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Feasibility of green mussel, *Perna viridis* farming in Marudu Bay, Malaysia

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ABSTRACT

Bivalve aquaculture is an important source of affordable animal protein for coastal community. The success and sustainability of this industry is highly influenced by the suitability of the environment in which it is carried out. Present study was carried out to evaluate the feasibility of green mussel (*Perna viridis*) farming in Marudu Bay. The site suitability for green mussel farming was evaluated based on biophysical parameters and food availability. The *in situ* environmental parameters, phytoplankton abundance and composition were collected from 10 sampling stations on monthly interval from May 2014 to April 2015. The results showed that the environmental parameters and food availability in most of the sampling stations were suitable for green mussel. However, the presence of phytoplankton taxa (Chaetoceraceae) which are unfavorable by green mussel in most of the stations located at the bay pocket make those areas less recommended for green mussel farming. In contrast, stations located on the mouth of the bay exhibited high site suitability rating points and hence are highly recommended for cultivation of green mussel.

1. Introduction

Green mussel, *Perna viridis* is a large and fast growing warm water marine bivalve (Rajagopal et al., 2006). It is an ideal candidate for aquaculture due to its high growth rate, high fecundity and the all year round reproductive capability (Laxmilatha, 2013; Hickman, 1992). Aquaculture of green mussel provides an alternative for increasing production and supply of affordable protein to coastal community (Khan et al., 2010; Guo et al., 1999).

Unlike fish and shrimp aquaculture, bivalve cultivation is a self-regulate aquaculture that requires no additional feed and minimal maintenance effort (Tan and Ransangan, 2014). Commercial cultivation of green mussel is extensively carried out in tropical countries (Rajagopal et al., 2006). Areas with high chlorophyll-*a* concentration are often selected for culture sites (Rajagopal et al., 1998). However, poor growth performance of mussel has also been reported in areas with moderate levels of chlorophyll-*a* (Ren and Ross, 2002). This may be explained by the fact that good quality food (composition) is equally important in promoting the growth of green mussel (Tan and Ransangan, 2016).

In Sabah, Northeast Malaysian Borneo, *P. viridis* aquaculture was first introduced in Marudu Bay using broodstock originated from Johor in the year 2000 (Tan and Ransangan, 2015a). The cultivation was performing well in the first decade. Unfortunately, it began to collapse in the year 2010. Although it has been over six years now, the green mussel population in the area has not been able to restore due to lack of suitable food (Tan and Ransangan, 2016). Therefore, there is an urgent need to find alternative cultivation sites for *P. viridis* farming in the bay.

This paper describes the process of site selection for *P. viridis* farming based on the biophysical variables and food availability. The finding of the study is expected to contribute to the development of tool for good planning and management practices of a sustainable green mussel aquaculture.

2. Materials and methods

2.1. Sampling

The sampling was conducted in ten stations within the Marudu Bay (6° 35′ to 7° N; 116° 45′ to 117° E) (Fig. 1). Sampling stations were chosen based on water depths and anthropogenic influences. Stations 1, 2, 3 and 10 were located at the bay pocket, characterized by shallow coastal water of less than 5 m depth. Stations 4, 5, 7, and 9 were located at depths ranged from 5 to 10 m, while Stations 8 and 6 were at 13 m and 21 m depths, respectively. For influences of anthropogenic factors, stations 1, 2 and 10 were adja-

