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Assessment of Spatial and Temporal Variations of Water Quality for Future Mariculture Operation in Ambong Bay, Sabah, Malaysia

Fang Sing Ong, Julian Ransangan

Borneo Marine Research Institute, University Malaysia Sabah, Kota Kinabalu, Malaysia
Email: liandra@ums.edu.my

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Abstract

Study was conducted with the aim to understand the temporal and spatial variations of water quality parameters (temperature, salinity, pH, DO, TSS, NO_3^-, NO_2^-, NH_3-N and PO_4-P, and phytoplankton cell density) in Ambong Bay, Sabah, Malaysia in order to provide reference for future mariculture development in the bay. Samplings were carried out once a month in two stations (coastal and open sea) within the bay for 12 months period from September 2015 to August 2016. Results showed that there were significant differences in pH and NO_2^- when compared spatially, whereas salinity, DO, TSS, phytoplankton cell density, NO_3^-, NH_3-N, and PO_4-P were temporally significant. The fermentation processes by anaerobic bacteria, organic acids from decaying vegetation and acidic clays in the mangrove soils might explain the significant spatial differences in pH and NO_2^-. The bay was dominated by dinoflagellate, *Prorocentrum* spp. (mean abundance of 16.23% and 24.44%, respectively) a potentially toxic algae species. Correlation matrix showed that NH_3-N was positively correlated with PO_4-P ($r = 0.475$, $p < 0.05$) but negatively correlated with salinity ($r = -0.517$, $p < 0.01$). Besides, salinity was positively correlated with DO ($r = 0.505$, $p < 0.05$) and TSS ($r = 0.408$, $p < 0.05$). In addition, DO and TSS were also positively correlated ($r = 0.451$, $p < 0.05$). Phytoplankton cell density was positively correlated with TSS ($r = 0.644$, $p < 0.01$). In general, the water quality in Ambong Bay is within the standard values permitted by the Malaysia Marine Water Quality standard for marine life, fisheries, coral reefs, recreational and mariculture (Class 2), except for NO_3^-. In conclusion, any mariculture operation to take place in Ambong Bay in the near future should take the temporal variation of the water quality into account. Moreover, effects of toxic phytoplankton to culture fishes should also be taken care and monitored frequently.

Keywords

Water Parameters, Spatial and Temporal Variations, Ambong Bay, Aquaculture

1. Introduction

Quality of seawater plays important role in human health, marine organisms and ecosystem. Good water quality is also needed to maintain feasible aquaculture production because water is necessary requirement for fish farming. Fish perform all its physiological activities in the water. Thus, the maintenance of good water quality is essential for survival and optimum growth of culture organisms, as well as the success or failure of an aquaculture operation [1].

Physical properties of seawater include temperature and total suspended solids (TSS), are factors which determine the equilibrium structure in the marine ecosystem, whereas chemical characteristics such as pH, dissolved oxygen (DO), salinity, and water nutrients (e.g. nitrogen and phosphorus) are crucial in biological productivity because of its influence on physiological processes inaquatic organisms [2]. Phytoplankton is important biological parameters which represent the primary food supply in any aquatic system hence minor change in physico-chemical parameters can influence this primary production [3].

Ambong Bay is situated in the Southern part of Kota Belud, about 50 km north of Kota Kinabalu, the capital city of Sabah. The bay is shared and governed by Tuaran and Kota Belud district offices. The inner part of the bay is fringed by mangrove forests while the outer part is formed by beautiful sandy beach [4]. Mangrove is important coastal vegetation that provides natural habitat to many marine lives in the bay. Numerous commercially important fish, shellfish and prawn species rely on mangrove for their life cycles [5]. This makes Ambong Bay a potential area for both tourism and mariculture.

Mangrove habitats are known to be an important spawning, breeding and nursery ground for many fishes and prawns [6]. However, the growing human population surrounding the bay has contributed to the exploitation of water and mangrove areas for mariculture and human settlement [4]. To date, study on water quality in the area has only been done in the nearby coastal waters (e.g. [7]) and none has been done within the bay. Previous study conducted in the bay was mainly focused on human intervention on mangrove area (e.g. [4]). Therefore, current study was conducted to understand the temporal and spatial variations of surface water parameters (temperature, salinity, pH, DO, TSS, phytoplankton cell density and water nutrients) for better future planning and management of mariculture operation in the bay.

2. Materials and Methods

2.1. Sample Collection

Samplings were carried out once a month in Ambong Bay, Sabah for 12 months period (September 2015-August 2016). Sampling stations were situated nearby Kampung Baru-Baru (Figure 1), one of the bivalve mollusc culture farms in the area which focus mainly on green-lipped mussel (*Perna viridis*) and Pacific oyster (*Crassosstrea gigas*) culture. Kampung Baru-Baru is also one of the villages participating in "Green-lipped Mussel Rearing Project" organized by the Sabah Fisheries Department. Coastal station (06˚17'59.2''N, 116˚17'36.22''E) was located at the inner part of the bay and was surrounded by mangrove forests, whereas open sea station (06˚18'16.9''N, 116˚18'16.6''E) was located approximately 2 km away from the coastal station.

Temperature (˚C), salinity (psu), pH, and dissolved oxygen (mg/l) of the seawater at 0.5 m below water surface were measured *in-situ* using a multi-function environmental sensor (YSI, Loveland. Co, USA). Water samples were collected at 0.5 m below water surface using a *Van Dorn* water sampler for total suspended solids (TSS) and phytoplankton cell density analyses.

2.2. Sample Analysis

In laboratory, water samples were filtered through GF/C glass microfiber filters (Whatman™, No. 1822-047) for TSS analysis. Filtered water samples were then stored in refrigerator (4˚C) for water nutrients analysis. The inorganic nutrients,

