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Application of the Adjusted Sharpness Index and Estimated Condition Factor to Compare Growth Conditions of the Blood Cockle, *Tegillarca granosa*, in Penang, Perak, and Selangor, in Malaysia

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Abstract

Long-term and short-term growth performance indices (sharpness index adjusted for size dependency, SI_{adj} and estimated condition factor, CF, respectively) were applied to the blood cockle, *Tegillarca granosa* collected from four localities (Bukit Kecil Village, Penang; Kuala Sepetang, Perak; Buloh River, Selangor; and Teluk Kumbar, Penang) along the west coast of Malaysia to compare the environmental quality of the culture grounds of the blood cockle. We observed spatio-temporal patterns of the two indices and found that CF negatively correlated with SI_{adj}, indicating that an elongate-shaped cockle had a large mass of soft tissue where the seasonal trend of these two indices matched the maturation and spawning cycles in Bukit Kecil Village, where cockles showed good growth, and the difference in the correlation slopes exhibited suitability of local variations for cockle culture. With a wide variation range, CF negatively correlated with sediment's oxidation-reduction potential (ORP), suggesting that the dietary benefit from eutrophication overcame the risk of sub-lethal hypoxia.

Discipline: Fisheries
Additional key words: cockle, condition factor, ORP, sharpness

Introduction

Blood cockle, *Tegillarca granosa* (Linnaeus 1758), is a common bivalve species in Southeast Asia as a major aquaculture target especially in Malaysia and Thailand. Other countries such as Indonesia and Myanmar are in progress to introduce culture techniques for this cockle species. With the example of state of Selangor making more than 200 culture plots as large as 50 ha on average (DoF Selangor 2008), in Malaysia, state governments have licensed the use of culture plots on mudflats partitioned primarily for user access and management instead of prioritising biological suitability. Fishers release cockle spats in licensed plots, wait for their growth, and then cultivate them after 8-12 months, relying on the animal's natural ability to survive in the given space.

After a notable increase from 2008 to 2011, in response to the government program in Selangor, the national cockle production decreased and has stagnated at a low level (DoF Malaysia 2001-2020). The reason for this collapse is still unknown. Therefore, to improve aquaculture efficiency, biologically suitable culture plots should be chosen for the species to concentrate cockle spats and human efforts. If the cockles signal about a place suitable for their growth and survival, this information could be used to design culture plots more efficiently.

Our previous study proposed two indices to assess the long- and short-term growth of blood cockles, which are the adjusted sharpness index (SI_{adj}) and the estimated condition factor (CF), respectively (Saito & Teoh 2020). The biggest advantage of the new indices is that they can

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be easily calculated using three variables (shell length, width, and total body weight) without opening the shells. Furthermore, the adjusted sharpness index is more convenient than the conventional index, a simple ratio between the short and the long axes of a shell, because it is free from size dependency, and cockles of mixed sizes can be compared.

The present study aims to apply the new indices to blood cockles from different localities along the west coast of Malaysia, to observe and record their spatio-temporal patterns and examine the relationship between SI_{adj} and CF. Stable food supply enhances the cockles' soft tissue growth and shell elongation, which leads to high CF and low SI_{adj}, respectively. In contrast, food deficit prevents soft tissue growth and shell elongation, causing low CF and high SI_{adj}, respectively. However, because shell morphology responds to environmental change more slowly than soft tissue, changing environments might complicate the correlation between the two indices, thereby providing considerable relevant information.

Materials and methods

Sampling took place in three culture grounds along the coasts of 1) Kampung Bukit Kecil (Kg. Bukit Kecil; Bukit Kecil Village); Simpang Ampat, Penang; 2) Kuala Sepetang, Perak; and 3) Sungai Buloh (Sg. Buloh; Buloh River), Selangor (Fig. 1) to obtain up to three replicates from subset areas as follows. Blood cockles were also collected manually from 4) Teluk Kumbar, Penang, although this place is not used for aquaculture. First, surface sediment's oxidation-reduction potential (ORP) in Kg. Bukit Kecil, Kuala Sepetang, and Sg. Buloh were measured. With the following of dredge sampling for cockles being conducted at 1-3 subset areas in each locality to obtain three replicate samples from each subset area if possible, using an Ekman-Birge grab, bottom sediment was collected and ORP at the surface of the mud, within 2-3 cm below the top surface, was immediately measured using a YSI Pro1030 with an Ag/AgCl electrode (YSI Inc.). The dredged distance changed depending on the situation to collect an adequate number of cockles. Table 1 lists the origins of the cockle specimens (state, locality, sampling date, presence/absence of sediment ORP measurement, number of subset areas within a locality, and number of cockles collected in each dredge replicated within a subset area).

