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GROWTH AND MORTALITY OF GREEN MUSSEL *Perna viridis* FARMED AT AMBONG BAY AND MARUDU BAY, SABAH, MALAYSIA

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ABSTRACT

Asian green mussel is commercially farmed in tidal waters in several enclosed bays in Sabah, Malaysia. In this study, two areas on the west coast of Sabah – Ambong Bay and Marudu Bay – were selected for the monitoring of the growth and mortality rates of green mussels farmed in suspension raft. Both growth and survival rates were then correlated with physicochemical parameters (dissolved oxygen, pH, salinity, temperature, water transparency, chlorophyll-*a*), nutrients (phosphate (PO_4^{3-}), ammonia (NH_3-N), nitrate (NO_3-N) and nitrite (NO_2-N) and condition index of mussel from each study site, as well as between the study sites. The twelve-month growth study (September 2017 to August 2018) was started with a total of 180 mussel specimens (90 at each site). The initial size (mean) of the mussel seed used was 47.7 ± 3.5 mm and 51.1 ± 3.9 mm for Marudu Bay and Ambong Bay, respectively. Mussels in Marudu Bay attained mean size of 73.47 ± 11.05 mm (SGR 0.17% ± 0.22) compared to 64.05 ± 7.44 mm (SGR 0.11% ± 0.22) for Ambong Bay at the end of the experiment. The cumulative mortality rates were 9.2% ± 4.9 and 55.5% ± 30.0 for Marudu Bay and Ambong Bay, respectively. The Pearson correlation indicated a significant positive relationship between mortality and water transparency ($r = 0.684$, $p<0.01$). There was a significant negative relationship between ammonia in seawater and mussel mortality ($r = -0.561$, $p<0.01$), as well as significant negative relationships between nitrate and growth ($r = -0.480$, $p<0.05$) and mortality ($r = -0.460$, $p<0.05$), as indicated by Spearman's Rank-order Correlation analysis. Overall, the growth performance of green mussels farmed in Marudu Bay was better than in Ambong Bay, however, the mortality of mussels in Ambong Bay was higher.

Keywords:
Green mussel
Perna viridis
Culture
Growth
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INTRODUCTION

Green mussel *Perna viridis* was introduced to the state of Sabah in the 1990s and was mostly farmed in enclosed bays or river mouths in mangrove areas (DOFS, 2017). At Ambong Bay and Marudu Bay, mussels are cultured by hanging mussels in clusters using a polypropylene (PP) rope tied to a floating raft. Green mussels are filter feeders, processing large volumes of water around them to 'filter' phytoplankton, which is their main food (Garen et al., 2004; Vural et al., 2015; Tan et al., 2016). The growth rate of green mussels can reach up to 10 mm per month (Rajagopal et al., 1998a) and is much faster during young age (Vural et al., 2015). This fast growth makes the aquaculture of green mussel profitable in this region (Tan and Ransangan, 2014). Furthermore, with low production cost, farmers can receive high returns from mussel aquaculture. Market demand and prices for green mussels are determined by their size as measured by their shell length (SL) (Vakily, 1989). The local market size for green mussels is around 76 mm in shell length (SL) or 120-140 g/mussel and priced at RM10-12/kg (USD2.3-7.75) (DOFS, 2017). Elsewhere in Asia (e.g. India) the marketable size of green mussels varies from 50 to 60 mm SL, which is achievable within a 6-12 month culture period (Rajagopal et al., 1998b).

Green mussel has become one of the most important bivalve species for aquaculture in Sabah, Malaysia. It reached a peak total annual production of 347 t and was valued at RM 1.7 million (USD390,000) in 2008 (DOFS, 2017). However, this value decreased due to a sudden mass mortality event in 2010 (Taib et al., 2014). This mass mortality event was recorded simultaneously all over Malaysia, resulting in a drastic reduction of nationwide production of green mussels of more than 80% (DOFM, 2018). Studies investigating the problem, however, did not find a single possible cause for the mass mortality event (Tan and Ransangan, 2014; Taib et al., 2014). However, studies have shown both biotic and abiotic factors, including physicochemical parameters, food availability, predation and diseases, could contribute towards such a catastrophic event (Tan and Ransangan, 2019). Since then, the production of green mussels in Sabah has remained low and has never fully recovered. This is evident from the average annual production of green mussels in Sabah, which is around 3 t per year, recorded between 2011 and 2017 (DOFS, 2017).

Mass mortality events of green mussels in neighbouring countries, such as the Philippines in 2007 (Cebu and Orale, 2017) and Thailand in 2010 (Anongponyoskun et al., 2012), were both attributed to unfavourable seawater conditions as the main cause of the mortality. In the Philippines, the mass mortality of green mussels in Samar Bay, which wiped out 90% of the production, was thought to be due to the poor water quality at the farms (Cebu and Orale, 2017). In Thailand, low concentrations of dissolved oxygen in Sri Rancha Bay, Chonburi Province reduced the production of green mussels in the area by more than 80% for that year (Anongponyoskun et al., 2012).

Hence, this study was conducted to investigate the relationships between physicochemical parameters and water nutrients to the growth and survival rates of mussels in Marudu Bay and Ambong Bay. Information derived from this study is useful for monitoring the progress of mussel farming in the areas as well as for future sustainable management of the green mussel aquaculture in Sabah.

MATERIALS AND METHODS

Study site

Two sampling stations with existing green mussel farms were selected for this study; one station in Marudu Bay and another station was in Ambong Bay. The sampling station in Marudu Bay is a mariculture farm located in Kg. Taritipan (Lat 6° 34' 43.5"N; Long 116° 51' 16.7"E) and sampling station in Ambong Bay is located in Kg. Baru-Baru (Lat 6° 17' 59.0"N; Long 116° 17' 36.5"E) (Note: Kampung or Kg. is a village in Bahasa Malaysia). The farms are operated by the communities in the respective areas. The mariculture farm at Marudu Bay is situated at the mouth of Sungai Taritipan (Note: Sungai or Sg. is a river in Bahasa Malaysia) where green mussels are cultured together with marine fishes as well as other bivalves. This area is surrounded by a vast mangrove forest (Fig. 1a). In Ambong Bay, the green mussel farm is located at Kg. Baru-Baru on the western margin of the bay (Fig. 1b). The area is also surrounded by mangrove forest.