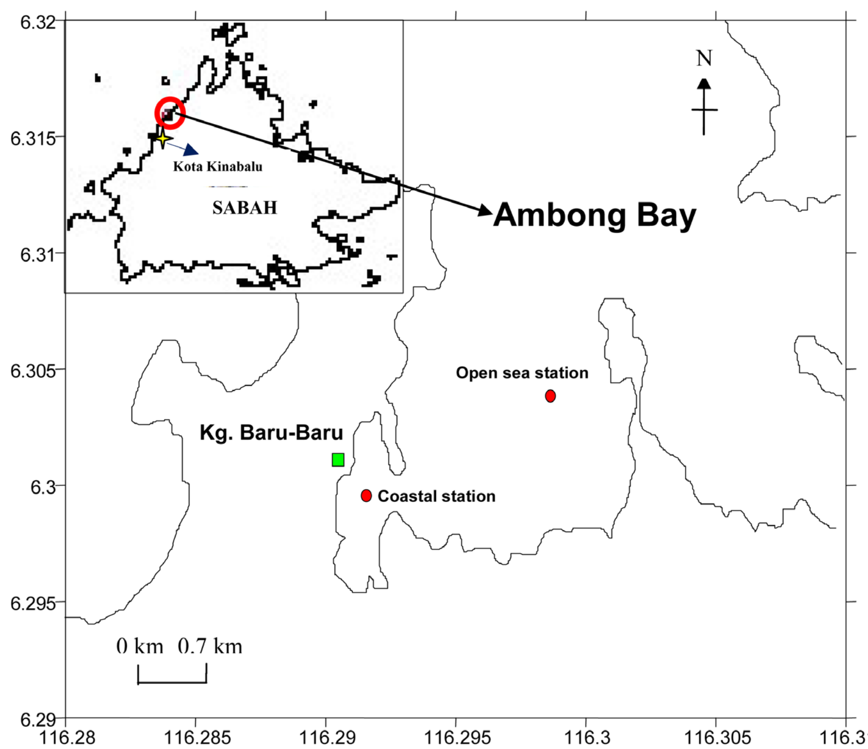

Figure 1. Location of sampling stations (coastal and open sea) in Ambong Bay.

including total dissolved phosphorus (PO_4-P), total ammonia-nitrogen (NH_4-N), nitrate (NO_3^-) and nitrite (NO_2^-) were analyzed following [8].

The filters for TSS analysis were then dried to constant weight in an oven for 24 hours at 105˚C. The difference in weight over that of the fully dried empty filters represents the TSS (mg/L) [9].

For phytoplankton cell counting, the water samples were preserved with Lugol's solution in the field. In the laboratory, samples were poured into a one litre measuring cylinder and left concentrated for 24 hours using Utermöhl sedimentation method [10]. The supernatant were then discarded and retained only about 50 ml. The phytoplankton cell densities were then quantified using a Sedgwick Rafter chamber under a Carl Zeiss microscope at 400× magnification [11].

Data on rainfall for Ambong Bay area was obtained from Malaysia Meteorological Department.

2.3. Statistical Analysis

Statistical analyses were performed using the SPSS statistics software. Tests were judged to be significant at $p < 0.05$ level. Pearson's correlation coefficient test was performed to evaluate the relationship between the water parameters. One-way ANOVA test was applied to test for significant differences in environmental variables, water nutrients, and phytoplankton cell density among stations and months.

3. Results and Discussion

The summary of waters parameters (mean ± SE, range) at the coastal and open sea stations in Ambong Bay from September 2015 to August 2016 is shown in **Table 1**.

Table 1. Water parameters of the two sampling stations in Ambong Bay from September 2015 to August 2016.

Parameters	Coastal Station		Open Sea Station	
	Mean ± SE	Range	Mean ± SE	Range
Temperature (˚C)	31.42 ± 0.32	30.0 - 33.2	30.83 ± 0.36	28.3 - 33.1
pH	7.67 ± 0.08	7.45 - 8.07	7.89 ± 0.06	7.56 - 8.30
Salinity (psu)	33.22 ± 0.42	30.75 - 34.94	33.08 ± 0.38	30.98 - 34.61
DO (mg/l)	5.04 ± 0.26	3.12 - 6.60	5.60 ± 0.29	3.66 - 7.00
TSS (mg/l)	0.0515 ± 0.020	0.0182 - 0.2672	0.0454 ± 0.024	0.0133 - 0.2756
NO_3^- (mg/l)	0.3091 ± 0.0823	0.0805 - 0.9898	0.1850 ± 0.0386	0.0305 - 0.4562
NO_2^- (mg/l)	0.0009 ± 0.0002	0.0002 - 0.0023	0.0004 ± 0.0001	0.0001 - 0.0008
PO_4-P (mg/l)	0.0078 ± 0.0013	0.0027 - 0.0188	0.0066 ± 0.0008	0.0041 - 0.0107
NH_3-N (mg/l)	0.0464 ± 0.0035	0.0278 - 0.0642	0.0443 ± 0.0046	0.0282 - 0.0834
Phytoplankton density (cell/ml)	5.30 ± 2.61	0.81 - 26.55	5.39 ± 2.36	0.64 - 24.96

3.1. Temperature

As shown in **Figure 2**, highest water temperature recorded in coastal and open sea stations was 33.2˚C in November 2015 and 33.1˚C in May 2016, respectively, whereas the lowest was 30.0˚C in August 2016 for coastal station and 28.3˚C in February 2016 for open sea station. The mean value of temperature for the two stations was in the range of 30.83˚C to 31.42˚C (**Table 1**). Ambong Bay is located on the west coast of Sabah, where it is experiencing equatorial climate and regular temperature throughout the year [12]. The range of temperature was probably due to the time of sampling, which affected by tide and heating from the sun [13]. Although there were variations in water temperatures between the two stations indifferent months, these variations are not significant ($p > 0.05$). According to [14], water temperature for tropical aquaculture species is best at 25˚C - 32˚C. This suggests that the water temperature in Ambong Bay is still within the optimum level for aquaculture.

3.2. pH

The pH measurements recorded in the two stations are presented in **Figure 3**. It was noticed that the pH in open sea station was highest (8.30) in October 2015 and lowest (7.56) in December 2015. For coastal station, maximum pH was recorded in October 2015, at 8.07 and minimum in July 2016 at 7.12. In general, pH value in open sea was higher, with mean of 7.89 ± 0.06, while coastal station was 7.67 ± 0.08 (**Table 1**). Although pH recorded in the two stations showed to have significant difference ($p < 0.05$), variations of pH within the station throughout the sampling period were insignificant ($p > 0.05$). The presence of fermentation process by anaerobic bacteria forming organic acids [15] [16], decaying vegetation and acidic clays [17] [18] in the mangrove soils might explain the lower pH recorded in the coastal station. According to [18] and [13], pH may also

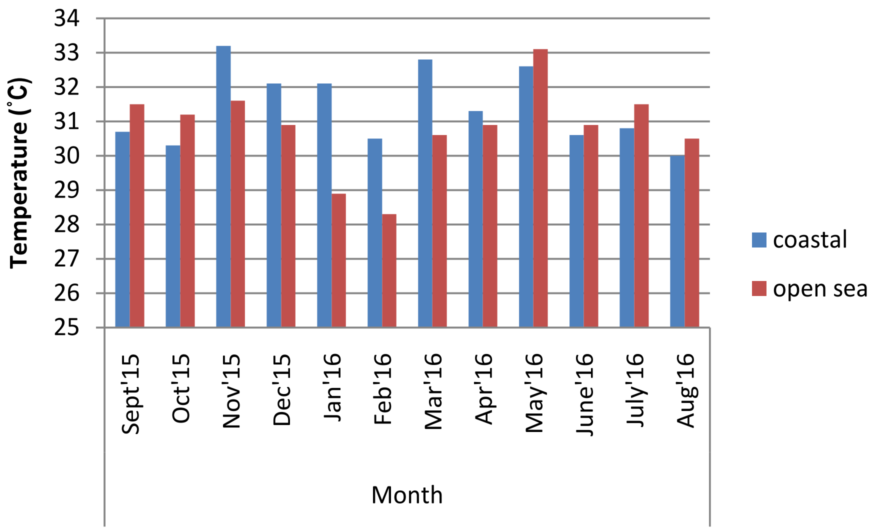

Figure 2. Temperature (˚C) recorded in sampling stations from September 2015 to August 2016.