Shell length (L, cm), shell width (W, cm), and total body weight (G, g) of the cockles were measured in the laboratory using hand caliper and digital balance. Furthermore, adjusted sharpness index (SI_{adj}) and estimated condition factor (CF) of the cockles were calculated following the formulae proposed by Saito and Teoh (2020).

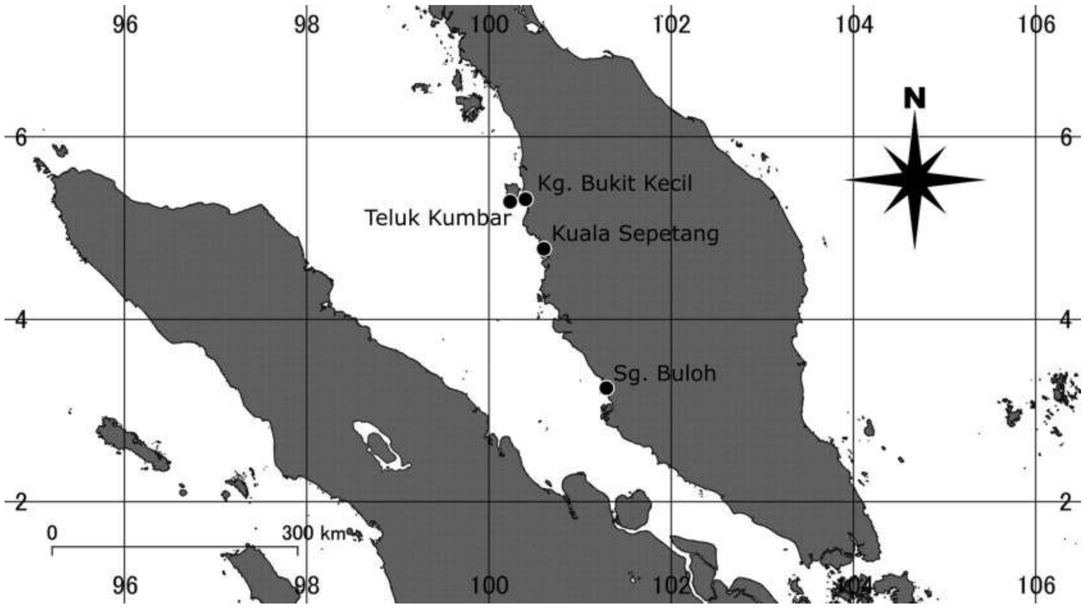

Fig. 1. Geographic positions of the four localities from where blood cockles were sampled, *Tegillarca granosa*, on the west coast of Malaysia
The background map was made using QGIS (QGIS.org 2020) and the GSHHS database (Wessel & Smith 1996).

$$SI_{adj} = \frac{W - 0.570L^{1.192}}{L}$$

$$CF = \frac{G_{total} - 0.643W^{2.757}}{G_{total}}$$

The outliers (extreme values in SI_{adj} and CF) were removed following the interquartile range (IQR) criterion. Furthermore, data calculation and visualization was performed using R: A language and environment for statistical computing, version 4.0.2 (R Core Team 2020), working in RStudio: Integrated Development for R version 1.3.1093 (RStudio Team 2020), ggplot2: Elegant Graphics for Data Analysis (Wickham et al. 2016), and an open program under the CC0 license for computing mean and standard error (Chang n.d.).