Sampling duration

This twelve-month study involved monthly sampling between September 2017 and August 2018. All sampling was conducted during the new moon phase, where the time of sampling was scheduled to coincide with the daytime lowest tide for the particular month.

Environmental variables

During each sampling event, *in situ* physicochemical parameters including temperature (°C), pH, dissolved oxygen (DO (mg/l)) and salinity (PSU) were measured at 0.5 m depth below the surface using a *Hydrolab Quanta* (Hach Environmental, USA). Water transparency was measured using a Secchi disc and recorded in centimetres (cm). Monthly rain data during the sampling period were acquired from the Meteorological Department of Malaysia for Tuaran and Kota Marudu stations.

Chlorophyll-a and water nutrient analyses

In each sampling period, three replicates of 1 L each of seawater were collected at 0.5 m below the surface using a 2 L water sampler (Wildco, USA). The water samples were kept chilled in an ice-filled cooler box while on transit from the field to the laboratory and processed (filtered) within 24 hours of collection. The water samples were filtered using a 0.45 µm cellulose nitrate membrane

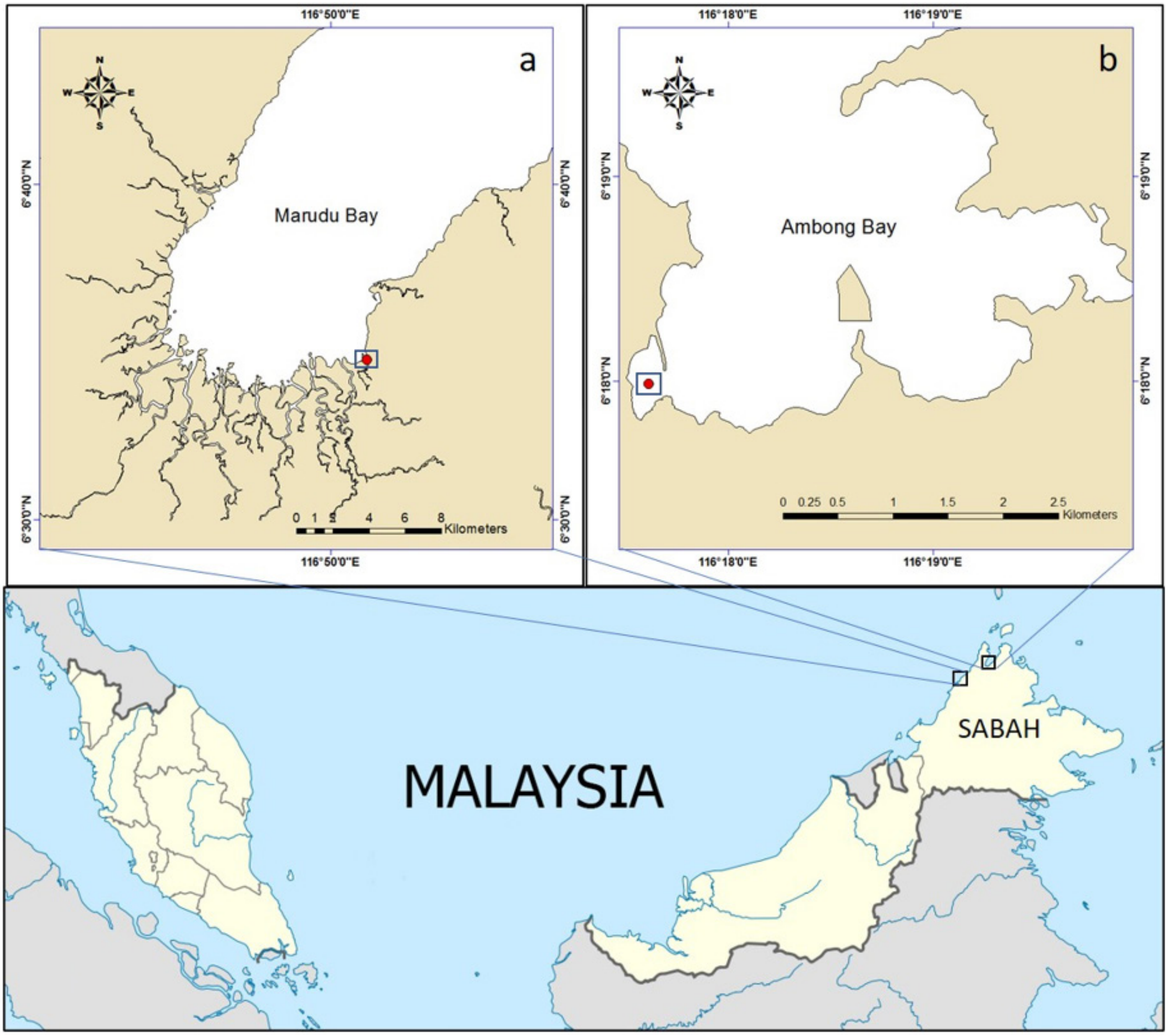

Fig 1. Study sites in Kg. Taritipan, Marudu Bay (a) and Kg. Baru-Baru in Ambong Bay (b)

filter (Whatman; diameter 47 mm). The membrane filters were kept in the microfuge tube covered with aluminium foil and stored at -20°C until used for chlorophyll-*a* analysis following Parson et al. (1984). The filtrate was used for water nutrient analysis - phosphate (PO_4^{3-}), ammonia (NH_3-N), nitrate (NO_3-N) and nitrite (NO_2-N). The nutrient analyses were immediately carried out using the DR Spectrophotometer 2700 (Hach, USA) at 880 nm (Phosphate-Hach Method 8155), 655 nm (Ammonia-Hach Method 8048) and 507 nm (Nitrate-Hach Method 8192 and Nitrite-Hach Method 8507), respectively.