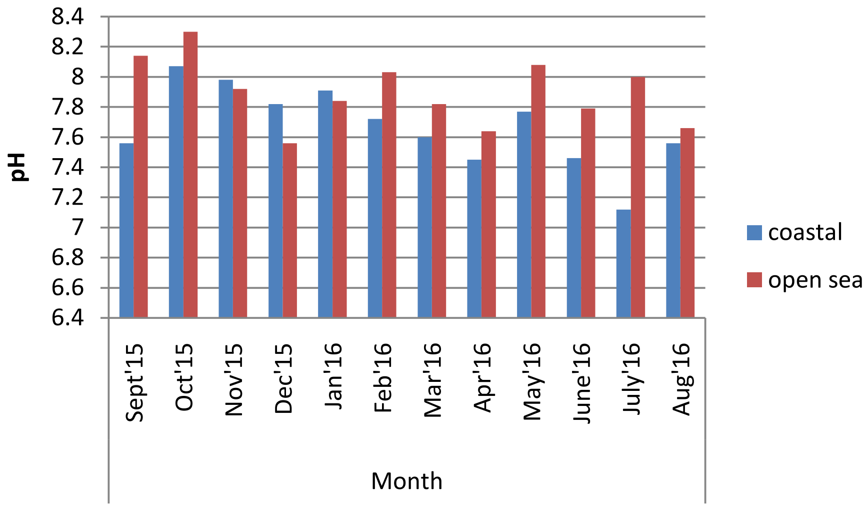

Figure 3. pH recorded in sampling stations from September 2015 to August 2016.

be affected by water discharges from household and aquaculture activities. For marine organisms, the optimum pH is usually between pH 7.5 - 8.5 [14]. Below pH 6.5, some species may experience slow growth, fail to maintain its salt balance and reproduction [17].

3.3. Salinity

Salinity was the highest in February 2016, measured at 34.94 psu and lowest in June 2016, at 31.57 psu for coastal station (**Figure 4**). For open sea station, the highest salinity was recorded in March 2016, at 34.61 psu and lowest in August 2016, at 31.24 psu (**Figure 4**). The salinity in the two stations was not significantly varied ($p > 0.05$). However, salinity fluctuated significantly on temporal basis ($p < 0.05$). From September to October and November to March, Sabah experiences inter-monsoon and northeast monsoon seasons, respectively. During these periods, Sabah is expected to experience rainy season, or 'wet season'. According to [19] and [20], heavy rainfall should lower the value of salinity due to the large inflow of freshwater. However, salinity reading in both stations showed a gradual increase from September 2015 to January 2016, and then the values remained high with not much difference from February to April 2016. This was due to the *El-Nino* phenomenon that has affected rainfall pattern. As shown in **Figure 5**, there was a decrease of rainfall starting from September 2015 to January 2016. Similarly, no rainfall and salinity changes recorded from January to March 2016. This causes the salinity level to less fluctuating.

3.4. Dissolved Oxygen (DO)

Maximum DO recorded in coastal and open sea stations was 6.60 mg/l and 6.80 mg/l in March 2016 respectively, whereas minimum DO was 3.12 mg/l in coastal station and 3.66 mg/l in open sea station during September 2015 (**Figure 6**). In general, DO at open sea station was higher than coastal station, with mean of

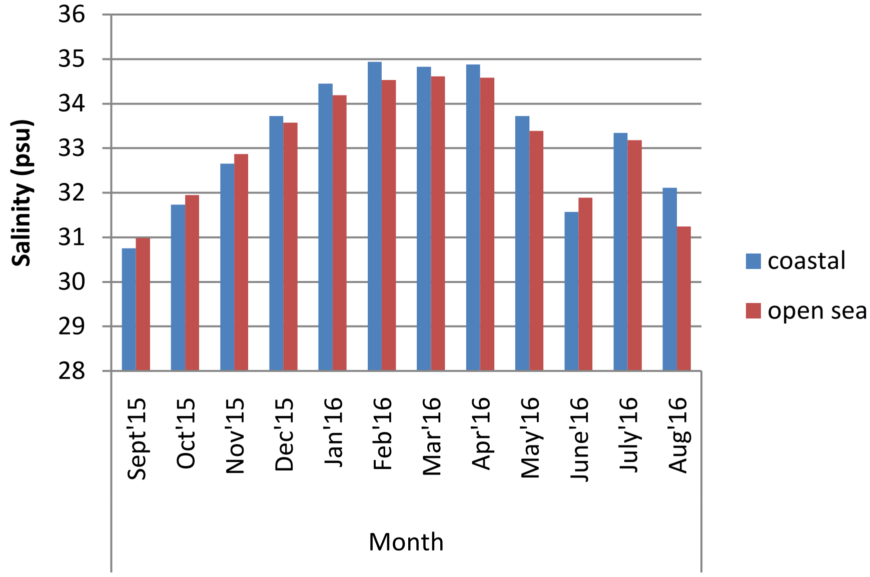

Figure 4. Salinity (psu) recorded in sampling stations from September 2015 to August 2016.

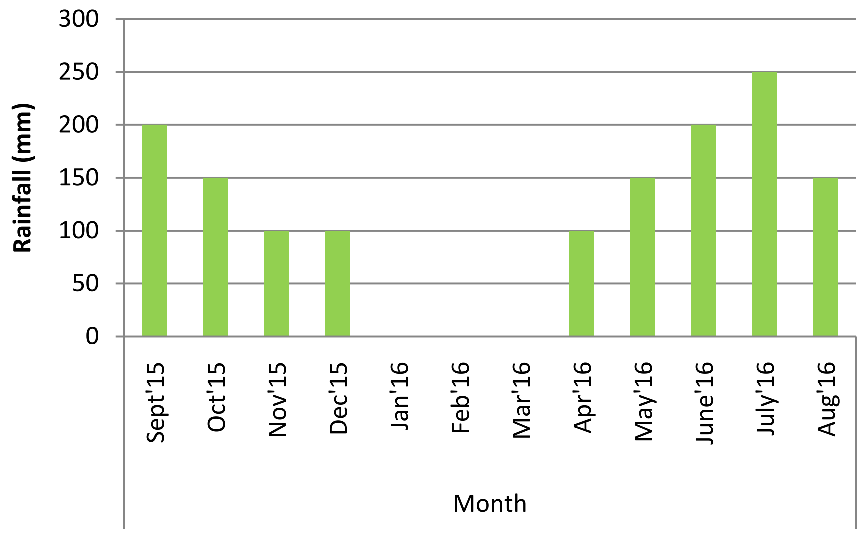

Figure 5. Monthly rainfall data in Ambong Bay area from September 2015 to August 2016 (Source: Malaysia Meteorological Department)