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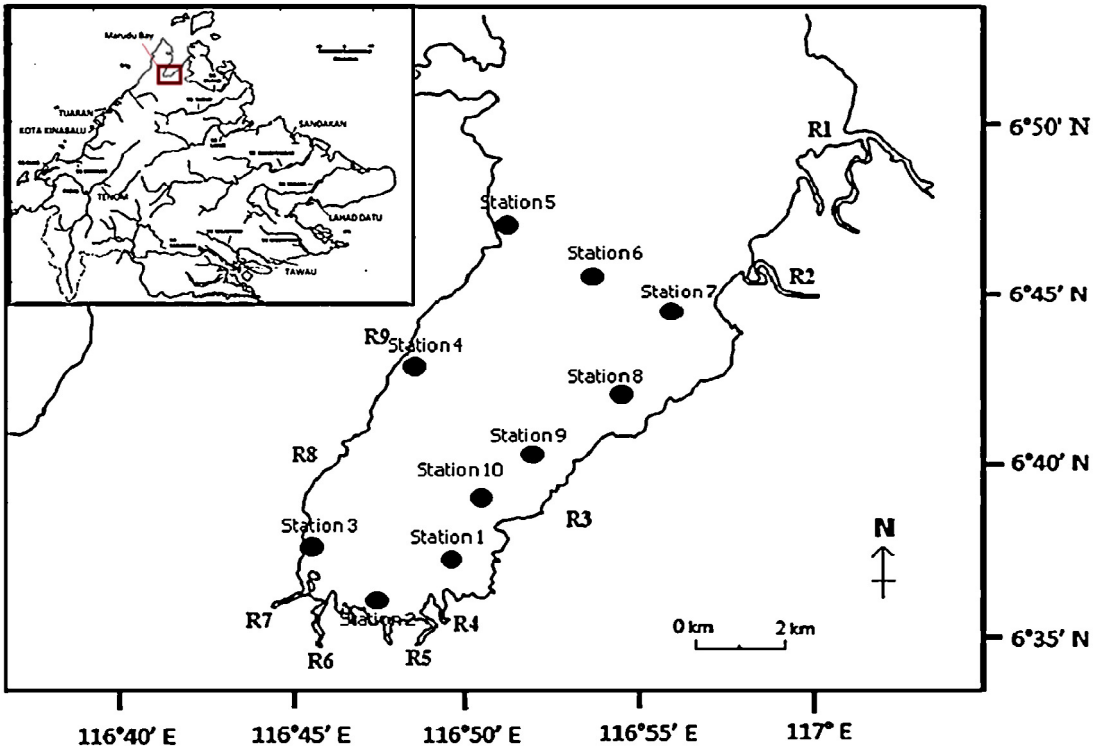

Fig. 1. Location of the ten sampling stations in Marudu Bay.
Note: R1 = Pitas River; R2 = Bangkoka River; R3 = Marasimsim River; R4 = Taritipan River; R5 = Raku River; R6 = Sumbilingan River; R7 = Marudu River; R8 = Karangawan River; R9 = Matunggong River.

cent to high human density areas. Station 1 was at the green mussel farm. Station 3 was located in front of a river mouth and also the main artisanal fishing ground, while many anchovy fishing platforms (*bagang*) were operating in stations 7 and 8.

Samplings were conducted once monthly during full moon (spring tide) and approximately the same time at 8.00–8:30 amduring high tide. The sampling was last for 12 months, from May 2014 until April 2015.

2.2. Sample collection

At each station, *in situ* environmental parameters including temperature, salinity, pH and dissolved oxygen (DO) at 0.5 m below the water surface were measured using a multi-function environmental sensor (YSI; Loveland, CO, USA). The salinity, pH and DO sensors in the multi-functional sensor were calibrated according to the manufacturer's instruction on every sampling day. Water current was measured using current meter (Stanley, USA) and water transparency was measured by Secchi disc.

One litre (1 L) of sub-surface water sample (0.5 m below the water surface) was collected using a 1-L Van Don water sampler (KC Denmark), then pre-filtered immediately through 0.45 μm pore-size cellulose ester membrane filters (Whatman) for total chlorophyll-*a* determination (Parsons et al., 1984).

Qualitative samples of phytoplankton were collected by vertical tow of plankton net (mesh size 20 μm) to cover 0.5 m above the sea floor to the water surface. The net was towed several times until the water in the sample collector coloured by the concentrated algae. The sample was then immediately preserved with Lugol's solution (Saraceni and Ruggiu, 1974). Species identification was accomplished using a Carl Zeiss light microscope at 400× and 1000× magnification according to Hartley (1996).

For phytoplankton quantitative analysis, 1 L of seawater samples were collected at 0.5 m depth using a 1-L Van Don water sampler (KC Denmark), and immediately preserved with Lugol's solution (Saraceni and Ruggiu, 1974). In laboratory, the samples were concentrated by Utermöhl sedimentation method (Aktan et al., 2005) into 50 mL. The phytoplankton cell density was then counted as cells/mL using a Sedgwick Rafter chamber at 400× magnification (Aktan et al., 2005).