Results

In the present study, cockles collected from four localities in Malaysia were measured, and data distributions of SI_{adj} and CF in each locality were compared with the overall average trend, with the aim being to apply the adjusted sharpness index (SI_{adj}) and estimated condition factor (CF) to observe and record spatio-temporal patterns in growth of blood cockles. Negative correlation between the mean estimated condition factor (CF) and the mean adjusted sharpness index (SI_{adj}) was observed (Fig. 2). It implied that, among same-sized cockles, round-shaped tends to have a low CF and, conversely, an elongated cockle usually has a high CF. Because our previous study reported a positive correlation between conventional sharpness index (SI = width / length) and shell length (Saito & Teoh 2020), SI_{adj} was adjusted to remove this size dependency. The mean CF was widely scattered around the regression line, suggesting remarkable spatio-temporal variations in growth conditions. Data points below the regression line tended to have longer error bars both in SI_{adj} and CF, indicating that a poor dietary environment caused broader individual differences in cockle growth, presumably resulting from the competition for food.

The present results also reveal negative correlations between mean CF and mean SI_{adj} within each locality (Kg. Bukit Kecil, Kuala Sepetang, and Sg. Buloh, except for the case in November 2019). However, each locality had different ranges of SI_{adj} and CF, and its own preference of isolytic probability ellipses (Fig. 3, Table 2). Cockles in Kg. Bukit Kecil had low SI_{adj} (implying that they had more elongated shell shapes) and high CF. However, the mean CF decreased and its standard error increased for individuals with high mean SI_{adj} values,

Table 1. List of blood cockle specimens (state, locality, sampling date, presence/absence of sediment ORP data, number of subset areas dredged within a locality, number of cockles in each dredge replicated within a subset area)

State	Locality	Date	ORP	Subsets	Cockles in subset
Penang	Kg. Bukit Kecil	2018/02/10	+	1	(14, 11, 11)
		2018/05/11	+	2	(28, 37, 19), (14, 25, 25)
		2018/05/21	+	2	(28, 54, 70), (191, 87, 127)
		2018/07/26	+	2	(5, 32, 22), (43, 99, 26)
		2018/11/27	+	2	(18, 19, 24), (21, 22, 61)
		2019/03/12	+	2	(21, 129, 120), (26, 57, 39)
Perak	Kuala Sepetang	2018/02/09	+	1	(201, 79, 184)
		2018/05/10	+	2	(54, 8, 7), (35, 46, 30)
		2018/05/22	+	2	(61, 79, 81), (52, 66, 25)
		2018/07/25	+	2	(14, 31, 50), (56, 69, 60)
		2018/11/26	+	2	(206, 83, 120), (85, 179, 79)
		2019/03/11	+	2	(145, 309, 55), (149, 52, 131)
Selangor	Sg. Buloh	2017/08/14	-	1	(235)
		2018/02/08	+	1	(22, 50, 35)
		2018/05/09	+	2	(9, 11, 26), (29, 23, 16)
		2018/05/23	+	3	(6, 11), (1, 7, 14), (6, 5, 8)
		2018/07/24	+	3	(2, 1, 1), (5, 1, 10), (14, 4, 5)
		2018/11/28	+	2	(5, 4, 11), (1, 1, 2)
		2019/03/13	+	3	(1, 4, 12), (1), (8, 13, 8)
		2019/11/12	+	2	(7, 5, 3), (112, 64, 99)
Penang	Teluk Kumbar	2020/01/15	-	1	(90)

Cockles from Teluk Kumbar were not dredged but collected by hand.

suggesting uneven food acquisition among individuals. Cockles in Kuala Sepetang and Sg. Buloh showed high sharpness indices (meaning that they had round-shaped shells), indicating that shell growth was consistently slow in both localities. SI_{adj} and CF in Kuala Sepetang aggregated within the middle range intervals, and