Growth performance and condition index

At the start of the experiment, a total of 90 green mussels (for each station) were collected in the investigated area, from the wild, using spat collectors. The initial mean size (mean) of mussels at Marudu Bay was 47.7 ± 3.5 mm, and for Ambong Bay it was 51.1 ± 3.9 mm. Mussels were cultured in small cages made from netlon (30 cm x 30 cm x 20 cm), suspended at a depth of 0.5 m from the water surface from a small raft. The growth of mussels was calculated from monthly estimates of mean size derived from measurements of the shell length (SL) of 30 mussels. The specific growth rate (SGR) and cumulative mortality rate (CMR) were calculated following Karayücel and Karayücel (1999).

$$\text{Specific growth rate (SGR)} = [(\ln L_2 - \ln L_1) / (T_2 - T_1)] \times 100\%$$

where L_1 & L_2 mean shell length values at times T_1 & T_2 in days.

The cumulative mortality rate (CMR) was calculated based on the number of empty shells removed from the cage divided by the total numbers of mussels at the beginning of the experiment as shown by the equation below:

$$CMR = (NT / No) \times 100\%$$

where

NT = Number of empty shells removed from the cage
No = Number of mussels at the beginning.

For condition index (CI) analysis, four (4) mussels were sampled monthly from each station during each sampling time. Mussel specimens for CI analysis were taken from the grow-out cages at the farming site and not from the batch for mortality estimation. The mussel tissues were oven-dried to constant weight at 60°C for 7-10 days and CI was then calculated from the ratio of dry tissue (meat) over dry shell weight (Davenport and Chen, 1987).

$$CI = (\text{Dry weight meat} / \text{shell weight}) \times 100$$

Statistical analyses

The means for the physicochemical parameters, water nutrients, chlorophyll-*a* concentration and condition index were analyzed using the SPSS Window Statistic Package (version 23). All variables were tested for normality and homogeneity before proceeding to specific testing. Independent *t*-tests were performed as done to compare the means of the variables between the two stations. Correlation tests were conducted to determine the correlation between growth, mortality and the other variables. Tests were considered significant at p<0.05. Non-parametric tests, Mann-Whitney and Spearman Rank-order were only performed when the variables did not meet the assumption of parametric analysis.

RESULTS

Physicochemical variables

Over the year of sampling dissolved oxygen (DO) concentration at Marudu Bay ranged between 1.93-5.60 mg/l compared to 2.99-5.08 mg/l at Ambong Bay; pH ranged between 7.04-8.16 at Marudu Bay compared to 7.65-8.28 at Ambong Bay; temperature ranged between 28.86-32.11°C at Marudu Bay compared to 28.49-31.57°C at Ambong Bay; salinity varied between 13.28-32.20 PSU at Marudu Bay and 29.08-34.54 PSU at Ambong Bay; water transparency at Marudu Bay ranged between 20-90 cm compared to 80-220 cm at Ambong Bay, and chlorophyll-a concentration ranged between 1.13-32.57 µg/L at Marudu Bay compared to 0.59-7.59 µg/L Ambong Bay (Figure 2).

At Marudu Bay, the dissolved oxygen (DO), pH, salinity and water transparency mean values were significantly lower than those at Ambong Bay (DO, 3.624 ± 1.04 vs. 4.225 ± 0.56 mg/L; 168 $t_{(46)}$=-2.476, p<0.05; pH, 7.54 ± 0.30 vs. 8.00 ± 0.18; $t_{(46)}$ = -5.469, p<0.05; salinity, 27.7 ± 4.75 vs. 32.1 ± 1.53 PSU: $t_{(46)}$ = -4.372, p<0.05; water transparency, 61.25 ± 20.68 vs. 141.67 ± 48.39 cm; $t_{(22)}$=-5.293, p<0.05), whereas the mean chlorophyll-a concentration was significantly higher (Chlorophyll-a, 6.31 ± 7.14 vs. 2.89 ± 1.72 µg/L; $t_{(70)}$ = 3.895, p<0.05). Temperature at both sampling sites did not differ significantly (Temperature, 29.9 ± 0.86 vs. 30.1 ± 0.87°C). Marudu Bay (mean = 32.4 mm) received heavy rainfall in January 2018 (471.9 mm). Meanwhile Ambong Bay (mean = 60.8 mm) received heavy rainfall in October 2017, December 2017 and May 2018 with 569.9 mm, 498.2 mm and 519.0 mm, respectively (Fig. 2). Nonetheless, there was no significant difference in rainfall between the two sites.

Growth and mortality

The cumulative growth (Fig. 3) of green mussels in Marudu Bay was significantly higher (73.47 ± 11.05 mm) than in Ambong Bay (64.05 ± 7.44 mm; $t_{(22)}$ = 2.447, p<0.05). The monthly SGR percentage for mussels at Marudu Bay and Ambong Bay ranged from -0.06% - 0.71% (0.17% ± 0.22) and from -0.18% - 0.54% (0.11% ± 0.22), respectively (Fig. 4). Mann-Whitney test (U=23, p<0.05) results showed that the mean cumulative mortality rate of mussels in Marudu Bay was significantly lower (9.2% ± 4.9) than in Ambong Bay (55.5% ± 30.0). The mussels in Ambong Bay experienced higher mortality in November-December 2017 and January 2018 (Fig. 4), respectively.

Condition index

The condition index (CI) of mussels (N = 48) at Marudu Bay ranged from 3.08 to 7.99, with a mean (±SD) 5.01 ± 1.03 compared to Ambong Bay which ranged from 1.76 to 8.25 with a mean (±SD) 4.73 ± 1.43 (N = 48). However, there was no significant difference of CI in mussels from the two study sites (Fig. 5).

