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Research article

Influence of Environmental Factors on Blood Cockle Production Potential at Klong Khone, Samut Songkharm Province and Bang Taboon, Phetchaburi Province

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Abstract

Keywords

seawater;

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blood cockle;

growth rate;

production potential

The aim of this study was to evaluate the influence of environmental factors on blood cockle production potential at Klong Khone and Bang Taboon. Seawater, sediment and cockles were collected for 6 months from October 2018 to March 2019. The results revealed that seawater quality in both areas did not meet seawater quality standards for aquaculture. The sediment of both areas was found to be clay. Salinity, pH and organic matter (OM) were low in the wet season. Klong Khone had more production potential than Bang Taboon in the wet season, during which the growth rates of cockles (GR) ranged from 1.09-4.68 and 0.30-1.74 g/month, respectively. In the dry season, Bang Taboon had more production potential than Klong Khone with the GR ranging from 0.89-2.21 and 0.00-1.56 g/month, respectively. Partial correlation revealed that in the wet season, with controlled pH of seawater, NO_3^--N, PO_4^{3-}-P and salinity of sediment, GR correlated with the salinity of seawater with r values of 0.46, 0.41, 0.53 and 0.51, respectively. However, GR correlated with PO_4^{3-}-P during the dry season when the salinity of seawater and grain size (0.06-0.125 mm) were controlled with r values of 0.51 and 0.44, respectively. Therefore, the salinity of seawater (wet season) and PO_4^{3-}-P (dry season) were the main factors affecting the GR. Cockle production potential tended to increase when the salinity of seawater was over 19 psu, the temperature was not higher than 30ºC, DO was not less than 3 mg/l. It also tended to be higher in sediment that was basically clay, of grain size smaller than 0.06 mm, and with pH higher than 6.5 and water content (WC) more than 70%.

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1. Introduction

Blood cockle farming began in Thailand more than ten decades ago. The early ventures were small, local-run businesses that collected natural spats of blood cockles and cultivated them in suitably controlled environments. These farms were first started at Bang Taboon, Bann Leam in Phetchaburi province with the average area of 0.008-0.016 km^2 and the timeline from cultivation through harvesting was about 1-2 years. A while later, an expansion of blood cockle farming broadened along almost all the coastlines in Thailand. Throughout that time and still today, most aquaculture sites are located on the Inner Gulf coast area: Phetchaburi, Samut Songkhram and Samut Sakhon; along the Eastern Gulf coast area: Chanthaburi and Chonburi; along the Southern Gulf coast area: Surat Thani, and on the Andaman Sea coast area: Satun [1]. Blood cockles are considered to be one of the essential and vital seafood products in the Thai economy, even though the production of blood cockles is smaller in volume compared to other shellfish. In 2017, a volume of 25,861 tonnes of blood cockles were produced which represented about 26.32% of the total shellfish aquacultural volume. However, in terms of value or profitable gain, blood cockle production was ranked number one and was valued at USD 84 million, or about 61.98% of total shellfish aquaculture value [2]. Unfortunately, the average annual blood cockle production in Thailand significantly decreased over the last five years (2013-2017). Production dwindled from 71,325 tonnes in 2013 to 25,861 tonnes in 2017. Following the report in 2017, the provinces of Samut Songkharm and Phetchaburi were ranked second and fourth in terms of blood cockle production, generating 7,676 and 2,472 tonnes, respectively. They were only behind Surat Thani's production of 8,486 tonnes. However, Samut Songkharm and Phetchaburi were in an adjoining area, and if the production of these two provinces were combined, the total volume would have been 10,148 tonnes, or about 40% of total shellfish aquaculture production [2]. The Inner Gulf coast area has been recognized as a predominant region of blood cockle production of the country. The blood cockle industry is a significant economic contributor to local communities and the country, so it is very important to ensure the sustainable cultivation of the species in this region.

In recent time, a wastewater crisis has affected blood cockle farming a number of times in Phetchaburi and Samut Songkharm, and the aftermath of those incidents has negative impact on the province's economy. One of those took place in November 11, 2016, and it produced a letter of request for assistance from groups of cockle farmers in Bang Taboon and Khlong Khon. Their farms had been adversely affected by the discharge of wastewater from an industrial plant in Ratchaburi into the Mae Klong River that then ran into the sea. It left contaminated water in the area. In the early week of October 2016, there was an investigation of dissolved oxygen (DO) in the lower Mae Klong River and it was found to be approximately 1-2.8 mg/l. As a result, a mass mortality of blood cockles was estimated at 60% of total production in this region and the total damage was worth approximately USD 867,656 [3]. According to the report from the Chairman of the cockle farmer groups in Bang Taboon and Klong Khon [4], in 2015, an average cultivated area of 6.4 hectares of blood cockles produced up to 36 tonnes, but by 2018, only 5 tonnes were able to be harvested. Furthermore, in 2011, blood cockle farmers used to harvest about 4,000 kilograms of cockles per 0.16 hectare and earned a profit up to USD 2,566 per 0.16 hectare. In 2018, the harvest had dropped to 200 kilograms of cockle per 0.16 hectare and took a loss of USD 561 per 0.16 hectare. It appears that the problems are ongoing. Blood cockles are dying off because the natural balance of their habitat is being disturbed. Studies have identified the pollutants in the water are from discharge of wastewater from industrial plants, and also from waste from agricultural farms and household. These are some of the main causes that have contributed not only to the significant decrease in blood cockle production but also to the decline of the whole aquaculture habitat. Today, the blood cockle cultivating in the provinces of Phetchaburi and Samut Songkharm is still facing crisis in production, and the output of the farms has dwindled dramatically. Moreover, the situation seems to be worsening. Farmers are facing even greater losses in profitability and more financial difficulties.

In order to prevent the blood cockle population from gradually disappearing and to maintain local economies, we need to implement an effective solution as quickly as possible. Thus, the purpose of this research is to study the current status of environmental factors that affect the cockles. Then, the data obtained will be used to analyze the relationship between cockles and environmental factors in order to determine the influence of environmental factors on the production potential of cockle in these areas.

2. Materials and Methods

2.1 The study area

The research was conducted in Klong Khone, Samut Songkharm province and Bang Taboon, Phetchaburi province, Thailand (UTM 604845 E, 1470990 N). As shown in Figure 1, the study area was divided according to the density and quantity of the farms and the number of affected farms. Therefore, each area classified into two groups: one with 6 sampling stations in Klong Khone (KC 1-6), and another with 20 sampling stations in Bang Taboon (BTB 1-20). All of them (26 stations) were blood cockle farms located in the estuary zones. These areas were exposed to many pollutants from upstream, both point and non-point sources [5]. The data were collected for 6 months from October 2018 to March 2019, which represented the wet season (October to December) and the dry season (January to March), respectively. At each sampling station, data were collected at low tide during the spring tide in order to evaluate influence of environmental factors on blood cockle production potential.

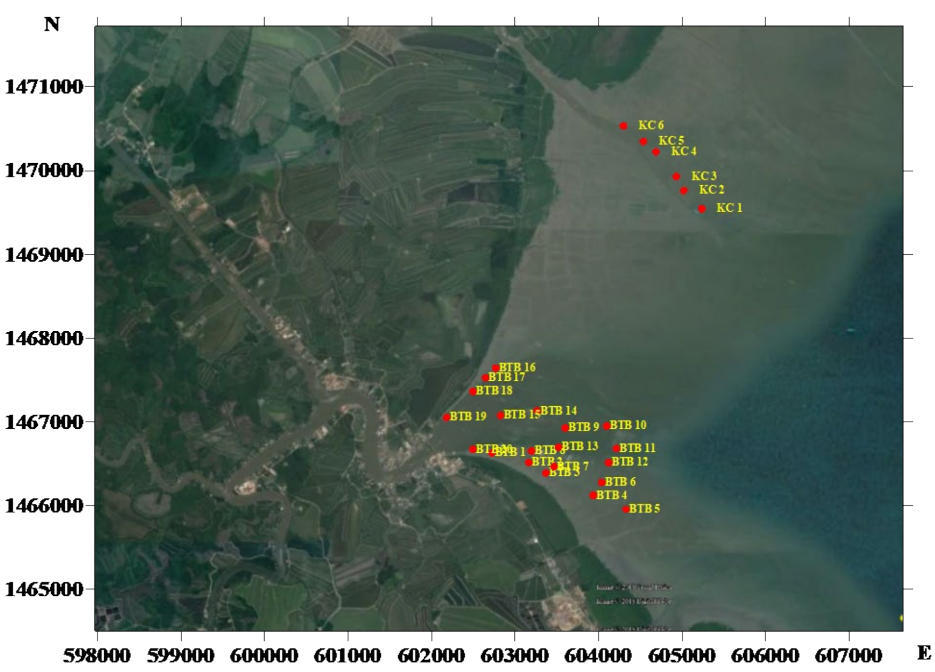

Figure 1. Map of sampling stations at Klong Khone and Bang Taboon areas

2.2 Field sampling

In this study, duplicate sampling was collected at the 26 stations, and samples were taken three times at each station and tested for seawater quality and sediment quality. In each station, in situ seawater quality was investigated. Salinity and pH of water were measured using refractometer and Cybercan PC 300 (EUTECH Instruments, Singapore), respectively. Then, temperature and dissolved oxygen (DO) were analyzed in situ by Cybercan DO 110 (EUTECH Instruments, Singapore). Finally, seawater was collected for analyses of total suspended solids (TSS), ammonium-nitrogen (NH_4^+-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), phosphate-phosphorus (PO_4^{3-}-P) and chlorophyll *a* in the laboratory. Sediment was sampled at 0 - 1 cm depth from the sediment surface by gravity core and repeated three times. Then, the sediment samples were stored in plastic bags to determine salinity, pH, grain size, water content (WC) and organic matter (OM) in the laboratory. The sampling of blood cockles was carried out at the same station and time as samples for seawater and sediment, during the low tide period. Blood cockles were collected within a 1 x 1 m quadrant grid by hand picking. Cockles were stored alive in plastic bags and transported to the laboratory. Shell size and body weight of the sampled blood cockles were measured immediately after arrival at the laboratory.