2.3. Suitability of sites for P. viridis farming

Variation of environmental parameters over one year period was used to evaluate the suitability of each station for *P. viridis* farming (Sallih, 2005). The environmental variables including temperature, salinity, pH, dissolved oxygen, water current, chlorophyll-*a* concentration and water depth were given a weighted value based on its effects to the growth or survival of the bivalves (Tables 1 and 4). The rated value of each parameter was multiplied by the weighted value for the parameter to determine the total weight value of the station. Subsequently, the total weighted values were then used to evaluate the suitability of the stations for *P. viridis* farming by comparing to the reference (Tables 2 and 4).

2.4. Statistical analyses

Phytoplankton diversity and evenness were expressed as Shannon-Wiener index (*H*') (Ramos et al., 2006; Shannon and Weaver, 1963) and Pielou's evenness index (*J*') (Ramos et al., 2006; Pielou, 1966), respectively.

All statistical analyses were performed using the SPSS Windows Statistical Package (version 21). Tests were judged to be significant at $p > 0.05$ level. The composition of phytoplankton family Chaetocerotaceae in each station was calculated by the sum of *Chaetoceros* spp. and *Bacteriastrum* spp. One-way ANOVA was then performed

Table 1
The weighted value and rating point for the range of environmental parameters for mussel farming based on FIGIS (2005), Saxby (2002), Hickman (1992), Aypa (1990), Lovatelli (1990), Sivalingam (1977).

	Salinity (ppt)	Dissolved oxygen (mg/L)	pH value	Temperature (°C)	Chlorophyll-*a* (μg/L)	Water current (m/s)	Water depth (m)	
Rating point	10	27–32	>8	7.9–8.2	26–32	2 0.0–3.0	0.1–0.3	>8
	9	25–33	6–7	7.8–8.3	25–33	1.8–3.5	0.15–0.35	8
	8	24–34	5–6	7.7–8.4	24–34	1.6–4.0	0.2–0.4	7
	7	23–35	4–5	7.6–8.5	23–35	1.4–4.5	0.25–0.45	6
	6	18–36	3–4	7.5–8.6	22–36	1.2–5.0	0.3–0.5	5
	5	15–40	–	7.4–8.7	21–37	1.0–5.5	0.35–0.6	4
	4	12–45	–	7.3–8.8	20–38	0.8–6.0	0.4–0.7	3
	3	10–50	3–2	7.0–8.9	19–39	0.6 v6.5	0.6–0.9	–
	2	5–55	2–1	6.9–9.0	18–40	0.4–7.0	0.9–1.5	–
	1	0–65	–	6.8–9.1	17–41	<0.4 and >7.0	> 1.5	1
weighted value		0.15	0.15	0.1	0.15	0.15	0.15	0.15

Table 2
The suitability categories of sites for bivalves farming (Sallih, 2005; Kingzett and Salmon, 2002).

Weighted category	Site evaluation	Recommendation
1.0–2.5	Not advisable	Not suitable for green mussel farming and cannot support the culture
2.6–5.0	Poor	May support green mussel but not recommended
5.1–7.5	Medium	Capable and moderately suitable for green mussel farming
7.6–10.0	Good	Suitable for green mussel farming and highly recommended

to test for significant differences in composition of Chaetocerotaceae among stations.

3. Results

3.1. Environmental parameters

The annual range of environmental parameters in Marudu Bay is summarized in Table 3. In general, Marudu Bay has a typical environmental condition, in which the variations of most parameters, except salinity were small and similar in all stations. The high fluctuation in salinity of more than 10 psu was recorded in stations 3, 4 and 10.

No significant difference ($p > 0.05$) was observed in salinity, dissolved oxygen, pH value, temperature and chlorophyll-a throughout the stations. However, the current speed in station 6 was significantly higher ($p > 0.05$) than that in other stations. In addition, the water depth in stations 1, 2, 3 and 10 was significantly lower ($p > 0.05$) than that in other stations.

3.2. Phytoplankton composition

A total of 47 phytoplankton genera, representatives of 33 families were identified (Table 4). The phytoplankton community in Marudu Bay was dominated by genus *Chaetoceros* spp. (48% of the total count), followed by *Bacteriastrum* spp. (22% of the total count). The phytoplankton family Chaetoceroceae accounted for 40–83% of the total phytoplankton community in Marudu Bay. The Chaetoceroceae composition in stations 1, 2 and 10 (77–83%) was significantly higher, while in stations 4, 7 and 9 (40–56%) was significantly lower ($p > 0.05$) than in other stations (59–68%).

