to fall. Seawater pH normalization is alongside DO. After 11-days of typhoon it seems to have positive impact on pH and DO. In an environment with low organic matter and low respiration levels, any hydrogen ions released may be absorbed by the alkalinity of surrounding seawater and resulted in increased pH (O'Boyle *et al.,* 2013).

The results for ammonia throughout the samplings (3 days, 11 days and 26 days after the fish kill incident) seemed to be different from other nutrients. The extremely high concentrations of ammonia were recorded on the sampling 26 days after the fish kill incident, and the source seemed to be from the farthest from the shoreline. This is very interesting fact, as the ammonia concentration increased after day 26 of typhoon. Further investigation is needed in order to find the cause of this. The effects of rising ammonia levels in seawater actually do not act in isolation; many other factors contribute such as increasing human pressure, including climate change (e.g. temperature, rising carbon dioxide, hypoxia etc.). Ammonia's aquatic toxicity is principally due to the unionised form (NH_3) (Wurts, 2003). As pH increases, the toxicity of ammonia increases because the relative proportion of unionised ammonia increases. The toxic level of ammonia to fish is both pH and temperature dependent (Stuart, 2010). Toxicity increases as pH increases and as temperature increases. Ammonia levels in excess of the recommended limits may harm aquatic life.

The other three nutrients measured i.e. nitrate and nitrite, were found to be exceeded the permissible levels of the recommended limits of MMWQCS standard for Class 2 water quality (for aquaculture and recreation), in the results of the sampling on 3 days after the fish kill incident. However, the concentrations of these parameters

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seemed too reduced and returned to permissible levels on the 11 days and 26 days samplings after the fish kills incident. The results also showed that the source of nitrate was land-based because a higher concentration of nitrate was recorded nearest to the shoreline.

Phosphate concentrations are extremely high during the sampling on the 11 day after the fish kill incident comparatively to 3 days and 26 days after the fish kill incident. This finding result was similar to Wang *et al.* (2016); they claimed this incident happened due to the role of vertical mixing resulting from the strong wind effect. As the wind subsided, the run-off and open oceanic water intrusion became more important for changing the physical and chemical parameter. The rise in phosphate at 11-days after typhoon also has greatly caused the growth of phytoplankton in seawater (Fig. 9).

Phytoplankton composition showed that the majority of the phytoplankton found in the samples was not harmful species but they might have indirect association to fish mortality. Phytoplankton has the role and importance in ecological function as a primary producer that directly and indirectly fuels the food chain (Domingues *et al.,* 2008). They have important impacts on water quality by affecting turbidity and concentration of dissolved oxygen and play other major roles in many ecosystem processes. On 13 August 2019, although chlorophyll *a* was high, the phytoplankton density was approaching normal range of 100,000 cells/L. This could be due to an overestimation of chlorophyll, which was caused by high turbidity (Katlane *et al.,* 2012). On 21 August 2019, chlorophyll *a* concentration was high especially in river mouth and fish farm. This was in accordance with abnormally high total phytoplankton density of 1,563,896 cells/L in surface and bottom water column compared to 13 August 2019. High presence of phytoplankton might cause less penetration of sunlight to the seawater and eventually may lead to reduced dissolved oxygen for the other marine organism. In other words, this might inadvertently result in fish kill event as in 13 August 2019. The condition was further deteriorated by low pH making the fishes more vulnerable than what they were used to. Some phytoplanktons were able to adapt to changes in pH, this mean only the phytoplankton composition would shift towards more their favourable conditions. During the Typhoon Lekima, there might be a small scale nutrient upwelling in which nutrient being brought up to the surface seawater and this would promote phytoplankton growth. High nutrient concentrations were indicative of high phytoplankton productivity, with conditions conducive to diatom blooms (Roberts *et al.,* 2019). On 13 August 2019 after 3 days of typhoon generally there was high nutrient and suitable for certain phytoplankton such as *Coscinodiscus* sp. coupled with other environmental factors and later on shift

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towards *Chaetoceros* sp. on 21 August 2019 which was abnormally high in cell density in particular phosphate was relatively higher than on 13 August 2019. This suggests different species had different preference on the growth conditions.

The storm and strong water current that had been caused by the Typhoon Lekima had churned up the sediments and nutrients at the seafloor, thus leading to the drastic changes and degradation of the water quality surrounding the coastal areas of Penang. This had also caused stress to the living organisms in the surrounding waters. The cultured fish, which were in captivity and at high density (compared to the wild fishes), faced the extreme conditions (e.g. low dissolved oxygen)

The results 11 days and 26 days after the massive fish kills incident showed that the water quality results at study site are mostly within the MMWQCS Class 2 Standard.

Conclusion

The study examined the possible marine pollution factors that had caused the death of cultured fish in Penang in conjunction to Typhoon Lekima. The storm and the strong currents from the typhoon may have churned up sediments and seafloor and caused drastic changes in the water quality around the affected coastal areas. Further investigation needs to be done to further understand the causes of the massive fish mortality.

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