Nutrient concentrations

Phosphate concentration data were normally distributed at the two sites (parametric testing), whereas ammonia, nitrate and nitrite data were not, thus non-parametric testing was conducted for these variables. The ammonia concentration at Marudu Bay (0.04 ± 0.05 mg/L) was significantly higher (U=393, p<0.05) than at Ambong Bay (0.02 ± 0.02 mg/L). Phosphate, nitrate and nitrite concentrations were not significantly different. The mean values ± SD of phosphate, nitrate and nitrite at Marudu Bay vs. Ambong Bay were phosphate, 0.08±0.06 vs. 0.07±0.04 mg/L; nitrate, 0.011±0.006 vs. 0.011±0.005 mg/L; nitrite, 0.004±0.001 vs. 0.005 ± 0.001.

The concentrations of phosphate (PO_4^{3-}) and ammonia-nitrogen (NH_{3-} N) were higher at Marudu Bay in October 2017 compared to the rest of the sampling months. The concentrations of phosphate and ammonium-nitrogen (Fig. 6) in Marudu Bay in October 2017 were 0.247 mg/L and 0.207 mg/L, respectively. Meanwhile, concentrations of these two nutrients in Ambong Bay (phosphate, 0.06 ± 0.04 mg/L; ammonia-nitrogen, 0.02 ± 0.02 mg/L) were low throughout the sampling period.

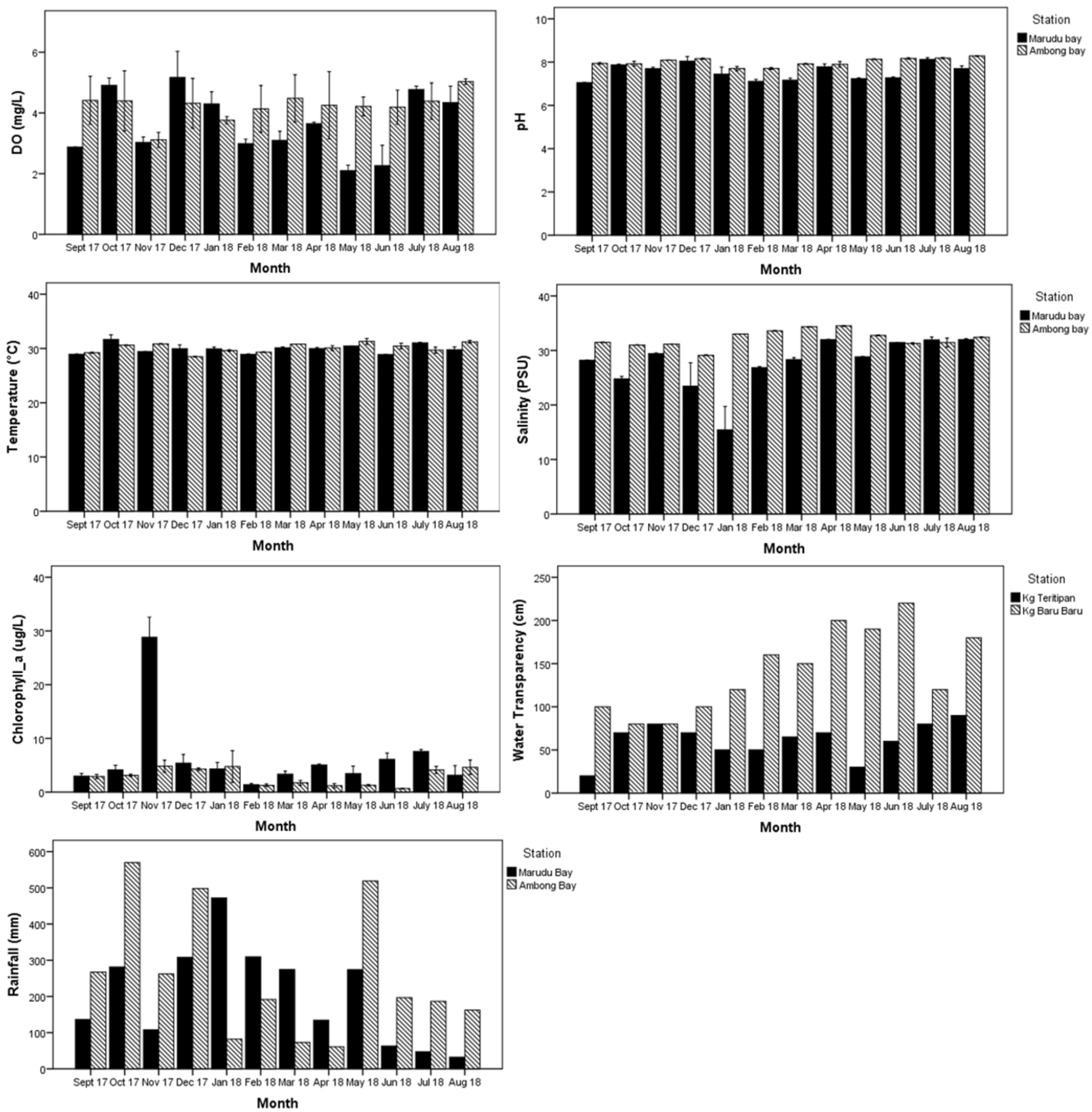

Fig 2. Physicochemical parameters of water in Marudu Bay and Ambong Bay recorded between September 2017 and August 2018

Relationship between physicochemical parameters and nutrients with mussel growth and mortality

Pearson correlation revealed there was a positive relationship between mortality and water transparency ($r = 0.684$, $p<0.01$) (Table 3). Spearman's rank-order correlation revealed a significant negative relationship between ammonia concentration and mortality rate ($r = -0.561$, $p<0.01$). Nitrate concentration had a significant negative relationship with mussel growth ($r = -0.480$, $p<0.05$) and mortality rate ($r = -0.460$, $p<0.05$).