The phytoplankton cell density ranged from 14 to 71 cells/mL, whereas the Shannon-Wiener diversity (*H*') and Pielou evenness (*J*') indices of phytoplankton community in Marudu Bay ranged from 1.39 to 2.17 and 0.40–0.65, respectively.

3.3. Suitability of sites for P. viridis farming

The result of the site evaluation is summarized in Table 5. Environmental variables in stations 1 and 3 were categorised as 'medium', while other stations were categorised as 'good' in term of suitability for green mussel farming. In general, the stations 3, 4, 9 and 10 recorded relatively lower rating for salinity than other stations. In stations 4 and 5, pH value gets a low rating point, while low rating for water depth was recorded in stations 1, 2 and 3.

4. Discussion

4.1. Environmental variables

Marudu Bay has an equatorial climate with regular environmental conditions due to its proximity to the equator (Tan et al., 2016b; Malaysian Meteorological Department, 2014). In general, the range of environmental variables (temperature, salinity, pH, water depth and DO) in all stations recorded over a period of 12 months were within the tolerance ranges of *P. viridis* (Tan and Ransangan, 2014; Sallih, 2005). However, stations 3, 4, 9 and 10 experienced relatively higher temporal salinity fluctuation mainly during high rainfall monsoon, particularly in February to March. *P. viridis* is a marine water mussel species that requires high salinity of 27–35 ppt for optimum growth (Tan and Ransangan, 2014; Rajagopal et al., 2006; Aypa, 1990). Therefore, low salinity caused by fresh water dilution during heavy rainfall season might negatively affect the growth and survival of the bivalve (Saxby, 2002). In addition, the shallow water depth in stations 1, 2 and 3 might not effectively prevent ground predators and high water turbidity (Aypa, 1990). On the other hand, stations 4 and 5 experienced relatively higher pH value fluctuation. Organic effluents from land are known to be the main factor reducing the pH value in marine environments (Sany et al., 2014). The relatively higher pH values in stations 4 and 5 could be explained by its remote distance of these sites from the human settlement and sources of organic pollutants (Tan and Ransangan, 2015b).

4.2. Phytoplankton composition

Small diatom taxa like *Chaetoceros* spp. (48%) and *Bacteriastrum* spp. (22%) were found dominant in Marudu Bay. In contrast, large *Coscinodiscus* spp. was reported to dominate the water of Sepanggar Bay, on the west coast of Sabah (Sidik et al., 2008).This contradiction could be the result of difference nutrients concentration in these two bays (Cermeno et al., 2006). In nutrients depleted environment like Marudu Bay, small phytoplankton species have an advantage in effectively absorbing the available nutrients over the larger phytoplankton species (Tan and Ransangan, 2015b; Cermeno

Table 3
Environmental parameters (min-max) in Marudu Bay recorded from May 2014 to April 2015.

	Salinity (psu)	Do (mg/L)	pH	Temperature (°C)	Chlorophyll-a (mg/L)	Current speed (m/min)	Water depth (m)
Station 1	24.1–34	3.7–7.2	7.8–8.5	28.4–32	4.46 ± 2.07	6.7–58.9	3.5–4.7
Station 2	23.9–34.3	3.7–7	7.8–8.4	28.4–32	4.14 ± 2.51	5.8–47.9	3.8–4.8
Station 3	18.3–33.7	4.0–6.6	7.9–8.3	28.8–31.1	4.17 ± 1.89	6.7–45.3	2.1–2.7
Station 4	22.0–34.0	4.1–6.7	8.1–8.7	27.4–31.1	3.10 ± 1.09	5–46.3	5.0–5.9
Station 5	25.9–34.3	4.0–6.9	8.1–8.7	27.6–32.3	2.75 ± 1.24	4.7–50.2	9.3–11.3
Station 6	26.4–33.7	3.9–7.2	8.0–8.5	27.8–30.8	3.03 ±v1.46	12.4–50.2	20.5–27.4
Station 7	23.9–33.4	3.5–7.3	7.7–8.5	27.2–31.9	2.87 ± 1.54	2.5–51.6	5.2–7.9
Station 8	25.5–33.7	3.5–7.2	8.0–8.5	27.9–31.2	2.73 ± 1.08	3.0–42.1	13.3–15.7
Station 9	25.3–34.0	3.6–7.3	8.0–8.5	27.4–31.4	2.06 ± 1.01	6.3–45.5	9.0–13.0
Station 10	22.2–33.4	3.8–6.6	7.8–8.3	28.3–31.8	5.15 ± 4.31	5.6–43.9	3.9–8.2

Table 4
Phytoplankton composition in Marudu Bay recorded from May 2014 to April 2015.