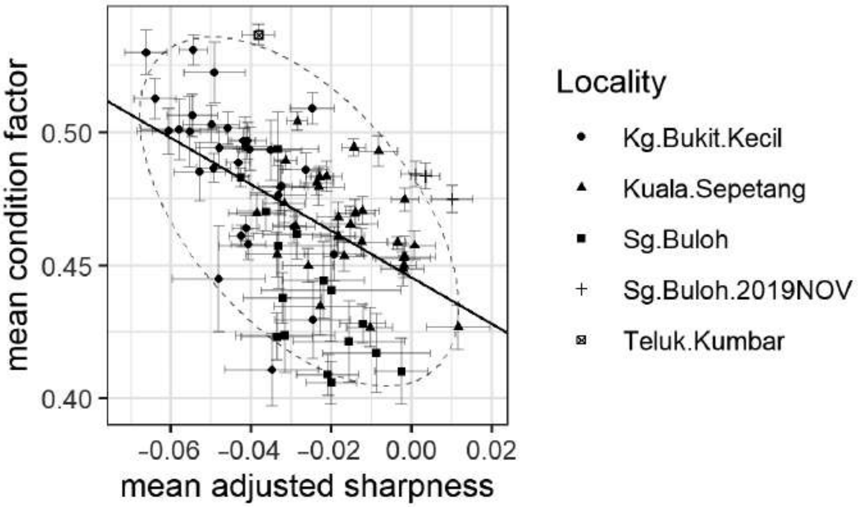

Fig. 2. Two-dimensional data plot of mean condition factor (CF) explained with mean adjusted sharpness index (SI_{adj})
Error bars indicate standard errors. The equation of the regression line is Y = −0.875 X + 0.445, and the level of isolytic probability ellipse is 95%.