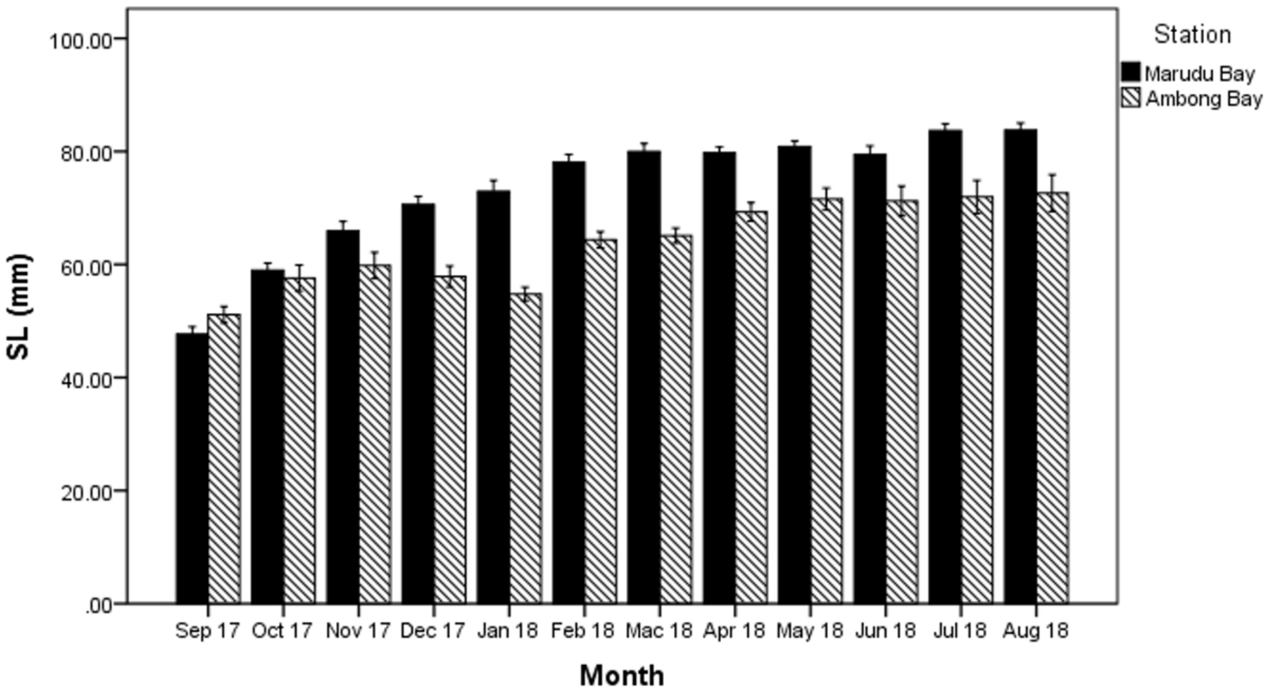

Fig 3. Growth of green mussels in Marudu Bay and Ambong Bay recorded between September 2017 and August 2018

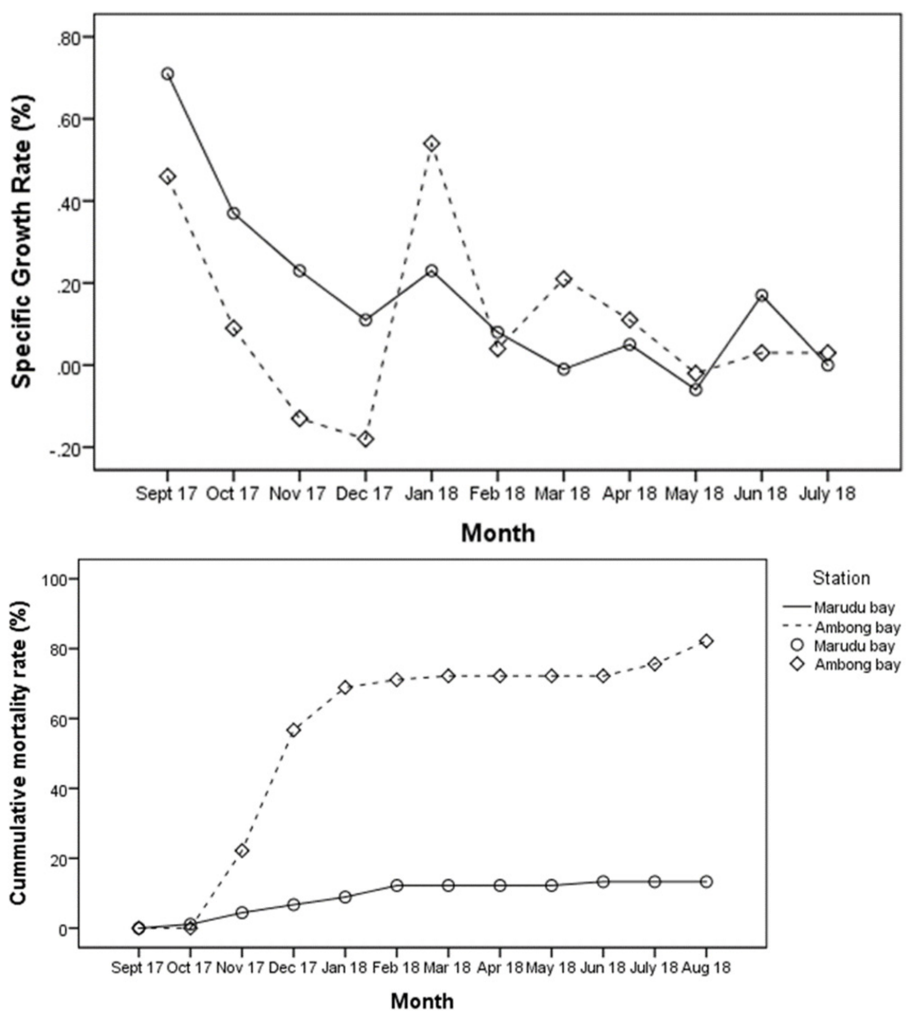

Fig 4. Specific growth rate and cumulative mortality of green mussels recorded throughout the study period