2.3 Seawater analysis

Total suspended solids (TSS) of the seawater were measured by filtering (GF/C filter paper) and drying in a hot air oven at 103-105ºC for three days [6]. After drying, the samples were weighed again and the dry weights were measured using a 4-digit analytical balance. The concentrations of NH_4^+-N, NO_2^--N, NO_3^--N and PO_4^{3-}-P were determined following standard methods [6]. Chlorophyll *a* concentration was determined by a spectrophotometric method as described by Parsons *et al.* [7].

2.4 Sediment analysis

Grain size was analyzed using a sieve with pore sizes of 1, 0.125 and 0.06 mm to filter sand, silt and clay, respectively. The pH and salinity measurements were conducted as described by Jones [8]. Water content (WC), or the percentage of water in the sediment, was determined by subtraction of dry weight (after drying in hot air oven at 105ºC for three days) from wet weight. Finally, organic matter (OM) was determined using the wet oxidation method [9]. After obtaining the results of seawater quality and sediment quality, these results were treated together using descriptive statistics as follows: mean ±SD for evaluation of the existing conditions of the water quality and sediment, and two-way ANOVA for determining the significance of spatial (station) and seasonal (month) variation in seawater quality and sediment quality at significant level 95% ($\alpha = 0.05$).

2.5 Blood cockle analysis

In this study, blood cockle growth rate (g/month) was evaluated for the production potential of cockles [10]. Blood cockle size was determined by measuring three shell axes as length, height and width (Figure 2) as described by Şahin *et al*. [11]. The shell size of each sample was measured using Vernier caliper. Finally, each sample of fresh blood cockles (including meat and shell) was weighed on a 4-digit analytical balance. The resulting value was wet weight (WW).

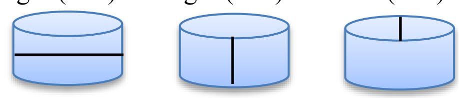

Figure 2. Shell size measurement

Finally, blood cockle growth rates were calculated for the production potential of cockles by the following equation:

$$GR = \frac{W_1 - W_0}{\Delta t}$$

Where GR = Blood cockle growth rate (mm/month or g/month)
W_1 = Length (mm), Height (mm), Width (mm) or whole-body wet weight (g) at final time (t = 1)
W_0 = Length (mm), Height (mm), Width (mm) or whole-body wet weight (g) at initial time (t = 0)
Δt = the time difference of t_0 and t_1 (month)

2.6 Correlation analysis

The relationship between environmental factors and cockle production potential was analyzed using the Pearson correlation coefficient (r_{xy}) and Partial correlation. Finally, the results from the correlation analysis were also used to find out the environmental factors that affected blood cockle production potential.

3. Results and Discussion

3.1 Environmental factors

3.1.1 Seawater quality

The results showed that the seawater quality in Klong Khone and Bang Taboon did not meet the seawater standards for aquaculture. According to the standard of class 3 (seawater quality criteria for aquaculture in Thailand), NO_3^--N should not be more than 0.06 mg-N/l and PO_4^{3-}-P should not be more than 0. 045 mg-P/l, as shown in Table 1. The seawater quality in these two areas had likely been degraded due to the low salinity and DO in October (wet season). Furthermore, during this time, the temperature and nutrients were high as well. Additionally, it could have been that a tremendous quantity of freshwater had been flushed from the Mae Klong River and Phetchaburi River into the estuarine area. These factors may have led to the deterioration of seawater quality. In the previous study, Parekh and Gadhvi [12] investigated the seasonal variation of seawater in the Mithirdi Coast Bhavnagar on the western coast of India, and found the decreased levels of DO and salinity were due to heavy rainfall and large quantity of freshwater inflow to estuaries in the monsoon season. Ibrahim et *al.* [13] reported that the water runoff discharge from rivers was a factor affecting the lower salinity in the monsoon season. Furthermore, the temperature was high in October due to higher amounts of sediment particles in seawater absorbing more heat from solar radiation, and therefore increasing the temperature of the surrounding seawater [14, 15]. Similar trend in nutrient values was also high in October. This may have been caused by the discharge of

Table 1. Mean values (±SD) for environmental factors in the study area and P-values from Two-way ANOVA with α = 0.05 by month and station

Environmental Factors	Klong Khone (KC) Mean ±SD						Bang Taboon (BTB) Mean ±SD						P-values	
	Oct	Nov	Dec	Jan	Feb	Mar	Oct	Nov	Dec	Jan	Feb	Mar	Month	Station
Seawater parameters														
Salinity (psu)	9.00 ±2.00	25.83 ±6.21	19.50 ±1.38	19.50 ±1.76	15.33 ±0.82	16.33 ±1.03	14.05 ±5.13	19.00 ±2.05	22.45 ±1.73	21.35 ±1.60	21.75 ±1.12	26.05 ±3.98	<0.00***	0.03
pH	6.57 ±0.29	7.43 ±0.12	7.70 ±0.13	7.66 ±0.06	7.83 ±0.07	7.54 ±0.28	7.62 ±0.07	7.45 ±0.13	7.75 ±0.13	7.67 ±0.17	7.67 ±0.39	7.52 ±0.11	<0.00***	0.16
Temperature (ºC)	29.68 ±0.16	29.35 ±0.16	28.58 ±1.73	26.93 ±0.16	29.10 ±0.15	30.48 ±0.26	31.20 ±1.41	29.61 ±0.99	29.73 ±1.10	28.04 ±0.87	25.00 ±0.00	25.00 ±0.00	<0.00***	0.15
DO (mg·l^{-1})	3.93 ±0.20	4.35 ±0.24	4.90 ±0.56	4.35 ±0.13	6.14 ±0.20	5.19 ±0.39	3.27 ±0.83	4.62 ±0.87	6.77 ±1.06	4.72 ±0.29	6.14 ±0.44	5.49 ±1.25	<0.00***	<0.00***
TSS (mg·l^{-1})	37.17 ±13.19	35.20 ±10.64	55.19 ±23.24	21.67 ±4.57	44.67 ±11.65	104.22 ±28.20	51.90 ±22.38	50.73 ±15.98	54.80 ±23.94	44.51 ±13.08	57.28 ±26.20	225.33 ±86.41	<0.00***	<0.00***
NH_4^+-N (µg·l^{-1})	9.29 ±1.78	1.87 ±1.38	2.32 ±1.13	6.20 ±1.05	0.30 ±0.31	3.71 ±1.76	7.82 ±4.57	1.52 ±1.60	0.53 ±0.37	2.80 ±0.97	0.40 ±0.26	3.10 ±1.89	<0.00***	<0.00***
NO_2^--N (µg·l^{-1})	0.92 ±0.11	0.15 ±0.18	0.63 ±0.18	0.26 ±0.06	0.32 ±0.05	1.06 ±0.33	1.25 ±0.19	0.17 ±0.23	0.54 ±0.43	0.29 ±0.11	0.35 ±0.17	1.23 ±0.67	<0.00***	0.28
**NO_3^--N (mg·l^{-1})	0.44 ±0.02	0.38 ±0.03	0.28 ±0.02	0.40 ±0.01	0.07 ±0.01	0.20 ±0.03	0.44 ±0.02	0.33 ±0.04	0.25 ±0.02	0.44 ±0.05	0.10 ±0.01	0.30 ±0.04	<0.00***	0.17
**PO_4^{3-}-P (mg·l^{-1})	0.53 ±0.01	0.01 ±0.00	0.12 ±0.03	0.09 ±0.01	0.03 ±0.02	0.17 ±0.08	0.31 ±0.16	0.01 ±0.00	0.06 ±0.02	0.12 ±0.02	0.05 ±0.03	0.20 ±0.12	<0.00***	0.24
Chl *a* (µg·l^{-1})	10.35 ±0.92	32.26 ±13.70	7.02 ±0.99	4.39 ±2.46	15.69 ±4.81	6.08 ±1.90	15.85 ±13.15	18.82 ±6.33	16.76 ±6.49	12.73 ±4.26	14.41 ±4.63	10.13 ±5.24	<0.00***	0.61
Sediment parameters														
Salinity (psu)	4.83 ±0.41	5.83 ±0.75	10.00 ±2.00	8.00 ±1.41	-*	12.00 ±0.89	4.50 ±0.83	7.00 ±1.26	11.65 ±1.39	10.25 ±0.79	12.10 ±1.94	12.45 ±2.35	<0.00***	<0.00***
pH	6.89 ±0.22	7.65 ±0.29	7.63 ±0.25	7.11 ±0.31	-*	7.27 ±0.20	6.36 ±0.32	6.64 ±0.37	6.86 ±0.26	6.93 ±0.35	7.17 ±0.13	6.83 ±0.32	<0.00***	<0.00***
Grain size (%) 0.125-1 mm	33.09 ±5.33	38.72 ±4.43	23.13 ±8.02	17.88 ±5.86	-*	15.95 ±3.96	40.65 ±12.32	36.25 ±7.71	30.76 ±13.47	18.53 ±7.08	15.93 ±6.58	17.15 ±9.46	<0.00***	0.04
Grain size (%) 0.06-0.125 mm	8.20 ±3.03	6.27 ±1.44	5.24 ±1.64	6.65 ±2.99	-*	5.87 ±0.84	14.13 ±11.30	8.41 ±6.97	10.42 ±8.00	11.19 ±9.44	12.16 ±11.62	15.07 ±12.96	<0.00***	<0.00***
Grain size (%) <0.06 mm	58.71 ±2.41	55.01 ±4.94	71.63 ±7.75	75.47 ±4.91	-*	78.18 ±3.66	45.22 ±15.35	55.34 ±9.82	58.82 ±15.37	70.28 ±10.92	71.91 ±13.39	67.78 ±11.78	<0.00***	<0.00***
WC (%)	67.71 ±4.29	65.34 ±4.86	66.13 ±4.24	63.47 ±3.27	-*	63.53 ±5.15	69.30 ±8.05	68.17 ±7.62	70.05 ±7.71	70.78 ±8.22	67.32 ±7.79	63.56 ±12.39	<0.00***	<0.00***
OM (%)	4.04 ±0.35	4.18 ±0.31	5.25 ±0.16	4.26 ±0.16	-*	4.54 ±0.26	3.90 ±0.63	4.28 ±0.61	4.33 ±0.81	4.20 ±0.50	4.24 ±0.52	4.31 ±0.79	<0.00***	<0.00***