5.60 ± 0.29 mg/l in open sea and 5.04 ± 0.26 mg/l in coastal station (Table 1). Lower DO value in coastal station was most likely due to the decomposition of organic matters under aerobic conditions in mangrove and a decrease in the pH value of water [19]. It was found that DO between stations did not vary significantly ($p > 0.05$). However, variations in DO on the temporal basis seemed significant ($p < 0.05$). The significant variation in DO on temporal basis could be influenced by the water temperature, partial pressure of oxygen in atmosphere, salt contents in water and tides. Generally, DO decreases slightly as salinity increases. DO decreases more as temperature increases regardless of salinity [18]. Besides, DO in water is also affected by the tidal influence due to mixing of higher

DO water from offshore to inshore water and current speed [16] [21]. Saturation level of at least 5 mg/l is required for good growth of marine fish. Values lower than this can put the organisms under stress and may result in mortality [14].

3.5. Total Suspended Solid (TSS)

Both coastal and open sea stations recorded highest TSS in March 2016 at 0.2672 mg/l and 0.2756 mg/l (**Figure 7**), respectively. Lower TSS was recorded in both stations in June 2016 at 0.0182 mg/l and 0.0133 mg/l, respectively. In general, TSS was higher in coastal station, with mean of 0.0515 ± 0.0198 mg/l, whereas mean for open sea station was 0.0454 ± 0.0243 mg/l (**Table 1**). Statistical analysis

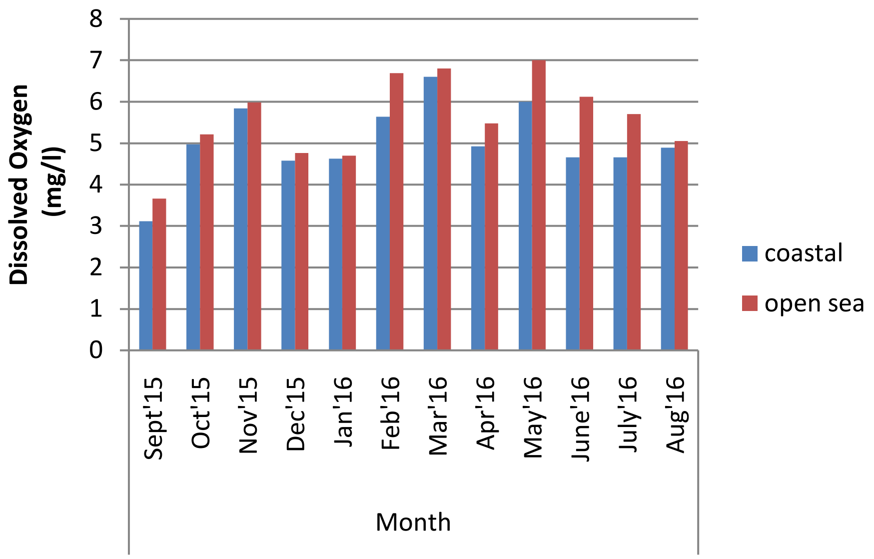

Figure 6. Dissolved oxygen (mg/l) recorded in sampling stations from September 2015 to August 2016.

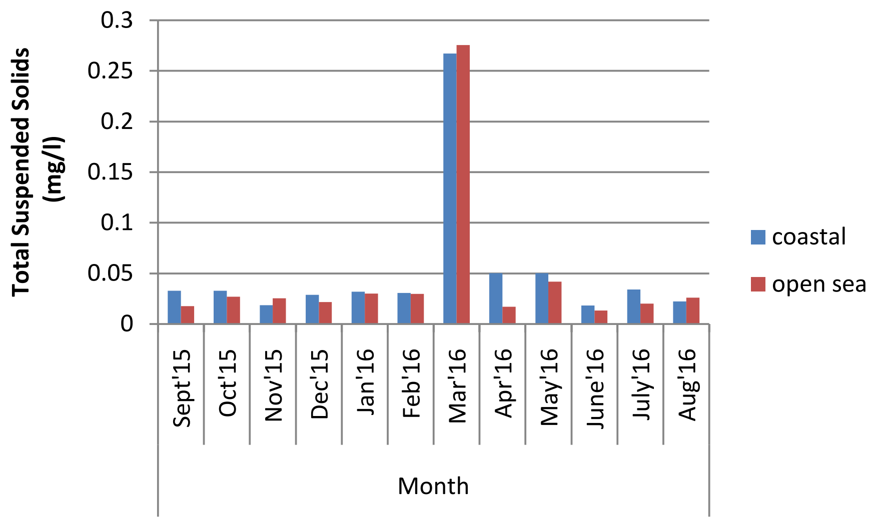

Figure 7. Total suspended solids (mg/l) recorded in the sampling stations from September 2015 to August 2016.

showed the TSS in both stations did not vary significantly ($p > 0.05$) spatially but variation seemed significant ($p < 0.05$) when compared temporally especially in March 2016. Study by [22] has shown that monsoon season influences TSS concentration to increase during high rainfall. However, this may not be the case in this study since no rainfall was recorded in March 2016 due to *El-Nino* phenomenon [23]. In fact, the lowest TSS concentration was recorded in June 2016 where *El-Nino* has gone and rainfall started to increase. The main reason is due to the high phytoplankton cell density in March (**Figure 12**). TSS is contributed by the living microorganisms (e.g. plankton and nekton) and non-living matters (e.g. plant debris or suspended soil particles) moving in water, thus high concentration of phytoplankton in the water will also increase the TSS value. Another reason could be due to the dilution effect by the heavy rainfall which reduced the concentration, as suggested by [13]. Besides, tidal influences due to strong currents during sampling also caused resuspension of sediments [13]. High concentration of TSS could clog fish gills. However, this study suggests that the current TSS concentration in Ambong Bay is still under the standard values (50 mg/l) set for marine life, fisheries, coral reefs, recreational and mariculture in Malaysian Marine Water (Class 2) [24].