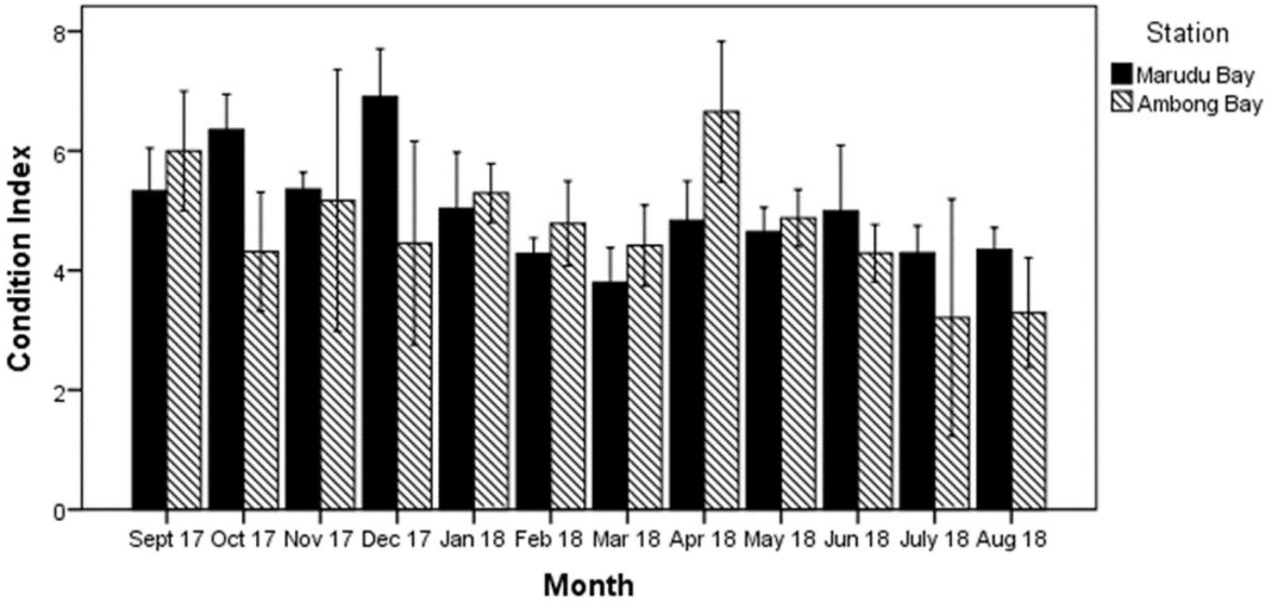

Fig 5. Condition index of green mussels in Marudu Bay and Ambong Bay recorded monthly between September 2017 and August 2018

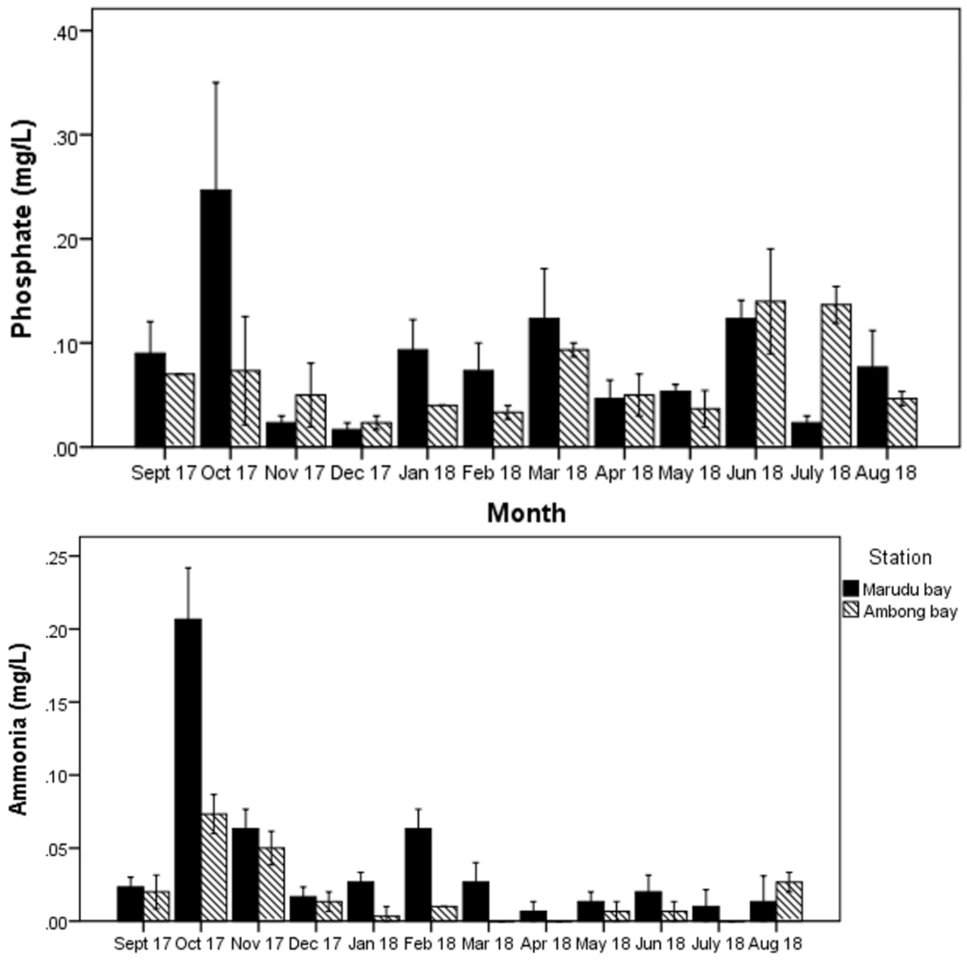

Fig 6. Phosphate and ammonia concentrations in Marudu Bay and Ambong Bay recorded between September 2017 and August 2018

DISCUSSION

Condition index of mussels

The condition index (CI) is used primarily to describe economic value and to characterize the health status of cultured bivalves (Lucas and Beninger, 1985). According to Župan and Šarić (2014), CI is important in quality assessment and marketing purposes because when the proportion of meat is higher, the product quality is better. The study by Yildiz et al. (2006) on Mediterranean mussels (*Mytilus galloprovincialis*) in the Dardanelles Strait noted that CI correlates with environmental parameters, especially chlorophyll-*a*, and it reaches its highest level before the spawning season. However, Çelik et al. (2012) reported that the CI of Mediterranean mussels in the Black Sea varied according to season due to the availability of food, reproductive cycle and environmental parameters. Three fatness categories (CI ≤ 2 (thin); CI = 2 to 4 (moderate); CI ≥ 4 (fat)) have been suggested (Davenport and Chen, 1987). In this study, it was noted that the CI of mussels in the two bays was constant with a mean value above 4.0 suggesting the mussels were fat. This observation is in agreement with the study of Ong and Ransangan (2019). Moreover, constant environmental parameters due to the absence of obvious seasonal patterns in the tropical climate may explain the high CI of mussels in the farming sites. However, it is a common practice in these farming sites to harvest mussels when they reach approximately 7.6 cm regardless of the CI index value.