Note: *No data **Not in class 3 (Seawater quality criteria for aquaculture) [24] ***P-value <0.001 and significant level 95% (α = 0.05) domestic wastewater in the upper areas that flowed down into the estuaries during the wet season [16]. In addition, the statistical results revealed that there were significant differences among months in all seawater parameters (P-value <0.05), therefore, the season (month) was more likely to have an influence on seawater changes than the spatial (station). In October (wet season) in the Klong Khone area, the seawater salinity and temperatures were lower than in the Bang Taboon area while nutrients and DO in the Klong Khone area were found to be higher than in the Bang Taboon area during wet season as well. It can be concluded that the seawater at this time (wet season) in Klong Khone was more affected by freshwater from the land than was Bang Taboon. However, the contributor of TSS in Bang Taboon was higher than in Klong Khone, probably because this area was the Phetchaburi River downstream (outlet).

3.1.2 Sediment quality

Sediment parameters were investigated during the study period are shown in Table 1. The characteristics of sediment in both areas were found to be clay. Salinity, pH and organic matter (OM) were low in October (wet season) due to heavy rainfall and the river runoff causing huge quantities of freshwater to be discharged into the estuarine. The statistical analysis revealed that there were significant differences in all sediment parameters among sampling stations and months (P-value <0.05). In the Klong Khone area, the proportion of sediment size smaller than 0.06 mm, and pH, were higher than that in the Bang Taboon area. It can be explained that the sediment characteristics of the Klong Khone area were more liquid and finer than the Bang Taboon area. Therefore, the Klong Khone area was suitable for the growth of benthos because grain size was less than 0.06 mm, or the clay has a lot of nutrients [17]. On the other hand, the proportion of sediment size 0.06-0.125 mm and 0.125-1.00 mm in the Klong Khone area were less than in the Bang Taboon area. This can demonstrate that the sediment distribution in the Bang Taboon area was more affected by freshwater runoff and monsoon from the land into the estuarine areas more than in the Klong Khone area. Furthermore, the pH of sediment in the Bang Taboon area was slightly more acidic than in the Klong Khone area because there was more organic matter accumulation from domestic waste pollution (having large community on the upstream) in the Bang Taboon area and also had a higher density of cockle culture than in the Klong Khone area. For this reason, the accumulation of domestic waste increased microbial activity which produced acetic acid in the sediment, and caused decrease of pH level [18-20]. The study also found that the pH values of both areas in October were lower than 7. That may be due to a direct effect of discharge and flow of freshwater runoff from the river into the estuarine area [15]. Moreover, the opening the floodgates caused waste flow down to the estuarine area and the sediment became more acid [15, 17]. For organic matter (OM), there was not much difference for each station (3.90-5.25%). However, when compared with other sites, it was found that the organic matter in Klong Khone and Bang Taboon were relatively high [18, 19, 21, 22]. Our result corresponds to clay texture that increases the accumulation of organic matter in the sediment causing organic matter degradation while acidity in sediment had increased. As a result, environment and habitat of benthic fauna became unsuitable for living [20, 23].

3.2 Production potential of blood cockle

This research determined the production potential of blood cockles involving analysis of the size and growth rate of the cockles. The size of blood cockles found in this study are shown in Table 2. During the study period in the Klong Khone area, the cockles were absent from stations KC 1, 2 and 6 (3 of the 6 stations) while cockles in Bang Taboon were found in 7 stations (Stations BTB 1, 2, 5, 8, 17, 18 and 19), as shown in Figure 1. This may be because the cultivation period of cockles was

Table 2. Mean values (±SD) for cockle size in each month as length, height, width and wet weight in Klong Khone (KC) and Bang Taboon (BTB)

Stations	Length (mm)						Height (mm)					
	Oct	Nov	Dec	Jan	Feb	Mar	Oct	Nov	Dec	Jan	Feb	Mar
KC 1	21.16	22.53	24.88	26.94	-*	-*	15.46	16.62	18.48	19.96	-*	-*
KC 2	21.29	27.11	-*	-*	-*	-*	15.46	20.31	-*	-*	-*	-*
KC 6	19.63	22.31	24.01	-*	-*	-*	14.93	17.10	18.49	-*	-*	-*
Avg (KC)	20.69	23.98	24.44	26.94	0.00	0.00	15.28	18.01	18.48	19.96	0.00	0.00
±SD	±0.92	±2.71	±0.62	±0.00			±0.31	±2.01	±0.01	±0.00		
BTB 1	21.06	23.98	-*	13.07	16.41	20.87	16.26	17.96	-*	9.78	12.65	16.37
BTB 2	24.06	25.89	-*	-*	-*	-*	18.00	19.98	-*	-*	-*	-*
BTB 5	-*	-*	-*	13.05	17.90	20.31	-*	-*	-*	9.79	13.88	15.63
BTB 8	25.74	26.35	27.83	-*	10.03	-*	18.78	19.53	20.96	-*	7.31	-*
BTB 17	37.58	-*	-*	-*	-*	-*	28.12	-*	-*	-*	-*	-*
BTB 18	24.19	-*	-*	-*	-*	-*	17.79	-*	-*	-*	-*	-*
BTB 19	26.85	27.28	-*	-*	-*	-*	20.20	20.94	-*	-*	-*	-*
Avg (BTB)	26.58	25.87	27.83	13.06	14.78	20.59	19.86	19.60	20.96	9.78	11.28	16.00
±SD	±5.73	±1.39	±0.00	±0.01	±4.18	±0.40	±4.25	±1.24	±0.00	±0.01	±3.49	±0.53

Stations	Width (mm)						Wet weight (g)					
	Oct	Nov	Dec	Jan	Feb	Mar	Oct	Nov	Dec	Jan	Feb	Mar
KC 1	12.89	14.22	15.89	17.75	-*	-*	2.74	3.92	5.10	6.66	-*	-*
KC 2	12.96	18.69	-*	-*	-*	-*	2.88	7.56	-*	-*	-*	-*
KC 6	11.84	13.80	15.33	-*	-*	-*	2.43	3.69	4.78	-*	-*	-*
Avg (KC)	12.56	15.57	15.61	17.75	0.00	0.00	2.68	5.05	4.94	6.66	0.00	0.00
±SD	±0.63	±2.71	±0.39	±0.00			±0.23	±2.17	±0.23	±0.00		
BTB 1	13.84	15.46	-*	7.42	10.28	14.41	2.76	4.50	-*	0.76	1.65	3.87
BTB 2	15.72	17.33	-*	-*	-*	-*	4.37	5.98	-*	-*	-*	-*
BTB 5	-*	-*	-*	7.45	11.38	13.68	-*	-*	-*	0.75	2.23	3.37
BTB 8	16.85	17.72	18.72	-*	5.38	-*	5.39	6.26	7.56	-*	0.51	-*
BTB 17	26.83	-*	-*	-*	-*	-*	18.63	-*	-*	-*	-*	-*
BTB 18	15.58	-*	-*	-*	-*	-*	4.65	-*	-*	-*	-*	-*
BTB 19	17.93	18.32	-*	-*	-*	-*	6.81	7.11	-*	-*	-*	-*
Avg (BTB)	17.79	17.21	18.72	7.44	9.01	14.04	7.10	5.96	7.56	0.75	1.46	3.62
±SD	±4.64	±1.23	±0.00	±0.02	±3.19	±0.52	±5.80	±1.08	±0.00	±0.00	±0.88	±0.35

Note: * All cockle had been completely harvested and there was no releasing of new juvenile cockle into the area.

different. Cockles in Klong Khone and Bang Taboon were cultivated from January to March 2018. However, the harvesting time periods between these two locations were different. In Klong Khone, cockles were harvested from December 2018 through February 2019; however, in Bang Taboon harvesting was completed by December 2018. Moreover, there were some farms in Bang Taboon that started to raise new juvenile cockles in January 2019. As a result of these different timings of harvesting and cultivating, there was a difference in cockle size between the two areas. Additionally, there was no cockle in some stations because all cockles had already been harvested. Besides, there was no releasing of new juvenile cockles into the area for cultivation during that time.