3.6. Water Nutrients

In general, total ammonia-nitrogen (NH_3-N) in coastal station was slightly higher than in the open sea, with mean concentration of 0.0464 ± 0.0035 mg/l and 0.0443 ± 0.0046 mg/l respectively (**Table 1**). The highest concentration of NH_3-N was recorded during September 2016 in open sea station, at 0.0834 mg/l and lowest during December 2015 in coastal station, at 0.0278 mg/l (**Figure 8**). Nitrate (NO_3^-) concentration was the highest during February 2016 in coastal station, at 0.9898 mg/l and lowest during November 2015 in open sea, at 0.0305 mg/l (**Figure 9**). In general, NO_3^- concentration in coastal station was higher than open sea station, at 0.3091 ± 0.0823 mg/l and 0.1850 ± 0.0386 mg/l respectively (**Table 1**). These values were higher than the standard values (0.06 mg/l) set for marine life, fisheries, coral reefs, recreational and mariculture (Class 2), in Malaysian Marine Water [24]. The highest concentration of NO_2^- was recorded during December 2015 in coastal station, at 0.0023 mg/l and lowest during January 2016 in open sea station, at 0.0001 mg/l (**Figure10**). NO_3^- was considered to be less toxic when compared with other inorganic nitrogen compounds, but at high level it can affect osmoregulation, oxygen transport, eutrophication and algal bloom [18].

The mean values of nitrite (NO_2^-) ranged from 0.0009 ± 0.0002 mg/l in coastal station to 0.0004 ± 0.0001 mg/l in open sea station (**Table 1**). As for total dissolved phosphorus (PO_4-P), highest concentration was recorded during November 2015 in coastal station, at 0.0188 mg/l and the lowest was recorded during March 2016 in open sea station, at 0.0007 mg/l only (**Figure 11**). In general, concentration of PO_4-P was slightly higher in coastal station than open sea station,

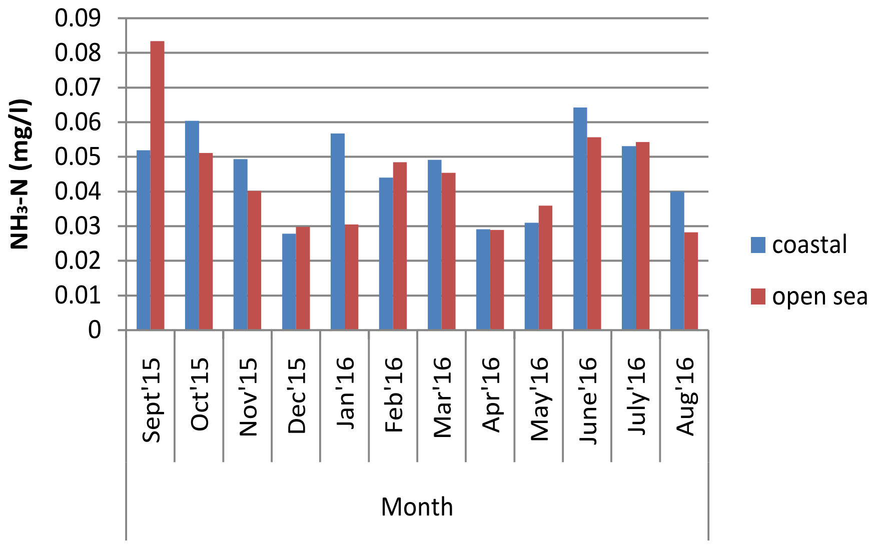

Figure 8. Total ammonia-nitrogen (NH_3-N) (mg/l) recorded in sampling stations from September 2015 to August 2016.

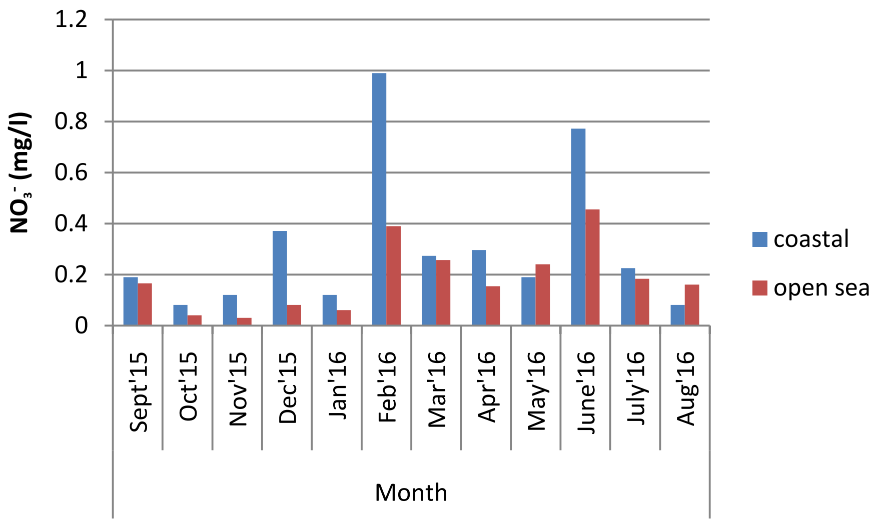

Figure 9. Nitrate (NO_3^-) (mg/l) recorded in sampling stations from September 2015 to August 2016.

at 0.0072 ± 0.0013 mg/l and 0.0056 ± 0.0009 mg/l respectively (Table 1). NH_3-N, NO_3^- and PO_4-P were found to have significant temporal differences ($p < 0.05$), while NO_2^- showed to have significant spatial differences ($p < 0.05$).

Distribution of nutrients is mainly influenced by season, tidal conditions and freshwater flow from land source [25]. Dilution by heavy rainfall may be one of the reasons of decrease in nutrients concentration in water [20] [25]. However, in the present study, the opposite results were obtained. Changes in concentrations of NH_3-N, NO_3^- and PO_4-P in different months did not appear to have link with the changes of salinity and rainfall. This indicates that the variations of NH_3-N, NO_3^- and PO_4-P in different months are most likely influenced by tides.

NO_2^- is the intermediate product from NH_4-N to NO_3^- during the process of nitrification and denitrification [26]. It is not a stable product and its absence or presence is not so unusual in low quantities [27] [28]. However, it can be used as a pollution indicator in water. In the present study, significantly higher concentration of NO_2^- in coastal station could be due to higher NH_4-N and NO_3^- concentrations in the water, which encouraged more nitrification and denitrification processes. This is due to coastal station exposes to more organic matters and vegetation detritus from mangrove forest and anthropogenic wastes from land compared to open sea station.

3.7. Phytoplankton Abundance and Cell Density

A total of 34 phytoplankton genera, representatives of 28 families, were identified from the two stations: 33 genera and 25 families in coastal station (**Table 2**); and 34 genera and 28 families in open sea station (**Table 3**). Both coastal and open sea stations were dominated by *Prorocentrum* spp. with mean abundance of 16.23% and 24.44%, respectively, followed by *Chaetoceros* spp. (17.26%) and *Thalassionema* spp. (14.65%) in coastal station and *Thalassionema* spp. and *Ceratium* spp. (12.76%) in open sea station. In general, open sea station has higher phytoplankton cell density, with mean ± SE of 5.39 ± 2.36 cells/ml. However, significant difference ($p < 0.05$) in phytoplankton cell density was only apparent on temporal basis. *Prorocentrum* spp. is a dinoflagellate consisting several toxic and harmful species [29] [30] [31]. *Ceratium* spp. and *Chaetocerous* spp. are also potentially toxic algae species [32]. Besides, toxic phytoplankton species are relatively poor in nutrition. The balance in the nutritional values is an important features of food quality [33], especially to shellfish or bivalve culture where most bivalve depends on phytoplankton as their primary food source.