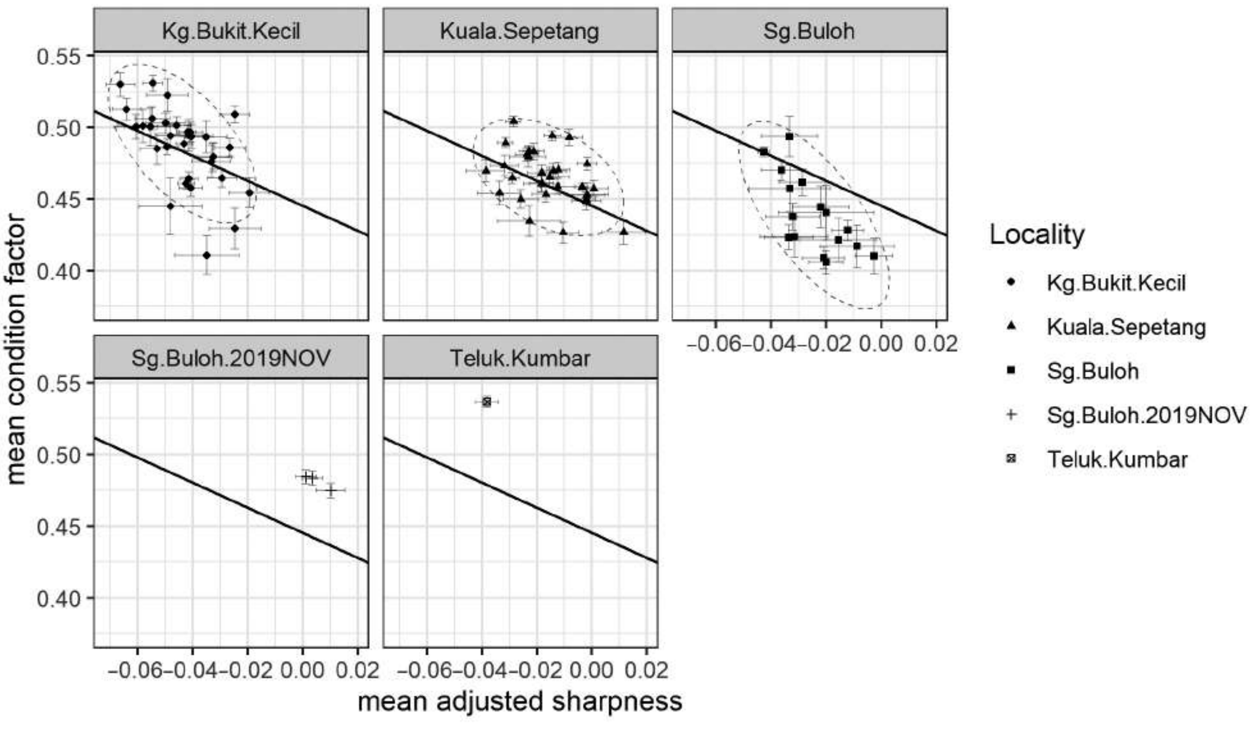

Fig. 3. Two-dimensional data plots of mean condition factor (CF) explained with mean adjusted sharpness index (SI_{adj}) in the four localities
Dredge samples from Sungai Buloh collected in November 12, 2019, were separated because the CF values were distinctly different from those of other samples in the same locality. Error bars indicate standard errors. The regression lines and the level of isolytic probability ellipse (95%) were the same as those in Figure 2.

individual differences were narrower than those in Kg. Bukit Kecil and Sg. Buloh, except for some data points below the regression line that showed a broader individual difference in SI_{adj}. The decline in mean CF along with increased SI_{adj} in Sg. Buloh was apparent, suggesting that cockles lost soft tissue mass under the adverse condition. Furthermore, the individual differences in SI_{adj} and CF were noteworthy for cockles from Sg. Buloh. Moreover, CF increased in November 12, 2019, but SI_{adj} remained high. This change suggests that the soft tissue weight of cockles quickly recovered as nutritional condition improved, and their round shell shape was maintained. Cockles from Teluk Kumbar showed moderate SI_{adj} and the highest CF values with minimal individual differences, suggesting that this place was suitable for cockles, without any severe competition between individuals.

In Kg. Bukit Kecil, CF increased as SI_{adj} decreased from February 10, 2018, to July 26, 2018, and CF decreased as SI_{adj} increased from November 27, 2018, to March 12, 2019 (Figs. 4, 5). Decreased SI_{adj} values indicate rapid growth in shell length, which is possible only under conditions of abundant food sources, as indicated by high CF values. The termination of rapid shell growth or increase in SI_{adj} values in November through March coincided with the spawning period in Malaysia, as reported by Yurimoto et al. (2014a). The gradual decline in CF values as observed on March 12, 2019, and remarkably low CF values on February 10, 2018, might indicate a loss of body mass due to spawning. In Kuala Sepetang, any temporal trend was hardly detectable in SI_{adj}, whereas CF declined from May 10, 2018, to July 25, 2018, then, suggesting maturation before spawning, recovered on November 26, 2018. In Sg. Buloh, the temporal variations in SI_{adj} and CF were unclear from August 14, 2017, to March 13, 2019, because their variations within the locality or between dredge samples masked the temporal variation. However, high CF values in the second half of the year (August 14, 2017, November 28, 2018, and November 12, 2019) might indicate maturation prior to spawning.

Considering the relationship between CF and sediment ORP, the variation in mean CF between dredge samples, with their upper margin, remarkably increased when the sediment became more reductive, as indicated by the low ORP (Fig. 6). With the wide variation, very high CF values occurred only with reductive sediment, indicating water eutrophication and risk of hypoxia.

Table 2. Summary of patterns in the adjusted sharpness index (SI_{adj}) and the estimated condition factor (CF) of blood cockles collected from four localities in Malaysia

State	Locality	Adjusted sharpness (SI_{adj})	Condition factor (CF)
Penang	Kg. Bukit Kecil	Low (elongated shell), indicating fast shell growth. Decreased from February 10, 2018, to July 26, 2018, and increased from November 27, 2018, to March 12, 2019. The termination of rapid shell growth or increase in SI_{adj} values in November through March coincided with the spawning period in Malaysia.	High. Increased then decreased inversely with SI_{adj}. The gradual decline as observed on March 12, 2019, and low values on February 10, 2018, might indicate a loss of body mass due to spawning.
Perak	Kuala Sepetang	Relatively high (round-shaped shells) aggregated within the middle range, indicating slow shell growth.	Middle, with narrow individual difference.
		No clear temporal variation.	Declined from May 10, 2018, to July 25, 2018, then recovered on November 26, 2018, suggesting maturation.
Selangor	Sg. Buloh	High (round-shaped shells), indicating slow shell growth, with large individual difference.	Middle to low with large individual difference. Declined along with increased SI_{adj}, suggesting that cockles lost soft tissue mass under the adverse condition. The high value coupled with high SI_{adj} in November 12, 2019, suggests nutritional improvement and maturation.
		No clear temporal variation.	No clear temporal variation, except high CF values in the second half of the year.
Penang	Teluk Kumbar	Middle.	The highest with minimal individual differences, suggesting that this place was suitable for cockles, without any severe competition between individuals.