3.2.1 Size of blood cockle

In Klong Khone, the size of blood cockles varied from 19.63-27.11 mm, 14.93-20.31 mm, 11.84-18.69 mm and 2.43-7.56 g in length, height, width and wet weight, respectively. The smallest blood cockles were recorded in October at station KC 6 which was in an area near the coast that received more freshwater and urban runoff than other stations. On the other hand, the largest blood cockles were recorded in January at station KC 1 which was located about 2 km away from the coast and thus received less freshwater and urban runoff than other stations.

In Bang Taboon, the size of blood cockles varied from 10.03-37.58 mm, 7.31-28.12 mm, 5.38-26.83 mm and 0.51-18.63 g in length, height, width and wet weight, respectively. In February, it was recorded the smallest blood cockles at station BTB 8 which was close to a channel outlet in Bang Taboon and farmers had recently sowed the cockle in nursery farm. The largest blood cockles were found in October at station BTB 17 which was located at a channel outlet along the mangrove forest (Figure 1).

This study compared the cockle sizes in two areas. It was revealed that the cockle size in the Klong Khone area was a little smaller than in Bang Taboon area. This may be because the cultivation period of the cockles was different. The sizes of adult cockles are about 16.8-39.1 mm [25] and can grow up to a maximum length of 44.4 mm [26]. Moreover, considering the average size of the cockles in each month revealed that cockles had increased in size over time in both areas (Table 2). This can be explained that the sizes of cockles in both areas had increased. However, the period of growth for cockles in the Bang Taboon area was divided into 2 periods, the first being between October to December 2018 and the second being between January and March 2019. This was because cockles raised from January to March 2018 were completely harvested during December 2018. Meanwhile, new cultivation began in January 2019 maing the cockles smaller at this time.

3.2.2 Growth rate of cockles

The difference of cockle sizes in each station were due to the different periods of cultivation. Only data from the analysis of cockle size might not be sufficient to determine the production potential of the blood cockles. Hence, growth rate analysis was better to demonstrate the production potential of blood cockles. As shown in Table 3, the results revealed that the growth rate of cockles in Klong Khone increased from 1.38-5.83 mm/month, 1.15-4.85 mm/month, 1.33-5.73 mm/month and 1.09-4.68 g/month in length, height, width and wet weight, respectively (Table 3). It can be seen that for each month the growth rate of cockle size increased over time. The lowest growth rate was found in November at the station KC 1 which was located about 2 km away from the shore. Meanwhile, the highest growth rate was found in the same month at the station KC 2 which was located closer to the coast and next to the station KC 1 (Figures 1 and 3).

The results for Bang Taboon showed that the growth rates of cockles were 0.43-4.85 mm/month, 0.74-4.09 mm/month, 0.39-4.13 mm/month and 0.30-2.21 g/month in length, height, width and wet weight, respectively (Table 3). The lowest growth rate was found in November at the station BTB 19 which was located at the river mouth and near the coast. This station received the most freshwater runoff from the Mae Klong River and Phetchaburi River and more discharge of domestic wastewater than other areas. Stations BTB 5 and BTB had the highest growth rates in February and March, respectively. Both stations were located at muddy flats in front of the mangrove forest in the southern side of the estuary (Figures 1 and 3), an area which probably had more nutrients than other areas.

Throughout the study period, the average value of cockle growth rate was considered in each month (Table 3). The results showed that in Klong Khone, the highest growth rate was found in October to November 2018, then the growth rate slightly decreased. This demonstrated that in October to November period, the environment was suitable for the growth of cockles and there was more production potential than other months. On the other hand, in Bang Taboon, the lowest growth rate was found in October 2018, and after that through to March 2019, the growth rate gradually slightly increased. The result of this growth rate in Bang Taboon indicated that the production potential in October was less than other months. According to the study in October (wet season), salinity was less than 19 psu and seawater temperature was higher than 30^{o}C (Table 1). Thus, these factors caused an unsuitable environment for blood cockle cultivation during that time.

Table 3. Mean values (±SD) for cockle growth rate throughout this study period as length, height, width and wet weight in Klong Khone (KC) and Bang Taboon (BTB)

Stations	Length (mm/month)				
	Oct-Nov 18	Nov-Dec 18	Dec 18-Jan 19	Jan-Feb 19	Feb-Mar 19
KC 1	1.38	2.35	2.06	-*	-*
KC 2	5.83	-*	-*	-*	-*
KC 6	2.68	1.70	-*	-*	-*
Avg±SD	3.29±2.29	2.02±0.46	2.06±0.00	0.00	0.00
BTB 1	2.92	-*	-*	3.34	4.46
BTB 2	1.83	-*	-*	-*	-*
BTB 5	-*	-*	-*	4.85	2.41
BTB 8	0.60	1.48	-*	-*	-*
BTB 19	0.43	-*	-*	-*	-*
Avg±SD	1.44±1.16	1.48±0.00	0.00	4.09±1.07	3.44±1.45
Stations	**Height (mm/month)**				
	Oct-Nov 18	**Nov-Dec 18**	**Dec 18-Jan 19**	**Jan-Feb 19**	**Feb-Mar 19**
KC 1	1.15	1.86	1.49	-*	-*
KC 2	4.85	-*	-*	-*	-*
KC 6	2.18	1.38	-*	-*	-*
Avg±SD	2.73±1.91	1.62±0.34	1.49±0.00	0.00	0.00
BTB 1	1.70	-*	-*	2.88	3.72
BTB 2	1.98	-*	-*	-*	-*
BTB 5	-*	-*	-*	4.09	1.75
BTB 8	0.74	1.44	-*	-*	-*
BTB 19	0.74	-*	-*	-*	-*
Avg±SD	1.29±0.64	1.44±0.00	0.00	3.48±0.85	2.73±1.39
Stations	**Width (mm/month)**				
	Oct-Nov 18	**Nov-Dec 18**	**Dec 18-Jan 19**	**Jan-Feb 19**	**Feb-Mar 19**
KC 1	1.33	1.67	1.86	-*	-*
KC 2	5.73	-*	-*	-*	-*
KC 6	1.96	1.53	-*	-*	-*
Avg±SD	3.01±2.38	1.60±0.10	1.86±0.00	0.00	0.00
BTB 1	1.62	-*	-*	2.86	4.13
BTB 2	1.61	-*	-*	-*	-*
BTB 5	-*	-*	-*	3.92	2.30
BTB 8	0.87	1.00	-*	-*	-*
BTB 19	0.39	-*	-*	-*	-*
Avg±SD	1.12±0.60	1.00±0.00	0.00	3.39±0.75	3.21±1.29
Stations	**Wet weight (g/month)**				
	Oct-Nov 18	**Nov-Dec 18**	**Dec 18-Jan 19**	**Jan-Feb 19**	**Feb-Mar 19**
KC 1	1.18	1.19	1.56	-*	-*
KC 2	4.68	-*	-*	-*	-*
KC 6	1.26	1.09	-*	-*	-*
Avg±SD	2.37±2.00	1.14±0.07	1.56±0.00	0.00	0.00
BTB 1	1.74	-*	-*	0.89	2.21
BTB 2	1.61	-*	-*	-*	-*
BTB 5	-*	-*	-*	1.48	1.14
BTB 8	0.86	1.31	-*	-*	-*
BTB 19	0.30	-*	-*	-*	-*
Avg±SD	1.13±0.67	1.31±0.00	0.00	1.19±0.41	1.67±0.76

Note: * All cockles had been completely harvested and there was no releasing of new juvenile cockles into the area.