3.8. Pearson Correlation Matrix

Table 4 showed the results of Pearson Correlation analysis on surface water parameters data in Ambong Bay. NH_3-N was positively correlated with PO_4-P ($r = 0.475$, $p < 0.05$) but negatively correlated with salinity ($r = -0.517$, $p < 0.01$). Besides, salinity was positively correlated with DO ($r = 0.505$, $p < 0.05$) and TSS ($r = 0.408$, $p < 0.05$). In addition, DO was found to positively correlated with TSS ($r = 0.451$, $p < 0.05$). Phytoplankton cell density was also positively correlated with TSS ($r = 0.644$, $p < 0.01$).

4. Suitability of Ambong Bay for Mariculture

Mariculture is a branch of aquaculture, where aquatic organisms (e.g. fish and shellfish) are cultured and harvested in marine environment. Site selection for mariculture based on seawater quality aspect is one of the important factors that determine the production and mortality [34]. Due to this, evaluation of water quality before starting any mariculture activity is essential to determine the types of aquatic organisms fitting to the site [35]. Mariculture activity in Ambong Bay

Table 2. Total cell count and abundance (%) of phytoplankton recorded in coastal station from September 2015 to August 2016.

Phytoplankton Genus (Family)	Sept'15 (%)	Oct'15 (%)	Nov'15 (%)	Dec'15 (%)	Jan'16 (%)	Feb'16 (%)	Mac'16 (%)	Apr'16 (%)	May'16 (%)	June'16 (%)	July'16 (%)	Aug'16 (%)
Chaetoceros (Chaetocerotaceae)	72.93	88.03	19.61	0.22	1.22	21.42	-	1.30	-	1.77	-	0.63
Thalassionema (Thalassionemataceae)	7.01	2.48	24.74	15.23	15.52	13.95	6.10	22.22	15.00	13.96	15.79	23.76
Pleurosigma (Pleurosigmataceae)	7.96	2.04	11.01	6.80	13.21	11.27	0.97	7.62	-	10.25	6.11	9.63
Navicula (Naviculaceae)	5.12	1.02	5.13	7.19	29.68	22.23	1.26	10.70	4.88	8.01	10.85	7.33
Nitzschia (Bacillariaceae)	1.55	0.83	6.49	6.44	6.22	1.87	0.73	4.85	1.16	7.90	3.33	0.97
Bacteriastrum (Chaetocerotaceae)	0.27	0.29	-	0.22	-	-	-	-	-	1.78	-	0.93
Protoperidinium (Protoperidiniaceae)	0.87	0.36	4.07	17.49	2.40	0.03	0.56	5.56	9.17	2.60	5.82	7.38
Asterolampra (Asterolampraceae)	0.46	0.09	-	0.11	1.03	0.91	0.03	0.39	0.39	-	-	0.98
Pseudonitzschia (Bacillariaceae)	0.64	1.86	5.13	3.75	6.44	1.05	0.32	3.98	0.39	9.48	1.55	0.66
Dactyliosolen (Rhizosolenaceae)	-	0.04	4.83	-	0.20	0.13	-	1.77	-	-	-	-
Cosinodiscus (Coscinodiscaceae)	1.82	2.13	8.90	7.97	9.74	8.90	0.12	3.50	4.58	14.80	5.21	9.96
Rhizosolenia (Rhizosoleniaceae)	0.38	0.23	1.06	0.55	4.59	0.15	0.12	3.09	-	2.44	-	3.51
Amphiprora (Amphiporidae)	-	0.12	-	0.33	-	-	-	-	-	-	-	-
Eucampia (Biddulphiaceae)	-	0.05	0.15	-	-	0.12	-	-	-	-	-	-
Dytilum (Lithodesmiaceae)	-	0.03	0.75	0.11	-	-	-	-	-	-	0.52	-
Lauderia (Lauderiaceae)	-	0.07	-	-	2.83	-	-	-	-	-	-	-
Guinardia (Rhizosoleniaceae)	-	0.23	-	-	0.53	-	-	-	0.72	-	-	-
Odontella (Eupodiscaceae)	0.23	0.01	2.87	0.32	0.25	6.06	-	0.88	-	0.88	1.09	1.90
Melosira (Melosiraceae)	-	-	0.60	-	0.25	-	-	-	-	0.73	-	-
Skeletonema (Skeletonemataceae)	-	-	0.60	0.10	-	-	-	-	-	-	-	-
Fragilariopsis (Fragilariaceae)	-	-	0.45	-	0.84	0.14	0.29	0.44	-	-	-	-
Gymnodinium (Gymnodiniidae)	-	-	-	7.36	-	-	0.03	0.44	1.17	0.81	0.55	0.99
Thalassiothrix (Thalassionemataceae)	-	-	-	1.08	1.42	-	-	0.90	1.20	0.81	0.55	-
Biddulphia (Biddulphiaceae)	-	-	-	0.10	-	-	-	1.23	-	-	-	-
Diploneis (Diploneidaceae)	0.30	-	-	0.33	0.83	0.87	0.12	0.99	0.39	-	0.50	0.64
Leptocylindrus (Leptocylindraceae)	-	-	-	-	0.20	-	-	-	-	-	-	-
Hemiaulus (Hemiaulacea)	-	-	-	-	-	0.04	-	-	-	-	-	-
Meuniera (Naviculaceae)	-	-	-	-	-	-	-	0.94	-	-	-	-
Gonyaulax (Gonyaulacaceae)	-	-	-	-	-	-	-	0.44	0.36	-	-	1.31
Haslea (Naviculaceae)	-	-	-	-	-	-	-	-	-	-	11.07	15.30
Prorocentrum (Prorocentraceae)	0.19	0.06	2.56	20.67	1.83	8.86	88.12	2.43	33.30	21.96	8.69	6.10
Ceratium (Ceratiacae)	0.27	0.01	0.75	2.85	0.78	2.00	1.23	24.59	10.34	1.80	20.16	7.39
Dinophysis (Dinophysiaceae)	-	-	0.30	0.73	-	0.03	-	1.73	16.94	-	8.23	0.65
Total count (cells/ml)	6.62	17.31	1.66	2.15	0.6	5.73	24.96	0.76	1.41	0.62	0.71	1.08
No. of family	14	16	16	18	17	17	13	18	12	14	13	16
No. of genera	15	20	19	22	21	19	14	22	15	16	16	19

Table 3. Total cell count and abundance (%) of phytoplankton recorded in open sea station from September 2015 to August 2016.