Under aerobic conditions, a sediment ORP greater than −50 mV appeared in five dredge samples from Sg. Buloh, and four of them coincided with low mean CF values.

Discussion

Human population growth, incentive to agriculture, and urban development in coastal zones and watersheds have caused marine eutrophication, organic pollution, and hypoxia. In contrast to global warming and ocean acidification, hypoxic events elicit constant adverse effects across taxonomic groups (molluscs, crustaceans, and fish), ontogenetic stages, and climate regions (Sampaio et al. 2021). Oxygen deficiency and hydrogen sulphide toxicity cause death of many organisms of different groups, and hence the deterioration of biodiversity, on sea bottom, except for tolerant minorities and short-lived opportunists (Baustian & Rabalais 2009, Diaz & Rosenberg 1995, Pearson & Rosenberg 1978, Sturdivant et al. 2013). Because fisheries target invertebrates, such as cockles, clams, and large crustaceans, are megabenthic organisms that need many months to attain a marketable body size, hypoxic events intercept their lifecycle, thereby impairing fishing and aquaculture. Hypoxia usually occurs in mid-summer within temperate regions, where benthic fauna shows a seasonal cycle in their abundance and biomass (Furota 1996, Pandiya rajan et al. 2021, Rakocinski & Menke 2016, Tsutsumi 1990).

In tropical estuaries, water stratification causes hypoxia round the year (Hsieh et al. 2021). However, coral reefs, mangrove forests, and seagrass meadows are resistant to oxygen depletion due to ecological mutualisms and self-rescue mechanisms. An obstruction to mutualisms is evident where mortality caused by hypoxia has been documented (Altieri et al. 2021). In cockle culture plots on mudflats, the monotonous landscape and simple community structures are not likely

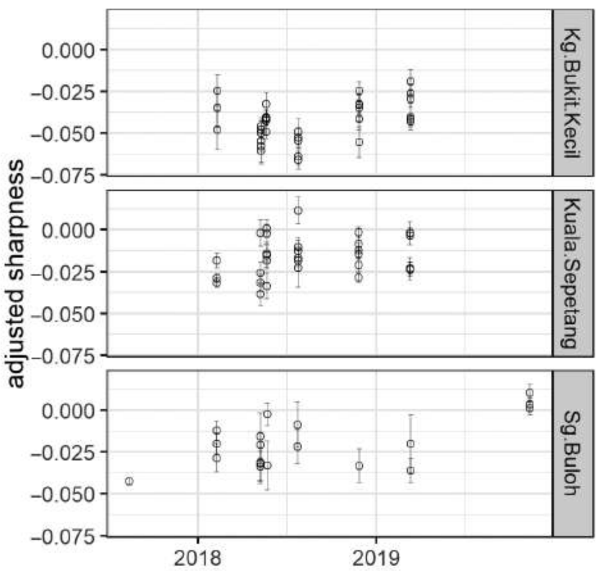

Fig. 4. Time series data plots of mean adjusted sharpness index (SI_{adj}) in three localities
Error bars indicate standard errors.

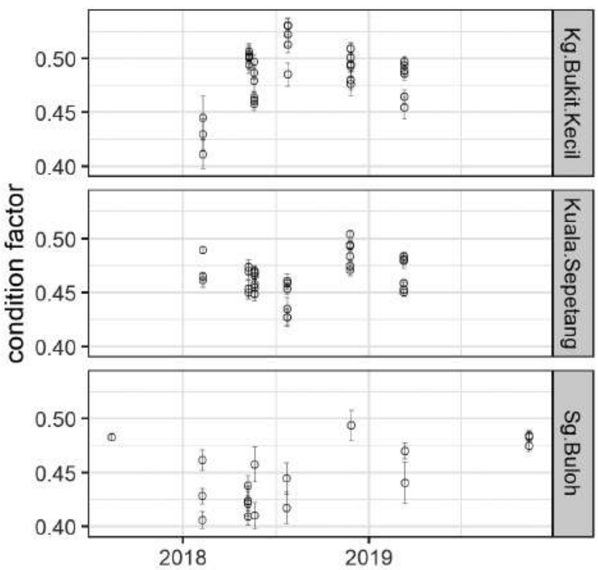

Fig. 5. Time series data plots of mean estimated condition factor (CF) in three localities
Error bars indicate standard errors.