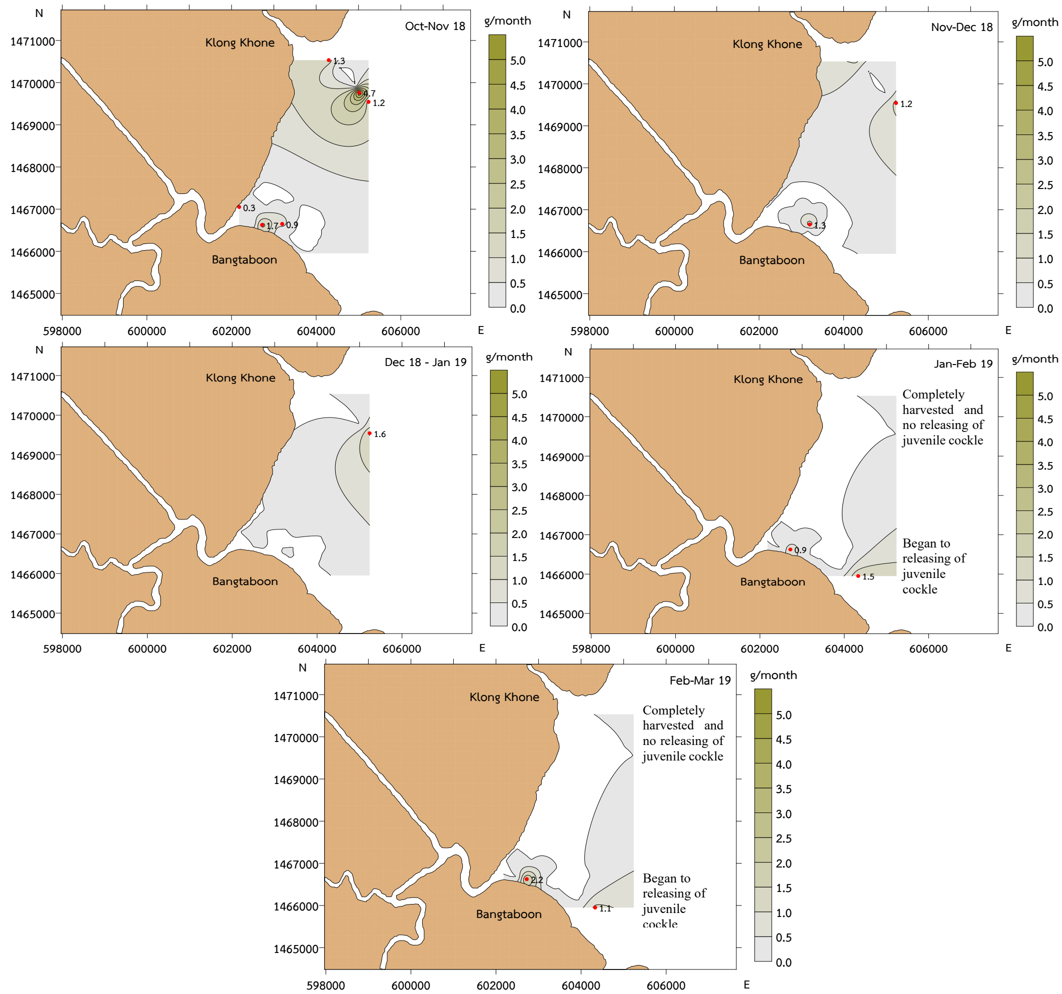

Figure 3. Cockle growth rate as determined by gain in weight (g/month) between October and November (top left), November to December (top right), December to January (center left), January to February (center right) and February to March (bottom)

By comparison of the average growth rate between the two designated areas, it was observed that Klong Khone had a higher growth rate than Bang Taboon during the wet season. The rates ranged from 1.09-4.68 and 0.30-1.74 g/month, respectively (Table 3). This study revealed that there was more production potential in Klong Khone area during wet season. The environmental factors that contributed to blood cockle growth during this period were seawater temperature lower than 30^{o}C, DO higher than 3 mg/l, and TSS less than 300 mg/l. Moreover, the pH of the sediment was neutral and the sediment characteristics of the Klong Khone area was more liquid and finer than those in the Bang Taboon area (Table 1). On the other hand, in the dry season, Bang Taboon demonstrated a higher growth rate than Klong Khone. It ranged from 0.89-2.21 and 0.00-1.56 g/month, respectively (Table 3). Although there was no growth rate data during February to March in Klong Khone, the environmental factors showed limitations for cockle growth. There were no blood cockle sample during the dry season in Klong Khone because the number of blood cockles depended on the cultivating period. Klong Khone started harvesting from December 2018 through February 2019 while Bang Taboon started to raise new juvenile cockles in January to March. In addition, the environmental factor data during the dry season in Klong Khone showed limiting factors for growth of blood cockle. As shown in Table 1, seawater salinity was less than 19 psu and temperature was close to 30ºC. This indicated that the area of Klong Khone has less production potential than Bang Taboon area in the dry season. Furthermore, the cockle density in the Klong Khone area was more than Bang Taboon area in the wet season with averages of 58.11 indv.m-2 and 41.33 indv.m-2, respectively. Meanwhile, the cockle density in Bang Taboon area was greater than Klong Khone area during the dry season, with averages of 29.83 indv.m-2 and 17.00 indv.m-2, respectively. The results confirmed that Bang Taboon had more production potential of cockles than Klong Khone in the dry season, while Klong Khone showed more production potential in the wet season. However, the number of cockles were not from natural breeding. The number depended on the cultivation patterns of each farm, which made it difficult to compare cockle density. Hence, the data on blood cockle gain of weight was reliable and was chosen to indicate blood cockle production potential.

3.3 Influence of environmental factors on blood cockle production potential

Pearson correlation analysis of the environmental factors and cockle production potential revealed that there were no statistically significant relationships at 95% confidence interval (α = 0.05). However, as shown in Figure 4 using Partial correlation, it was found that the major factor in the wet season when controlled the pH of seawater, NO_3^--N, PO_4^{3-}-P and salinity of the sediment were constant. The growth rate related to the salinity of seawater with r values of 0.467, 0.416, 0.539 and 0.515, respectively (Figure 4). This can be explained that during the wet season with the salinity of seawater variations, these parameters varied slightly because of the tremendous quantity of freshwater during that time. In the dry season, the analysis revealed that when the salinity of seawater and sediment size 0.06-0.125 mm were constant, the growth rate related to the phosphate-phosphorus (PO_4^{3-}-P) levels, with r values of 0.511 and 0.449, respectively (Figure 4). This may be because of less influence of freshwater in this area or less river runoff during the dry season where PO_4^{3-}-P became the major factor influencing the cockle production potential. During the dry season, salinity became stable (Table 1). Therefore, in this period, this parameter did not have much effect on cockle growth. Meanwhile, cockles still consumed phytoplankton for their growth and PO_4^{3-}-P was limiting factor for phytoplankton. Hence, PO_4^{3-}-P became an important influencing factor for cockles. Finally, it can be concluded from our results that the factor most affecting the blood cockle production potential in Klong Khone and Bang Taboon area were salinity of seawater (wet season) and PO_4^{3-}-P (dry season).

3.3.1 Salinity of seawater

As shown in Table 4, the lowest growth rate was 0.30 g/month which happened in the late rainy season during October through November. The salinity of seawater had an average of only 10.00 psu. It can be explained that the growth rate of cockle tended to dwindle when salinity decreased. Generally, blood cockles can be found spread in seawater with a range of salinity of 10-30 psu [27]. However, blood cockles tend to have higher growth rates when they live in the salinity range between 24-33 psu [18, 28-30]. When seawater has salinity below 19 psu, cockles respond by completely closing their shells and burying themselves in the mud in order to maintain the osmoregulation within their bodies. However, if they stay under this condition for more than 3 days,

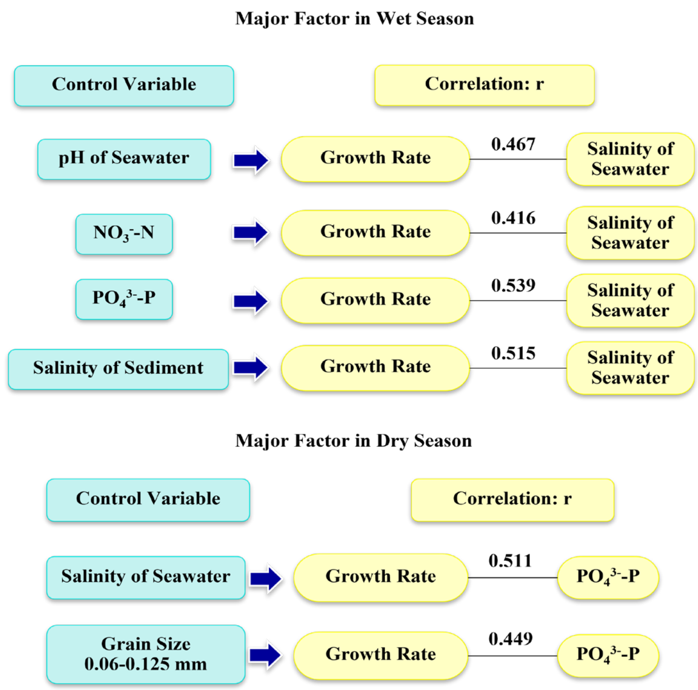

Figure 4. Environmental factors related to blood cockle production potential using Partial correlation

they may die eventually [31]. In addition, when the salinity of seawater is below 5 psu, cockles are unable to survive for a long time [19, 32]. Salinity reduction can reduce haemocyte production and integrity of lysosomes, which affect the immune system of the cockle [33]. For this reason, the immune system is unable to fight off infections. Therefore, when the salinity was low, cockle growth rate slowed down. The result of this study showed that when the salinity of seawater was higher than 19 psu, the production potential of cockles was quite high and the growth rate of cockle was 0.86-4.68 g/month (Table 4). Our results are in agreement with the research on the production potential of tidal flats for blood clam (*Anadara granosa*) culture in Bang Taboon Bay, Petchaburi province by Srisomwong *et al.* [10]. They reported that the optimum salinity level for cockle growth was approximately 20 psu.

3.3.2 Phosphate-phosphorus

The study showed that in the areas that contained phosphate-phosphorus (PO_4^{3-}-P) higher than 0.1 mg/l, cockle growth rate was likely to be higher than 1.2 g/month (Table 4). These results demonstrate that the growth rate tended to increase when the phosphate-phosphorus levels of the seawater increased. This may be because phosphate-phosphorus is an essential nutrient of phytoplankton which is the main food source for cockles. Natural cultures of cockles have phosphate-phosphorus (PO_4^{3-}-P) between 0.001-0.382 mg-P/l [18, 19, 32], and this relates to the results of this research. In some stations (BTB 8 and 19), although PO_4^{3-}-P was higher than 0.1 mg/l, the cockle growth rate was lower than 1.2 g/month. This was because these stations were adjacent to the river mouth which caused high loading of freshwater and pollution into the cultivation area. Subsequently, blood cockle die-off occurred.