Phytoplankton Genus (Family)	Sept'15 (%)	Oct'15 (%)	Nov'15 (%)	Dec'15 (%)	Jan'16 (%)	Feb'16 (%)	Mac'16 (%)	Apr'16 (%)	May'16 (%)	June'16 (%)	July'16 (%)	Aug'16 (%)
Chaetoceros (Chaetocerotaceae)	67.37	50.71	22.72	1.63	-	16.47	0.09	5.11	-	-	-	0.46
Thalassionema (Thalassionemataceae)	14.99	11.02	12.11	11.10	2.73	29.64	11.30	36.29	4.83	6.80	19.34	46.49
Pleurosigma (Pleurosigmataceae)	0.97	9.98	1.94	1.30	1.32	12.04	1.66	3.04	6.18	0.63	3.36	13.64
Navicula (Naviculaceae)	0.17	1.36	1.35	0.88	4.04	5.50	2.60	3.03	13.37	2.30	1.08	0.57
Nitzschia (Bacillariaceae)	0.46	2.06	5.23	2.30	2.19	4.43	1.39	0.85	0.42	1.90	2.73	1.32
Bacteriastrum (Chaetocerotaceae)	1.71	0.90	0.15	-	-	-	-	-	-	-	-	0.59
Protoperidinium (Protoperidiniaceae)	4.50	4.61	3.44	11.39	9.19		0.89	6.94	23.53	4.73	8.25	7.39
Pseudonitzschia (Bacillariaceae)	0.23	6.06	0.45	0.44	2.32	6.62	0.08	1.71	1.30	1.19	0.54	2.87
Cosinodiscus (Coscinodiscaeae)	1.42	5.77	1.35	4.80	7.17	7.99	0.41	4.25	0.99	9.40	8.33	7.89
Rhizosolenia (Rhizosoleniaceae)	0.91	3.05	1.35	2.49	1.02	0.66	0.04	7.98	-	0.42	1.70	4.37
Lauderia (Lauderiaceae)	-	0.81	0.30	-	-	-	-	-	-	-	-	-
Odontella (Eupodiscaceae)	-	0.12	0.60	0.11	-	6.13	-	2.51	-	-	1.11	0.75
Guinardia (Rhizosoleniaceae)	0.28	0.70	0.60	-	-	0.34	-	0.42	0.49	-	-	-
Asterolampra (Asterolampraceae)	0.06	0.26	-	-	0.11	0.54	0.40	-	-	-	-	-
Dytilum (Lithodesmiaceae)	-	0.03	-	-	-	0.51	-	0.83	-	-	-	0.53
Skeletonema (Skeletonemataceae)	-	0.64	-	-	-	-	-	-	-	-	-	-
Gymnodinium (Gymnodiniidae)	-	-	2.09	1.21	-		2.39	2.61	5.26	-	1.09	-
Dictyocha (Dictyochaceae)	-	-	0.30		-	0.20	-	-		-	-	-
Gonyaulax (Gonyaulaceceae)	-	-	9.57		-	-	-	-	6.75	0.40	1.75	0.62
Dactyliosolen (Rhizosolenaceae)	-	-	0.75	1.54	-	-	0.04	-	-	-	-	-
Thalassiothrix (Thalassionemataceae)	-	-	-	3.62	-	-	-	2.12	-	0.21	2.78	-
Melosira (Melosiraceae)	-	-	-	0.55	-	-	-	-	-	-	-	-
Eucampia (Biddulphiaceae)	-	-	-	0.97	-	-	-	-	-	-	0.55	0.83
Leptocylindrus(Leptocylindraceae)	-	-	-	1.29	-	-	-	-		-	-	0.40
Diploneis (Diploneidaceae)	-	-	-	0.44	-	0.11	-	0.44	0.48	-	0.54	-
Fragilariopsis (Fragilariaceae)	-	-	-	-	-	0.31	0.75	-	-	-	-	-
Ampiphora (Amphiporidae)	-	-	-	-	-	0.10	-	-	-	-	-	-
Meuniera(Stauroneisaceae)	-	-	-	-	-	0.54	-	-	-	-	-	-
Haslea (Naviculaceae)	-	-	-	-	-	-	-	-	-	-	3.40	1.24
Pronoctiluca (Noctilucaceae)	-	-	-	-	-	-	-	-	-	-	-	-
Pyrocystis (Pyrocystaceae)	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum (Prorocentraceae)	4.50	1.10	20.33	38.44	52.02	6.88	76.40	3.49	24.56	41.15	20.67	1.40
Ceratium (Ceratiaceae)	1.50	0.52	14.50	10.14	14.53	0.46	1.56	15.82	8.20	27.80	18.42	6.54
Dinophysis (Dinophysiaceae)	0.91	0.29	0.90	5.35	3.36	0.53	0.00	2.56	3.64	5.20	4.34	0.83
Total count (cells/ml)	4.386	15.73	1.67	2.03	1.49	4.9	26.55	0.81	1.14	2.39	0.97	2.6
No. of family	14	16	17	17	11	18	13	15	13	11	16	17
No. of genera	15	19	18	20	12	20	15	18	14	13	18	20

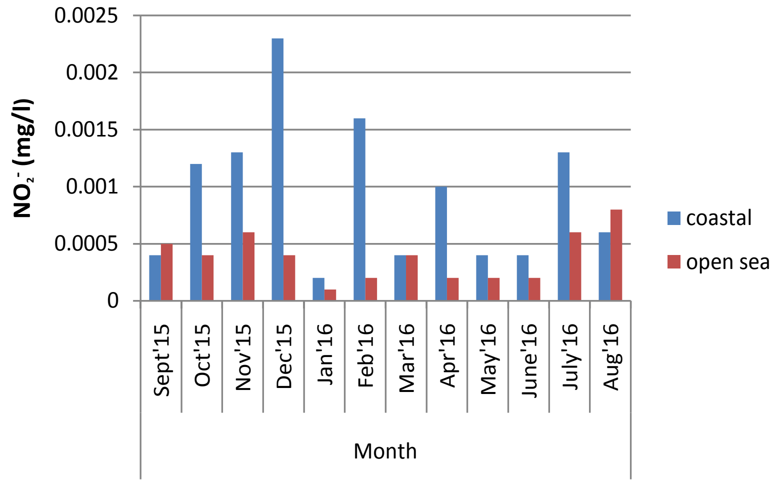

Figure 10. Nitrite (NO_2^-) (mg/l) recorded in sampling stations from September 2015 to August 2016.