Phytoplankton		Mean count		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Genus (Family)		(×104 cells/L)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Chaetoceros (Chaetocerotaceae)	1	1.8222	48.6	55.43	50.63	54.16	31.33	42.04	45.59	45.75	32.58	23.00	59.37
Bacteriastrum (Chaetocerotaceae)	2	0.8504	22.68	25.28	26.03	13.99	20.11	23.62	13.26	9.40	31.18	16.75	23.38
Skeletonema (Skeletomataceae)	3	0.1624	4.33	2.95	1.38	7.95	13.81	8.74	10.68	0.68	1.19	22.80	0.39
Proboscia (Rhizosoleniaceae)	4	0.159	4.24	1.22	1.74	1.70	3.48	4.24	5.66	9.22	18.31	3.95	1.44
Thallassionema (Thalassionemataceae)	5	0.1489	3.97	2.76	3.23	3.67	7.46	6.50	7.73	8.09	2.69	8.46	2.32
Lauderia (Lauderiaceae)	6	0.0979	2.61	1.98	3.84	0.72	4.11	1.43	0.42	1.04	3.73	1.34	3.54
Coscinidiscus (Coscinodiscaceae)	7	0.069	1.84	2.70	1.25	0.92	1.93	0.77	0.29	0.48	2.51	0.67	2.79
Leptocylindrus (Leptocylindraceae)	8	0.0686	1.83	1.20	3.06	2.01	1.28	2.96	1.84	2.86	2.03	3.65	0.34
Rhizisolenia (Rhizosoleniaceae)	9	0.0626	1.67	0.94	5.00	0.77	0.84	0.89	1.04	1.11	1.35	1.95	0.74
Nitzschia (Bacillariaceae)	10	0.0615	1.64	0.69	0.70	2.26	2.78	3.36	2.55	3.42	0.93	6.50	1.06
Pseudo-nitzschia (Bacillariaceae)	11	0.0604	1.61	0.31	0.21	1.09	0.46	1.46	7.29	10.91	1.43	5.96	0.38
Cylindrotheca (Bacillariaceae)	12	0.0266	0.71	0.15	0.11	4.23	2.64	0.34	0.51	1.08	0.05	0.63	0.18
Neoceratium (Ceratiaceae)	13	0.0206	0.55	1.06	0.54	0.69	0.56	0.42	0.23	0.58	0.26	0.35	0.19
Climacodium (Hemiaulaceae)	14	0.018	0.48	0.54	0.00	0.44	0.00	0.05	0.00	0.00	0.71	0.00	1.27
Guinardia (Rhizosoleniaceae)	15	0.018	0.48	0.52	0.06	0.77	0.08	0.89	1.15	0.62	0.07	0.59	0.67
Ditylum (Lithodesmiaceae)	16	0.0139	0.37	0.37	0.62	0.33	0.00	0.09	0.15	0.26	0.00	0.00	0.67
Pleurosigma (Pleurosigmataceae)	17	0.0131	0.35	0.30	0.40	0.60	0.84	0.23	0.53	0.76	0.05	0.93	0.10
Schuetiella (Gonyaulacaceae)	18	0.0131	0.35	0.00	0.01	0.00	6.17	0.23	0.00	1.56	0.00	0.03	0.00
Prorocentrum (Prorocentraceae)	19	0.0112	0.30	0.10	0.16	0.25	0.53	0.29	0.30	0.36	0.35	0.55	0.29
Climacosphenia (Climacospheniaceae)	20	0.0064	0.17	0.00	0.00	1.51	0.38	0.05	0.09	0.00	0.04	0.00	0.01
Fragilaria (Fragilariaceae)	21	0.0064	0.17	0.08	0.21	0.16	0.03	0.74	0.18	0.20	0.11	0.27	0.01
Protoperidium (Protoperidiniaceae)	22	0.0056	0.15	0.47	0.02	0.00	0.04	0.08	0.00	0.14	0.22	0.04	0.08
Odontella (Eupodiscaceae)	23	0.0049	0.13	0.03	0.09	0.45	0.00	0.38	0.20	0.10	0.04	0.13	0.11
Dinophysis (Prorocentraceae)	24	0.0041	0.11	0.06	0.17	0.28	0.24	0.00	0.09	0.33	0.00	0.16	0.04
Thalassiothrix (Thalassionemataceae)	25	0.0041	0.11	0.14	0.06	0.11	0.36	0.09	0.00	0.00	0.10	0.36	0.05