Table 4. Comparison of the growth rate (GR) with seawater quality

Months	**Station**	**GR (g/ month)**	**Sal (psu)**	**Temp (°C)**	**DO (mg·l^{-1})**	**pH**	**TSS (mg·l^{-1})**	**NH_4^+-N (μg·l^{-1})**	**NO_2^--N (μg·l^{-1})**	**NO_3^--N (mg·l^{-1})**	**PO_4^{3-}-P (mg·l^{-1})**	**Chl *a* (μg·l^{-1})**
Oct-Nov	BTB 1	1.74	17.50	28.90	4.49	7.46	66.87	0.63	1.01	0.38	0.10	33.60
	BTB 2	1.61	18.00	28.65	4.99	7.49	52.75	0.75	0.58	0.35	0.10	33.59
	BTB 8	0.86	20.50	29.70	3.81	7.49	54.25	4.90	0.64	0.38	0.10	18.25
	BTB 19	0.30	10.00	31.35	3.09	7.45	35.30	5.00	0.63	0.40	0.32	10.01
	KC 1	1.18	18.00	29.45	4.25	7.01	34.00	6.01	0.73	0.45	0.27	30.37
	KC 2	4.68	20.50	29.55	4.21	7.11	23.80	4.54	0.53	0.41	0.27	26.70
	KC 6	1.26	13.50	29.45	3.77	6.76	46.00	7.82	0.48	0.38	0.28	13.68
Nov-Dec	BTB 8	1.31	22.50	28.55	6.06	7.50	44.86	0.92	0.27	0.29	0.03	19.69
	KC 1	1.19	21.00	30.25	4.51	7.45	39.72	1.41	0.53	0.36	0.05	28.70
	KC 6	1.09	18.50	27.35	4.50	7.63	43.67	3.02	0.22	0.33	0.05	11.48
Dec-Jan	KC 1	1.56	18.50	29.05	4.48	7.66	28.22	4.08	0.41	0.34	0.09	3.84
Jan-Feb	BTB 1	0.89	22.50	25.95	5.16	7.55	58.60	3.08	0.39	0.37	0.11	14.18
	BTB 5	1.48	21.50	26.30	5.54	7.84	43.22	1.80	0.32	0.26	0.10	11.01
Feb-Mar	BTB 1	2.21	26.00	25.00	5.66	7.69	132.60	1.46	0.54	0.23	0.09	10.68
	BTB 5	1.14	26.00	25.00	6.58	7.84	82.22	0.39	0.39	0.18	0.06	9.18

3.3.3 Seawater temperature

Although the result of statistical analysis showed that seawater temperature did not correlate with the growth rate of cockles, our results indicated that when the seawater temperature was higher than 30ºC, the growth rate of cockles was reduced to 0.30 g/month (Table 4). In previous studies, cockles in Thailand were often found in seawater with temperatures between 25-32.8ºC [18, 28, 29]. Previous studies reported that high temperatures could affect blood cockles by inducing their spawning [25, 34, 35] and increasing the rate of absorption efficiency [36]. However, when seawater temperature was higher than 30ºC, the cockles became weak and eventually died [37]. According to our report, especially in October, the temperature of seawater in almost all stations was close to 30ºC. This would become dangerous for cultivating cockles. Moreover, Broom [26] reported that when the tide was lowest, the heat from the sun caused water and sediment temperatures to reach 40ºC which caused cockle stress and lower filtering rate. This was related to the study on the relationship between water and soil qualities on the condition index of the cockle *Anadara granosa* in Bandon Bay, Suratthani province by Nudee and Mahasawat [32]. They found that when temperature rises, cockles have a lower condition index which has a strong negative relationship with seawater temperature (r_{xy} = -0.71). Additionally, increases in seawater temperature can lead to a decrease in haemocytosis, lysozyme activity, and can inhibit phenoloxidase activity [33]. Hence, cockle farmers in Klong Khone and Bang Taboon should not release new juvenile cockles when the seawater temperature exceeds 30ºC in order to help the cockle growth and survival.

3.3.4 Dissolved oxygen (DO)

As mentioned above, the statistical analysis results showed that DO did not correlate with the growth rate of cockles. However, our results found that when DO was close to 3 mg/l, the growth rate of cockles was drastically reduced to almost equal to zero. For example, the growth rate (GR) of BTB 19 was 0.30 g/month, as shown in Table 4. These results are in accordance with previous research. According to the analysis of oxygen consumption of blood cockles by Naphetaphat *et al*. [38], it was found that when DO was less than 3.1 mg/l, the cockles closed their valve completely and stopped filtering to eat. Furthermore, Din and Ahamad [30] and Davenport and Wong [31] also clearly demonstrated that mass mortality of cockle occurred when the cockles had been under such conditions for more than 6 weeks. In addition, if the water contains a very low oxygen levels, cockles may only survive for 2 days. Decrease in oxygen levels can drop production of red blood cells (haemocytes) and reduce the phagocytosis process, which is an immune response. Moreover, it reduces the ability to filtering which causes the cockles to become weak, and easily be infected by pathogens and eventually die [33]. Thus, this result suggests that for the cockles to survive, the DO should not be less than 3 mg/l as well.

3.3.5 Total suspended solids (TSS)

In this study, the quantities of TSS ranged between 23.80-132.60 mg/l (Table 4). Cockles can live in seawater with TSS between 5-170 mg/l without filter-feeding and growth being affected [39, 40]. Therefore, the TSS in this study was suitable for cockle farming. Cockles can tolerate extremely high amount of TSS and be able to survive in this condition. This is a result of the cockle producing pseudofeces, which is false feces that pass through without digestion. The process starts when cockles feed on phytoplankton floating in the water mass near them. Unwanted suspended particles are wrapped in mucus, then excreted in the form of pseudofeces [41-43]. However, the cockles can easily die off when TSS is higher than 300 mg/l because of the small amounts of phytoplankton or organic matter containing less than 10% [30, 44]. These results were from other researchers who studied cockle growth and feeding behavior under similar environmental condition to our study.

Therefore, based on results from previous researchers, our results were in a range suitable for cockle growth and survival. This is the reason why TSS in seawater was one of the factors that has an influence on the growth of blood cockles.

3.3.6 Nutrient concentrations

The results of this study found that nutrient concentrations, including ammonium (NH_4^+-N), nitrite (NO_2^--N) and nitrate (NO_3^--N), showed no correlations with the growth rate of cockles. This may be because the levels of NH_4^+-N, NO_2^--N and NO_3^--N, observed throughout the study period were frequently found in natural cockle cultivation sites, details of which are based on previous research. The values of NH_4^+-N, NO_2^--N and NO_3^--N in this study were between nd.-0.5, nd.-0.03 and 0.001-0.787 mg-N/l, respectively [18, 19, 28, 29, 32]. The main inputs of nutrient concentrations in this study area were related to the large quantity of freshwater runoff from the Mae Klong River and Phetchaburi River and domestic wastewater in the upper areas that flowed into estuaries during the wet season, but were within the safe ranges as mentioned above. Therefore, the nutrient concentrations in this study were still suitable for raising cockles. However, if the nitrogen content is too high, it can affect the cockle growth and survival [32]. These indicated that higher amounts of nitrate resulted in low condition index (CI) and caused cockle toxicity with Pearson correlation coefficient of $r_{xy} = -0.58$. Although there is currently no research on the effects of ammonium on blood cockle growth, a study on the level of ammonium toxicity in Asian clams (*Corbicula fluminea*) revealed that sudden death occurred with exposure to 5.56 mg-N/l [45], and die-off occurred within 92 h at 0.8 mg-N/l NH_3 [46]. Additionally, research on the immune responses of Taiwan abalone (*Haliotis diversicolor supertexta*) at different concentration levels of NH_3-N [47] and NO_2^--N [48] proved that the Taiwan abalone had increased death and infections, and reduced integrity and feeding ability when the concentration levels of NH_3-N and NO_2^--N were high. As a result, it can be concluded that from these studies the higher amount of ammonium can cause a reduction in blood cockle filtration and immune responses. As a consequence of these events, a decrease in number of cockles in these areas occurred.

3.3.7 Chlorophyll *a*

Chlorophyll *a* is another factor affecting the production potential of cockles because they feed on phytoplankton [49, 50]. It was found that for naturally cockle sites, chlorophyll *a* in seawater was between 0-54 µg/l [21, 27, 39]. Srisomwong *et al*. [10] found that the optimum chlorophyll *a* for cockle growth was approximately 15 µg/l. Our results were in accordance with this research which revealed that the lowest growth rate occurred in an area of chlorophyll *a* containing only 10.01 µg/l (Table 4). In some stations, although the chlorophyll *a* was very low (3.84 µg/l), the growth of cockle depended not only on the chlorophyll *a* but also on temperature salinity, temperature and DO in seawater, and if those parameters were suitable, the rate of cockle growth could still increase. This may be due to chlorophyll *a* not being a main controlling factor of the cockle production potential in the Klong Khone and Bang Taboon area. In fact, other factors were probably more important.