Growth and mortality of mussels

The mussel seed in this study was obtained within the farming areas. A rapid growth rate of mussel seed at the beginning of the experiment was recorded at both stations. Rapid growth of juvenile mussels was reported in other studies (Hickman, 1979; Vural et al., 2015). Chatterji et al. (1984) related this phenomenon to high metabolic activity at the early developmental stage. In this study, the initial size (mean) of the mussel seed at Marudu Bay was 47.7 ± 3.5 mm, and at Ambong Bay it was 51.1 ± 3.9 mm. Over the twelve-month period, the mussel mean size at Marudu Bay reached 83.8 ± 3.5 mm whereas mussels at Ambong Bay grew up to 72.6 ± 6.4 mm. Over the twelve-month period, the shell length increased by 75.7% and 42.1% for Marudu Bay and Ambong Bay, respectively.

SGR of mussels at both stations was initially high but decreased continuously until December 2017. This can be explained by the fact that most of the remaining mussels were already bigger and hence the growth performance became slower. The SGR increased in January 2018 but then declined again afterwards. There are many factors, which can influence the growth of bivalve mussels including the availability of food (Seed and Suchanek, 1992), both its quantity and composition (Župan and Šarić, 2014). However, food availability is influenced by many factors including temperature, water depth and population density (Gosling, 2003). In other words, the synergistic interaction among these parameters is vital to provide sufficient food for mussels.

The cumulative mortality of mussels in Ambong Bay was high (>65%) during November-December 2017 and January 2018. Nonetheless, our study showed no significant fluctuation in physicochemical parameters of the water in Ambong Bay during the periods when mortalities were recorded as being high. Hence, finding a single causative factor may be difficult due to complex interactions between the physiological condition of mussels and the environmental factors in the habitat. These may include diseases, parasitism, overcrowding and predation.

Effects of physicochemical parameters on growth and mortality of mussels

In this study, the growth and mortality of green mussels farmed in Marudu Bay and Ambong Bay were found to correlate with water transparency and nutrient concentrations (ammonia and nitrate). For other environmental variables, these were within the normal range of green mussels. Our findings are in agreement with similar studies by Tan and Ransangan (2014) and Taib et al. (2014). The DO levels in Marudu Bay fluctuated and were quite low during the period May-June 2018. Nevertheless, only one mussel died during the period May-June 2018 in Marudu Bay. The mean DO value in Ambong Bay was slightly lower at 4.2 ± 0.56 mg/L compared to a previous study by Ong and Ransangan (2018) which reported 5.21 ± 0.66 mg/L. Such low DO could likely be the result of the decomposition processes of organic matter in the area. Mangrove forests are rich in organic matter, mainly from the decaying leaves that accumulate around the base of the trees (Lallier-Verges et al., 1998), which in turn affects the acidity of the immediate surrounding area (Toriman et al., 2013). DO is important for respiration and maintaining aerobic condition in the water column (Boyd, 2015). However, the analysis of the effect of DO on mussel growth and mortality at the study sites did not reveal any significant correlation. This could be explained by the fact that bivalves are able to tolerate low dissolved oxygen (Wang et al., 2011). However, prolonged exposure of low dissolved oxygen may become a stress factor for mussels and weaken their defence response (Sui et al., 2017).

The pH of nearshore waters fluctuates more than that of the open sea because of the biological activities that take place in the coastal areas (Cornwall et al., 2013). This may explain the pH level in Ambong Bay because this sampling location is located near to the shore which is covered by mangrove forest. Likewise, pH is also affected by the organic effluents brought about by run-off derived from terrestrial areas to the marine environment (Boyd, 2015). This situation may have influenced the pH in Marudu Bay which is located in the mouth of rivers and is surrounded by large areas of mangroves. However, the fluctuation in pH level in the study sites was not significant and it is within the tolerable range for mussels (Sallih, 2005).

Temperature has been shown to be one of the important variables influencing growth and mortality of mussels, especially in the temperate region. Previous studies (Freeman, 1974; Rajagopal et al., 1998b; Manoj and Appukuttan, 2003) found that temperature has a direct relationship with the growth of green mussels, especially in early stages when growth is much faster during summer compared to other seasons. The mean temperature at both study sites in this current study was high and constant throughout the sampling period but still within the tolerable range for green mussels.

Salinity in Marudu Bay varied throughout the sampling period and was lowest in November-December 2017 and January 2018, compared to Ambong Bay where it was more constant. This period is influenced by the high rainfall and freshwater intrusion from the Sg. Taritipan, especially during the northeast monsoon season. Monsoon seasons in Malaysia normally occur during May-September (Southwest Monsoon-SWM) and November-March (Northeast Monsoon-NEM) and often bring heavy rainfall and flooding to lowland areas (Sidik et al., 2010). The heavy rainfall during the monsoon season not only affects the salinity but also causes water to be turbid (Murugan et al., 2007). High levels of turbidity may reduce the oxygen intake (Alexander et al., 1994) that leads to hypoxia condition and may clog the gills of mussels (Smith et al., 2012). Monsoons have also been shown to cause nutrients fluctuation in water bodies (Mohammad-Noor et al., 2012).