Bacillaria (Bacillariaceae)	26	0.0034	0.09	0.19	0.08	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fragillidium (Pyrophacaceae)	27	0.0019	0.05	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Mastogloia (Mastogloiaceae)	28	0.0019	0.05	0.00	0.01	0.12	0.09	0.00	0.00	0.50	0.00	0.27	0.00
Entomonesis	29	0.0015	0.04	0.00	0.00	0.13	0.00	0.00	0.09	0.00	0.00	0.00	0.11
Hemiaulus (Hemiaulaceae)	30	0.0015	0.04	0.07	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.11
Noctiluca (Noctilucaceae)	31	0.0015	0.04	0.08	0.03	0.00	0.05	0.00	0.06	0.11	0.00	0.05	0.00
Meuniera (Stauroneisaceae)	32	0.0015	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Diplopsalis (Dinophysiaceae)	33	0.0011	0.03	0.01	0.08	0.00	0.03	0.04	0.01	0.11	0.01	0.00	0.04
Scoliopleura (Scoliotropidaceae)	34	0.0011	0.03	0.00	0.14	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.01
Corethron (Corethraceae)	35	0.0007	0.02	0.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Gymnodinium (Gymnodiniidae)	36	0.0007	0.02	0.01	0.00	0.00	0.03	0.02	0.04	0.00	0.00	0.31	0.00
Navicula (Naviculaceae)	37	0.0007	0.02	0.06	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Asterionellopsis (Fragilariaceae)	38	0.0004	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Gonyaulax (Gonyaulacaceae)	39	0.0004	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.02	0.10	0.00
Haslea (Naviculaceae)	40	0.0004	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.01
Podolampas (Protoperidiniaceae)	41	0.0004	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Pyrophacus (Goniodomaceae)	42	0.0004	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.04	0.00	0.05	0.01
Triceratium (Triceratiaceae)	43	0.0004	0.01	0.00	0.04	0.00	0.09	0.00	0.00	0.04	0.00	0.00	0.00
Phaeodactylum (Phaeodactylaceae)	44	0.0004	0.01	0.00	0.00	0.02	0.15	0.00	0.00	0.05	0.01	0.00	0.00
Dissodinium (Pyrocystaceae)	45	0.0000	0	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goniodoma (Goniodomaceae)	46	0.0000	0	0.01	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Hyalodiscus (Hyalodiscaceae)	47	0.0000	0	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ornithocercus (Dinophysiaceae)	48	0.0000	0	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Licmnophora (Licmophoraceae)	49	0.0000	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Number of family		34		27	27	23	22	20	19	23	20	22	23
Number of genera		49		36	34	31	31	27	26	31	26	30	32
Mean cell count (Cells/ml)		37.9		60.9	55.3	32.4	14.8	19.8	15.6	14.3	39.1	15.4	71
Shannon-Wiener diversity index (H')		1.82		1.51	1.60	1.80	2.17	1.87	1.87	1.98	1.77	2.22	1.39
Pielou evenness index (J')		0.47		0.41	0.45	0.52	0.63	0.57	0.57	0.58	0.54	0.65	0.40