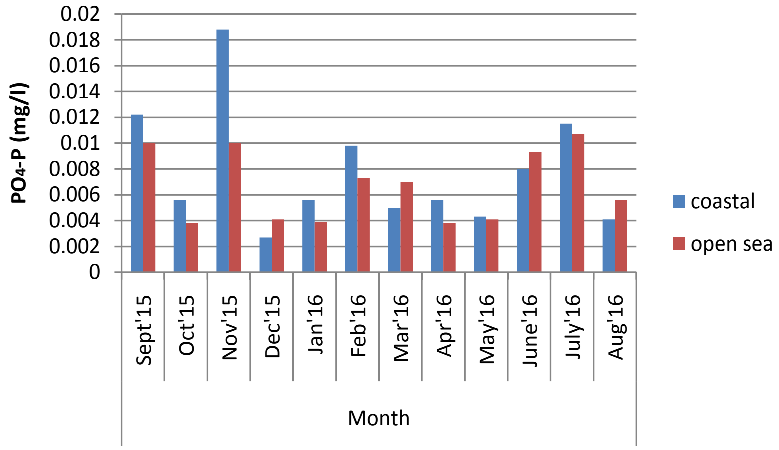

Figure 11. Total dissolved phosphorus (PO_4-P) (mg/l) recorded in sampling stations from September 2015 to August 2016.

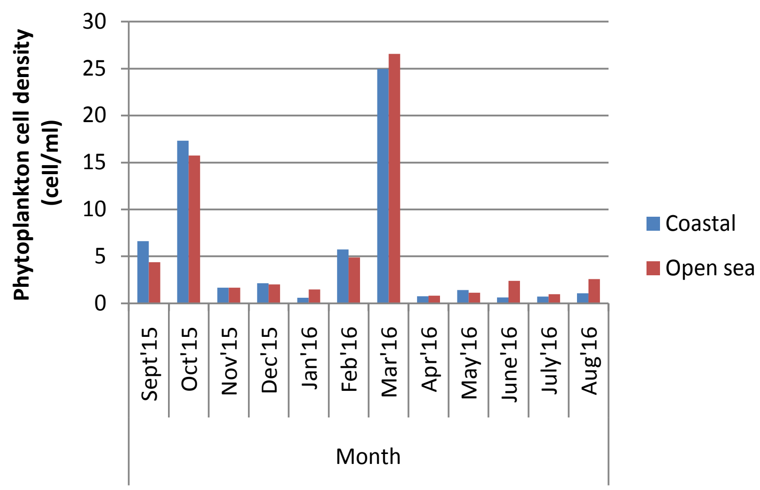

Figure 12. Phytoplankton cell density (cell/ml) recorded in sampling stations from September 2015 to August 2016.

Table 4. Pearson correlation matrix of water parameters in Ambong Bay.

	NO_3^-	NO_2^-	PO_4-P	NH_3-N	Salinity	Temperature	pH	DO	TSS	Phytoplankton
NO_3^-	1	0.279	0.136	0.138	0.181	−0.129	−0.253	0.128	0.020	0.129
NO_2^-		1	0.195	−0.121	0.049	0.178	−0.154	−0.192	−0.128	0.106
PO_4-P			1	**0.475***	−0.311	0.152	−0.025	−0.077	−0.136	0.003
NH_3-N				1	**−0.517****	0.001	0.261	−0.239	−0.011	0.237
Salinity					1	0.020	−0.157	**0.505***	**0.408***	0.040
Temperature						1	0.129	0.182	0.166	−0.132
pH							1	0.257	−0.098	0.157
DO								1	**0.451***	0.162
TSS									1	**0.644****
Phytoplankton										1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

is still in the beginning stage. However, the culture activity is expected to be expanding in the near future due to the considerable potential of the site, such as the availability of natural supply of bivalve spats (oysters and green mussel), and no major influence of water discharges from anthropogenic or industrial activities. At present, there are a few mariculture farms in the area, which mainly culturing mussel (green mussel and pacific oyster) and fish (grouper).

One of the important factors of site selection for bivalve farming is the availability and consistent supply of spats. Mussel and oyster culture in Sabah mainly relies on wild or natural spats. Once the spats settled, environmental conditions play important role in ensuring their growth and survival. For example, growth of green mussel is highly influenced by the food availability since it promotes sustainable growth [36]. However, the availability of food is influenced by environmental conditions such as temperature and salinity. Green mussel is known to tolerate wide ranges of temperature (10˚C - 35˚C) and salinity (5.2 - 39.8 ppt) [37] [38] [39]. As a filter-feeder, the absorption rate of green mussel is also influenced by the changes in TSS quantity. At very high TSS concentration, declining in filtration and ingestion rates were observed as a response to avoid malfunctioning by saturation of the gill [40]. It is found that TSS of more than 400 mg/l will have harmful effect on the growth of mussel [17].

Overall, water quality of the two sampling stations in Ambong Bay was shown suitable for green mussel culture, except for the phytoplankton composition, where the dominant phytoplankton, *Prorocentrum* spp., is one of the potential toxic algae or harmful algae species [29] [30] [31]. Recent study by [10] on green mussel farm in Marudu Bay demonstrated poor growth and high mortality even though the phytoplankton concentration was within the recommended value, which suggested that feeding behaviour of mussels is affected by the quality other than quantity. Moreover, the bioaccumulation of toxins from toxic algae in green mussel could also affect the suitability of the mussel for human consumption.

Fish farming is usually practiced in cages, where the site can be in open sea or coastal area. Due to the fact that fish does not have the ability to control their body temperature, sudden changes in temperature will affect their metabolic rate, oxygen consumption and as well as ammonia and carbon dioxide production [41]. High fluctuation in salinity will greatly affect the ionic balance in fish. Thus, temporal changes should be taken care of during the culture period. pH often influences the DO and ammonia levels, and extreme values can damage the gill and leading to fish death, whereas DO is found to be essential for the maintenance of osmotic activity and digestion [42].

Different species of fish have different tolerance towards water quality. In general, suitable water parameters for most tropical fish culture, according to [43] are: 7.0 - 8.5 for pH, > 4.0 mg/l for DO, 15 - 30 ppt for salinity, 27˚C - 31˚C for temperature, <0.5 mg/l for NH_3-N, <4 mg/l for NO_2^-, and <200 mg/l for NO_3^-. The mean values of water parameters in the two sampling stations in Ambong Bay are within the optimal value for fish farming. In this case, open sea station is more suitable for fish farming, because the station is situated further away from land and thus less anthropogenic influence. Moreover, open sea has better water exchange to avoid the deposition of suspended wastes at the bottom of the cage. However, toxic algae bloom is one of the concerns because it can clog the fish gills and cause mortality.

5. Conclusion

The water quality in Ambong Bay is within the standard values permitted by the Malaysia Marine Water Quality Standard (Class 2) for pollution and suitability of seafood farming for human consumption. However, in order to have a thorough understanding on the suitability of the bay for profitable mariculture operation, studies on growth and survival performance of candidate species need to be conducted to determine their potential yield in relation to water quality, hydrodynamic properties, biological and microbiological components in the bay.

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