3.3.8 Grain size

Cockles are mostly found in silt-clay, sandy loam or sandy clay with proportions of sand 17.33-64%, silt 16-59.35% and clay 1-36% [18, 19, 22]. However, an area that contains a proportion of clay or acquires a particle size smaller than 0.06 mm will likely support a high population cockle density. The reason is that clay is the finest texture of the soil, and it has more surface area for nutrient cations to adhere to. Therefore, clay holds the most nutrients than other soils. Thus, clay is more suitable for the growth of benthos, especially cockles [17]. This is in agreement with our results which found that in the sediment area with a particle size smaller than 0.06 mm at greater than or equal to 50%, the growth rate of cockle was higher than in other areas (Table 5).

3.3.9 pH of sediment

Even though this research found that the growth rate of cockles did not correlate with the pH of the sediment, the results of this study suggested that when the pH was lower than 6.5, the growth rate of cockles tended to decrease (Table 5). This may be due to the soil being slightly acidic, which affects the shell formation ability of mussels [17]. Moreover, the pH of sediment in the study area was similar to the other cockle cultivation sites [21, 22, 32]. Therefore, sediment should be adjusted to a neutral state or a pH of approximately 6.5-7 to promote increased production potential of cockle culture. Although the pH of sediment in stations BTB 1 and 2 were lower than 6.5, the cockle growth rate was higher than other stations. This may be because the particle size of sediment (<0.06 mm) was greater than 50% (68.43%), and the water content of the sediment was greater than 70% (70.45%) (Table 5). These conditions provide adequate water interstitial; subsequently, cockle stress from acidity sediment is lessened.

Table 5. Comparison of the growth rate (GR) with sediment quality

Months	Stations	GR (g/month)	Grain Sizes (%)			pH	Sal (psu)	WC (%)	OM (%)
			< 0.06 mm	0.06-0.125 mm	0.125-1.0 mm				
Oct-Nov	BTB 1	1.74	68.43	3.68	27.90	5.84	4.50	70.45	4.11
	BTB 2	1.61	55.87	5.77	36.38	6.28	5.50	71.32	4.03
	BTB 8	0.86	46.61	5.53	47.86	6.97	6.00	73.82	4.57
	BTB 19	0.30	47.80	12.55	39.66	6.28	4.50	61.60	4.18
	KC 1	1.18	52.47	6.00	41.52	7.18	5.00	72.05	4.49
	KC 2	4.68	53.50	6.20	40.30	6.90	5.00	71.52	4.46
	KC 6	1.26	57.65	10.97	31.38	7.39	5.00	64.37	3.91
Nov-Dec	BTB 8	1.31	62.44	4.12	33.44	7.16	9.00	71.97	4.79
	KC 1	1.19	61.51	5.41	33.08	7.59	9.00	70.40	4.78
	KC 6	1.09	66.22	5.87	27.90	7.86	7.50	63.28	4.79
Dec-Jan	KC 1	1.56	73.00	5.62	21.38	7.05	11.00	69.20	4.77
Jan-Feb	BTB 1	0.89	76.40	4.41	19.18	6.96	11.50	70.78	4.34
	BTB 5	1.48	67.97	7.33	24.70	6.98	12.50	76.70	4.56
Feb-Mar	BTB 1	2.21	80.47	4.27	15.26	6.54	13.50	71.20	4.46
	BTB 5	1.14	72.86	9.41	17.73	7.06	15.00	72.43	4.69

3.3.10 Water content (WC)

In a similar way to other factors in this study, there was no data or statistical analysis that suggested a relationship between water content (WC) and the growth rate of cockles. However, when studying the growth rate of cockles related to the water content, it seems that the rate was likely to increase when the water content of the sediment was greater than or equal to 70% (Table 5). This indicates that cockles may prefer to live in fine soils with interstitial water because it is probably easier for the cockles to move and bury themselves in the sediment. Therefore, if the sediment holds a greater proportion of water, it will provide more food for the cockles.

4. Conclusions

The seawater quality in Klong Khone and Bang Taboon areas did not meet the Thailand standard of seawater quality for aquaculture. During the wet season, the seawater quality tended to deteriorate more than in the dry season. The characteristics of sediment in both areas were found to be clay. Sediment in the Klong Khone area was more liquid and had finer particles than sediment in the Bang Taboon area. The pH value of sediment was slightly acid during the wet season. The production potential of cockles was indicated by the blood cockle growth rate. The results for average growth rate of cockles in the Klong Khone area were higher than the Bang Taboon area during the wet season. However, in the dry season, Bang Taboon cockles gained a higher growth rate than those in Klong Khone. Moreover, the cockle density in Klong Khone area was higher than Bang Taboon area in the wet season. In contrast, the cockle density in the Bang Taboon area was greater than in Klong Khone area during the dry season. This indicated that Bang Taboon had more production potential of cockles than Klong Khone in the dry season, while Klong Khone had more production potential in the wet season. The main factors affecting the growth rate of cockles were salinity of seawater in the wet season and phosphate-phosphorus (PO_4^{3-}-P) in the dry season. Cockle production potential tends to increase when the salinity of seawater is above 19 psu, seawater temperature is not higher than 30ºC, the DO in water is not less than 3 mg/l, and TSS is not more than 300 mg/l. Sediment quality has less influence on cockle production potential than seawater quality. Moreover, the sediment that is suitable for the growth of cockles should be clay of fine texture, with greater than50% of sediment particle smaller than 0.06 mm, with a pH greater than 6.5, and a water content (WC) in the sediment that is more than 70%.

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References

[1] Tokrisna, R., 2015. *Thai Aquaculture Status in the Context of ASEAN Economic Community*. Bangkok: Knowledge Network Institute of Thailand and Thailand Research Fund.

[2] Department of Fisheries, 2018. *Statistic of Marine Shellfish Culture Survey 2017 No. 17/2018*. Bangkok: Department of Fisheries.

[3] Cockle Farmer Group in Phetchaburi and Samut Songkharm Province, 2016. *Letter Requesting Support for the Department of Fisheries to File Damages on the Cockle Dies from Ratchaburi Ethanol Factory Co., Ltd No. 2533/2016.* Samut Songkharm: Bang Taboon Cockle Culture Group.

[4] Kraichit, C., 2018. *Climate adaptation in Bang Taboon, Phetchaburi Province.* Phetchaburi: Bang Taboon Cockle Culture Group.

[5] Saffian, N.S, Peng, C.T.C., Ilias, N. and Hwai, A.T.S., 2020. Overview and challenges of blood cockle culture in Malaysia. *IOP Conference Series: Earth and Environmental Science*, Penang, Malaysia, September 9-11, 2019, pp. 1-6.

[6] American Public Health Association (APHA), 2012. *Standard Methods for the Examination of Water and Wastewater.* 22nd ed. Washington DC: American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF).

[7] Parsons, T.R., Maita, Y. and Lalli, C.M., 1984. *A Manual of Chemical and Biological Methods for Seawater Analysis*. Oxford: Pergamon press.

[8] Jones, J.B., 1999. *Soil Analysis. Handbook of Reference Methods*. Boca Raton: CRC Press.

[9] Allison, L.F., 1965. Organic carbon. In: C.A. Black, ed. *Method of Soil Analysis, Part 2, Chemical and Microbiological Properties*. Madison: American Society of Agronomy, pp. 1367-1378.

[10] Srisomwong, M., Wangvoralak, S., Thawonsode, N. and Meksumpun, C., 2018. Production potential of tidal flats for blood clam (*Anadara granosa*) culture in Bang-tabun bay, Petchaburi province. *Science Asia*, 44, 388-396.

[11] Şahin, C., Duzguneş, E., Mutlu, C., Aydin, M. and Emiral, H., 1999. Determination of the growth parameters of the *Anadara cornea* R. 1844 population by the Bhattacharya Method in the Eastern Black Sea. *Turkish Journal of Zoology*, 23(1), 99-106.

[12] Parekh, H. and Gadhvi, I.R., 2015. Seasonal variation in physico-chemical parameter of seawater at Mathivirdi Coast Bhavnagar- West Coast of India. *International Journal of Research Engineering and Bioscience*, 3, 41-47.

[13] Ibrahim, N.E., Omar, W.B.W. and Mohamad. F., 2018. Population density and size of blood cockle, *Anadara cornea* in Setiu Wetlands, Terengganu during northeast monsoon season. *Journal of Sustainability Science and Management*, 13, 113-123.

[14] Chagas, G.G. and Suzuki, M.S., 2005. Seasonal hydrochemical variation in tropical coastal lagoon (Acu Lagoon, Brazil). *Brazilian Journal of Biology*, 65, 597-607.

[15] Srisunont, C., Nobpakhun, Y., Yamalee, C. and Srisunont, T., 2020. Influence of seasonal variation and anthropogenic stress on blood cockle (*Tegillarca granosa*) production potential. *Journal of Fisheries and Environment,* 44(2), 62-82.

[16] Srisunont, T., Srisunont, C., Watthanasuriyanon, P., Khongsang, S., Popa, W. and Hathaisamit, K., 2017. Study on water quality in extensive shrimp farming at Bangkhuntein District, Bangkok. *In Proceeding PACCON: Pure and Applied Chemistry*, Bangkok, Thailand, February 2-3, 2017, 259-263.