Table 5
Rating points and weighted assessment of sites for *P. viridis* farming.

	Weighted (w)	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7		Station 8		Station 9		Station 10	
		Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)	Rating (r)	Score (w*r)
Salinity	0.15	8	1.2	8	1.2	6	0.9	6	0.9	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	6	0.9
Dissolved oxygen	0.15	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2	8	1.2
pH value	0.1	7	0.7	8	0.8	9	0.9	5	0.5	5	0.5	7	0.7	7	0.7	7	0.7	7	0.7	9	0.9
Temperature	0.15	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5
Chlorophyll-a	0.15	7	1.05	7	1.05	7	1.05	9	1.35	10	1.5	9	1.35	9	1.35	10	1.5	10	1.5	9	1.35
Current speed	0.15	7	1.05	7	1.05	7	1.05	8	1.2	6	0.9	5	0.75	7	1.05	8	1.2	8	1.2	7	1.05
Water depth	0.15	5	0.75	5	0.75	3	0.45	6	0.9	10	1.5	10	1.5	8	1.2	10	1.5	10	1.5	7	1.05
Total			7.5		7.6		7.1		7.6		8.3		8.2		8.2		8.8		8.8		8.0
Weighted category		Medium		Good		Medium		Good		Good		Good		Good		Good		Good		Good	
Chaetocerotacea composition (%)		79.5 C		75.3 c		65.3 b		45.7 a		68.3 b		63 b		46.8 a		62.9 b		37 a		81.3 c	

et al., 2006). In addition, the higher total surface area to volume ratios (Irwin et al., 2006; Hein et al., 1995) and lower minimum cellular metabolic requirement (Teng et al., 2013; Grover, 1991) of small phytoplankton species also selectively allow them to survive at much lower nutrients concentrations than the larger cells. Similar results were reported in Daya Bay (Wang et al., 2006), where *Chaetoceros* spp. and other small phytoplankton species were dominant in the nutrients depleted environment. In contrast, larger phytoplankton taxa are able to store more surplus nutrients compared to smaller species (Raven et al., 2006). Therefore, larger phytoplankton species particularly *Coscinodiscus* spp. dominating the nutrient enriched coastal water such as Sepanggar Bay (Sidik et al., 2008) and Bengal Bay (Sarkar et al., 2006).

In general, the total phytoplankton cell density recorded in the current study (14 –71 cells/mL) was much lower than that in Sepanggar Bay (710–2050 cells/mL) (Sidik et al., 2008). This is expected because Sepanggar Bay has 5–10 times higher nutrients concentration (Anton et al., 2008) than that in Marudu Bay. Despite low cell density, the Shannon-Wiener diversity index (H'), Pielou's evenness (J'), and number of genera (n) recorded in Marudu Bay (H' = 1.39–2.17; J' = 0.40–0.65; n = 47) are comparable to that in the eutrophic water body such as in Sepanggar Bay (H' = 1.42–1.83; J' = 0.58–0.73; n = 40) (Sidik et al., 2008). This implies the environment of Marudu Bay favors the growth of certain phytoplankton taxa over other genera. We suspect the low phytoplankton diversity and evenness indices in Marudu Bay could be due to the long term (over 10 years) mass cultivation of a non-native and selective feeder bivalve species, *P. viridis* that could have probably modified the phytoplankton community structure in the bay (Tan and Ransangan, 2016; Tan et al., 2016a).

4.3. *Site suitability for* P. viridis *farming*

Site capability rating system is an important tool to achieve a fast and effective evaluation for potential farming sites of green mussel (Sallih, 2005). Based on the biophysical evaluation, stations 1 and 3 can be considered as moderate sites, whereas other stations came out to be the best potential sites for green mussel farming.

In term of food availability, the chlorophyll-a concentrations in all stations were higher than the minimum recommended concentration of 1 μg/L (Saxby, 2002). This indicates that the food availability in Marudu Bay is adequate to sustain the bivalve farming (Tan and Ransangan, 2014). On the other hand, food composition is equally important to ensure the sustainability of *P. viridis* farming (Ren and Ross, 2002). Chaetocerotaceae is known to entangle at the gills of shellfish (Ogongo et al., 2015). Therefore, the stations 1, 2 and 10 with significantly high composition of unfavourable phytoplankton taxa, Chaetoceroceae (Tan et al., 2016a) shall be avoided.

After taking all the biophysical parameters, food availability and food composition into consideration, it is concluded that stations 4, 7 and 9 are highly recommended sites but station 7 is singled out to be the best potential site for commercial green mussel farming in Marudu Bay.

5. Conclusions

It is a critical matter and has always been a priority to farmers and investors to identify the most suitable sites for successful and sustainable aquaculture activity. In this study, it has been shown that the existing site suitability rating system for green mussel culture can be more meaningful if quantity and quality of food composition available at the proposed site can be included in the assessment. With such inclusion, the site suitability rating system could become an important planning and management tool

for effective selection of potential farming sites for green mussel aquaculture in the future.

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