Water transparency was positively correlated with mussel mortality rate in Ambong Bay, but not in Marudu Bay. The high level of water transparency in Ambong Bay is due to the reduced input of particles in the water column. Nevertheless, although water transparency in Marudu Bay was low compared to Ambong Bay, there were no unusual mussel mortality events recorded during this study. It has been demonstrated that green mussels are able to adjust their metabolic rates in turbid waters (Summers et al., 1996). The mussel mortalities that occurred in Ambong Bay may be related to many factors including food availability, especially phytoplankton (Chatterji et al., 1984). However, judging from the concentration of chlorophyll-a (2.89 ± 1.72 µg/L), the phytoplankton abundance in Ambong Bay, although lower than that in Marudu Bay, should be sufficient to support the mussel growth (Saxby, 2002). Hence, the high cumulative mussel mortality rate in Ambong Bay may be explained by the phytoplankton composition (Tan and Ransangan, 2019) rather the abundance. Unfortunately, this was not investigated in the present study.

Effect of nutrients on growth and mortality of mussels

Nutrients enter the water from two main sources, which are point-source and nonpoint-source loads (Frick et al., 1996). During heavy rainfall, an influx of nutrients, especially from agriculture and forestry activities but also urbanisation, enters bays and other coastal waterways through river systems. Geographically, Marudu Bay is surrounded by many rivers whereas Ambong Bay is not. This allows Marudu Bay to be the endpoint receiver of nutrients and pollutants discharged from the surrounding terrestrial areas of Kota Marudu district (Aris et al., 2014). Besides having rapid township development, agriculture has become the major activity in Kota Marudu district and neighbouring districts (Kudat, Matunggong and Pitas). The land-use in the rural and semi-rural towns of Kudat, Matunggong, Pitas and Kota Marudu has been rapidly changing in favour of agricultural activities. The land use in these districts for agricultural activities from 2010 to 2016 has increased by 21% - Kudat, 52% - Matunggong, 27% - Pitas and 25% - Kota Marudu (DOA, 2017).

Despite an increase in active land use, the nutrient concentrations recorded at both sampling stations were low throughout the study period. Tan and Ransangan (2017) also recorded low nutrient concentrations in Marudu Bay. Ambong Bay is a small bay and the main contributor of nutrients is from the domestic waste produced by villages around the bay. There are four villages in Ambong Bay namely Kg. Baru-Baru, Kg. Igot, Kg. Tolus and Kg. Ambong, and all are situated in coastal and mangrove areas which have a direct connection to the bay (Saleh et al., 2011). Nutrients dissolved in seawater are normally used by phytoplankton to grow. Phytoplankton are the major food source for filter-feeder organisms including green mussels (Garen et al., 2004; Vural et al., 2015; Tan et al., 2016). Karayücel and Karayücel (1999) noted that the growth of mussels is correlated with food availability. Scarcity of food increases competition for food among mussels that may lead to starvation and mortality.

CONCLUSION

The physicochemical parameters of waters in Marudu Bay and Ambong Bay are typical of coastal waters in Malaysia and within the normal levels encountered by green mussels. Although the two bays are good sites for mussel farming, the growth performance of mussels farmed in Marudu Bay was observed to be better compared to that in Ambong Bay. Furthermore, mussels farmed in Ambong Bay appeared to experience higher mortality compared to those in Marudu Bay. In this study, the water transparency was positively correlated with mussel mortality but further research is needed to ascertain how water transparency causes mussel mortalities.

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SAŽETAK

RAST I MORTALITET ZELENE DAGNJE *Perna viridis* UZGAJANE U ZALJEVU AMBONG I MARUDU, SABAH, MALEZIJA

Azijski zeleni školjkaš komercijalno se uzgaja u plimnim vodama nekoliko zatvorenih uvala u državi Sabah u Maleziji. U ovom su istraživanju dva područja na zapadnoj obali Sabaha - zaljev Ambong i zaljev Marudu - odabrana za praćenje rasta i mortaliteta zelenih dagnji uzgajanih na visećim strukturama splava. Stopa rasta i preživljavanja su nadalje povezane s fizikalno-kemijskim parametrima (otopljeni kisik, pH, slanost, temperatura, prozirnost vode, klorofil - a), hranjivim tvarima (fosfat (PO_4^{3-}), amonijakom (NH_3-N), nitratima (NO_3-N) nitritima (NO_2-N) te indeksom kondicije dagnji iz svakog od područja ispitivanja, kao i između područja. Dvanaestomjesečna studija rasta (rujan 2017. - kolovoz 2018.) započeta je s ukupno 180 uzoraka školjkaša (90 na svakom području/lokaciji). Početna prosječna dužina korištenog nasada školjkaša bila je 47,7 ± 3,5 mm za zaljev Marudu te 51,1 ± 3,9 mm za zaljev Ambong. Na kraju eksperimenta, dagnje u zaljevu Marudu postigle su prosječnu dužinu od 73,47 ± 11,05 mm (SGR 0,17% ± 0,22) u usporedbi sa 64,05 ± 7,44 mm (SGR 0,11% ± 0,22) za zaljev Ambong. Stopa kumulativnog mortaliteta iznosila je 9,2% ± 4,9 za zaljev Marudu te 55,5% ± 30,0 za zaljev Ambong. Pearsonova korelacija ukazala je na značajan pozitivan odnos između mortaliteta i prozirnosti vode (r = 0,684, p<0,01). Postojala je i značajna negativna veza između amonijaka u morskoj vodi i mortaliteta školjkaša (r = -0,561, p<0,01), kao i značajne negativne veze između nitrata i rasta (r = -0,480, p<0,05) te mortaliteta (r = - 0,460, p<0,05), na što je ukazala Spearmanova korelacijska analiza. Općenito, rezultati ukazuju na bolji rast uzgajanih zelenih dagnji u zaljevu Marudu nego u zaljevu Ambong. Također, dagnje iz zaljeva Ambong imale su viši mortalitet.

Ključne riječi: Zelena dagnja, *Perna viridis*, uzgoj, rast, mortalitet, Malezija

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