[17] Sukudom, C., 2015. *Organic Contents and pH Profiles of Sediments in Cockle Farm at Bandon Bay, Surat Thani Province*. Master Thesis. Kasetsart University.

[18] Tuaycharoen, S., Chuaychandee, P. and Charoenporntip, M., 1997. *The Potential Area of Cockles Culture along the Coastline of Samut Sakhon Province, Technical Paper No. 28/1997.* Samut Sakhon: Samut Sakhon Coastal Aquaculture Development Center.

[19] Vichaiwattana, C. and Thepphanich, A., 2008. *Some Biological Aspects, Water-sediment Qualities and Cost-benefit of the Culture of Anadara nodifera (Martans, 1860) and Anadara granosa (Linnuaeus, 1758) in Bandon Bay, Suratthani Province, Technical Paper No. 42/2008*. Suratthani: Coastal Fisheries and Development Bureau.

[20] Salaenoi, J., Sukudom, C., Wongsin, T. and Sirisuay, S., 2015. Sediment Quality in Cockle Culture and Non-Cultured Area at Bandon Bay, Thailand. *International Conference on Plant, Marine and Environmental Sciences*, Kuala Lumpur, Malaysia, January 1-2, 2015, pp. 110-114.

[21] Tookwinas, S., Perngmark, P., Sirimontaporm, P., Tuaycharoen, S. and Sangsakul, P., 1986. *Study on the Growth Rate of Blood Cockle Anadara granosa L. and Aquatic Environment at Culture Bed in Pattani Bay, Technical Paper No. 2/1986*. Songkhla: National Institute of Coastal Aquaculture.

[22] Mongkolmaran, C., Jindanon, A., Kaewnukul, P. and Rattananan, T., 1986. *Study of Soil Properties in Cockle Farming Sites, Ranong, Nakhon Si Thammarat and Suratthani Province, Technical Paper No. 50/1986.* Bangkok: Department of Fisheries.

[23] Kumyod, S., 2015. *Cadmium, Lead and Zinc in Blood Cockle (Tegillarca granosa), Venus Clam (Meretrix meretrix) and Sediment from Ban Laem Coastal Area, Phetchaburi Province.* Master Thesis. Kasetsart University.

[24] National Environment Board, 2020. *Notification of the National Environmental Board: the Seawater Standard.* [online] Available at: https://www.ieat.go.th/handbook/Program_IEAT/pages/en/Department/MONRE.html.

[25] Harith, H., Husain, M.L. and Akhir, M.F.M., 2016. Coastal oceanographic processes associated with blood cockle (*Anadara granosa*) induce spawning season in Kapar, Selangor, Malaysia. *Journal of Ocean Engineering and Science*, 1, 289-299.

[26] Broom, M.J., 2016. Analysis of the growth of *Anadara granosa* (Bivalvia: Arcidae) in natural, artificially seeded and experimental populations. *Marine Ecology Progress Series*, 9, 69-79.

[27] Chouysurin, T., Tonsalee, N. and Sookchuay, C., 2004. *Environmental Factors and Spatfall Season of Cockle (Anadara granosa, Linnaeus) in Bandon Bay, Suratthani Province, Technical Paper No. 28/2004.* Suratthani: Suratthani Coastal Fisheries Research and Development Center.

[28] Vichaiwattana, C., Wongwiwat, N., Keaw-uksorn, S. and Mahasawat, J., 2007. *Comparison on culture of Anadara granosa (Linnaeus, 1758) and Anadara nodifera (Martans, 1860) in Bandon Bay, Suratthani Province, Technical Paper No. 14/2007*. Bangkok: Department of Fisheries.

[29] Tookwinas, S., 1985. *Cultivation of Cockles in Thailand, Technical Paper No. 1/1985*. Songkhla: Songkhla Institute of Coastal Aquaculture.

[30] Din, Z.B. and Ahamad, A., 1995. Change in the scope for growth of blood cockles (*Anadara granosa*) exposed to industrial discharge. *Marine Pollution Bulletin*, 31, 406-410.

[31] Davenport, J. and Wong, T.M., 1986. Responses of the blood cockle *Anadara granosa* (L.) (Bivalvia: Arcidae) to salinity, hypoxia and aerial exposure. *Aquaculture*, 56, 151-162.

[32] Nudee, V. and Mahasawat, J., 2007. *Relationship between Water and Soil Qualities with Condition Index of Cockle Anadara granosa in Bandon Bay, Suratthani Province, Technical Paper No. 19/2007*. Bangkok: Department of Fisheries.

[33] Ellis, R.P., Parry, H., Spicer, J.I., Hutchinson, T.H., Pipe, R.K. and Widdicombe, S., 2011. Immunological function in marine invertebrates: Responses to environmental perturbation. *Fish and Shellfish Immunology*, 30, 1209-1222.

[34] Jahangir, S., Siddiqui, G. and Ayub, Z., 2014. Temporal variation in the reproductive pattern of blood cockle *Anadara antiquata* from Pakistan (northern Arabian Sea). *Turkish Journal of Zoology*, 38, 263-272.

[35] Suwanjarat, J., Pituksalee, C. and Thongchai, S., 2009. Reproductive cycle of *Anadara granosa* at Pattani bay and its relationship with metal concentrations in the sediments. *Songkhlanakharin Journal of Science and Technology*, 31, 471-479.

[36] Nieves-Soto, M., Enriquez-Ocaña, F., Piña-Valdez, P., Maeda-Martínez, AN., Almodóvar-Cebreros, J.R. and Acosta-Salmón, H., 2011. Is the mangrove cockle *Anadara tuberculosa* a candidate for effluent bioremediation? Energy budgets under combined conditions of temperature and salinity. *Aquaculture*, 318, 434-438.

[37] Taylor, A.M., Maher, W.A. and Ubrihien, R.P., 2017. Mortality, condition index and cellular responses of *Anadara trapezia* to combined salinity and temperature stress. *Journal of Experimental Marine Biology and Ecology*, 497, 172-179.
[38] Naphetaphat, J., Kabinrum, S. and Sudmee, Y., 1990. *The oxygen consumption of cockle, Anadara granosa Linn., Technical Paper No. 15/1990*. Bangkok: Department of Fisheries.
[39] Ferreira, J.G., Hawkins, A.J.S. and Bricker, S.B., 2007. Management of productivity, environmental effects and profitability of shell fish aquaculture- the Farm Aquaculture Resource Management (FARM) model. *Aquaculture*, 264, 160-174.
[40] Rueda, J.L., Smaal, A.C. and Scholten, H., 2007. A growth model of the cockle (*Cerastoderma edule* L.) tested in the Oosterschelde estuary (the Netherlands). *Journal of Sea Research*, 54, 276-298.
[41] Iglesias, J.I.P., Navarro, E., Alvarez-Journa, P. and Armentina, I., 1992. Feeding, particle selection and absorption in cockles *Cerastoderma edule* (L.) exposed to variable conditions of food concentration and quality. *Journal of Experimental Marine Biology and Ecology*, 162, 177-198.
[42] Navarro, E., Iglesias, J.I.P. and Ortega, M.M., 1992. Natural sediment as a food source for the cockle *Cerastoderma edule* (L.): effect of variable particle concentration on feeding, digestion and the scope for growth. *Journal of Experimental Marine Biology and Ecology*, 156, 69-87.
[43] Urrutia, M.B., Iglesias, J.I.P., Navarro, E. and Prou, J., 1996. Feeding and absorption in *Cerastoderma edule* under environmental conditions in the bay of Marennes-Oleron (Wastern France). *Journal of the Marine Biological Association of the UK,* 76, 431-450.
[44] Hawkins, A.J.S., Bayne, B.L., Bougrier, S., Heral, M., Iglesias, J.I.P., Navarro, E. and Smith, R.F.M., 1998. Some general relationships in comparing the feeding physiology of suspension feeding bivalve molluscs. *Journal of Experimental Marine Biology and Ecology*, 219, 87-103.
[45] Cooper, N.L., Bidwell, J.R. and Cherry, D.S., 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) II: Porewater ammonia. *Journal of the North American Benthological Society*, 24(2), 381-394.
[46] Cherry, D.S., Scheller, J.L., Cooper, N.L. and Bidwell, J.R., 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: Water-column ammonia levels and ammonia toxicity. *Journal of the North American Benthological Society*, 24(2), 369-380.
[47] Cheng, W., Hsiao, I.S. and Chen, J.C., 2004. Effect of ammonia on the immune response of Taiwan abalone *Haliotis diversicolor supertexta* and its susceptibility to *Vibrio parahaemolyticus*. *Fish and Shellfish Immunology*, 17, 193-202.
[48] Cheng, W., Hsiao, I.S. and Chen, J.C., 2004. Effect of nitrite on immune response of Taiwan abalone *Haliotis diversicolor supertexta* and its susceptibility to *Vibrio parahaemolyticus*. *Diseases of Aquatic Organisms*, 60, 157-164.
[49] Kamermans, P., 1993. Food limitation in cockles (*Cerastoderma edule* L.): Influences of location on tidal flat and of nearby presence of mussel beds. *Netherlands Journal of Sea Research*, 31(1), 1-81.
[50] Montaudouin, X.D., 1996. Factors involved in growth plasticity of cockles *Cerastoderma edule* (L). identified by field survey and transplant experiments. *Journal of Sea Research*, 36, 251-265.