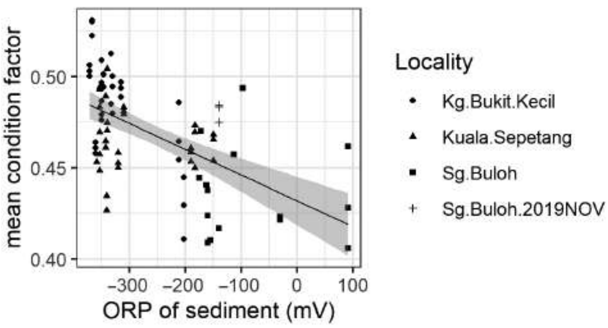

Fig. 6. Two-dimensional data plots of mean condition factor (CF) explained with sediment oxidation-reduction potential (ORP) in three localities
Dredge samples from Sungai Buloh collected in November 12, 2019, were separated because the CF values were distinctly different from those of other samples in the same locality. The equation of the regression line is $Y = -1.413E^{-4} X + 0.432$. The grey ribbon indicates a 95% confidence interval. ORP at the surface of the mud, within 2 cm-3 cm below the top surface, was measured using a YSI Pro1030 with an Ag/AgCl electrode (YSI Inc.).

to promote complex mutualisms. However, hypoxia is only a periodical stressor in intertidal mudflats, because semi-diurnal low tides expose sea bottom to air, and water mixing via wind waves provides oxygen to the bottom fauna. Field surveys on benthic fauna in intertidal cockle culture grounds have reported the presence of a variety of predators, competitors, and scavengers living together (Broom 1982, Lai et al. 2020).

In terms of biomass, bivalves are dominant in coastal ecosystems. Different bivalve species showed different growth patterns across a eutrophication gradient, where marine eutrophication elicits massive production of microalgae to support secondary production of filter-feeding bivalves that exploit particulate organic matter, especially phytoplankton and benthic microalgae in suspension. For example, northern quahogs (*Mercenaria mercenaria*) and eastern oysters (*Crassostrea virginica*) are tolerant to low dissolved oxygen in eutrophic conditions and, thus, could take advantage of food availability in these areas (Wall et al. 2013). At the same time, the growth rate of bay scallops (*Argopecten irradians*) decreases under eutrophic conditions. Another piece of literature reported a positive correlation between diatom abundance and the growth of *Macoma balthica* during a period of eutrophication in the Wadden Sea (Beukema & Cadee 1991). A tight coupling between bivalve growth and food quantity driven by nitrogen enrichment appeared in Cape Cod estuaries (Carmichael et al. 2012). Additionally, in the northern Adriatic Sea, eutrophication in 20th century led to increased shell sizes of a hypoxia-tolerant bivalve, *Corbula gibba* (Fuksi et al. 2018).

The mass mortality of blood cockles, as in the cases of various other bivalve species, sometimes occurs on aquaculture grounds (Yurimoto et al. 2014b). However, the cause of this event is not yet well known. In the case of European cockle, *Cerastoderma edule*, eight potential causes of mass mortality were likely: food limitation; density; oxygen depletion and organic loadings; temperature and salinity; parasites, pathogens, and commensals; toxicants and other persistent pollutants; predation; and changes in sediment, suspended solids, topography, and bathymetry (Burdon et al. 2014). A variety of environmental stressors with adverse effects on blood cockles would come into play, because fishers practice rearing blood cockles in estuarine areas, which are affected by many types of human activities. Blood cockles are oxygen regulators that are adapted to conditions that range from tidal exposure to hypoxia (Davenport & Wong 1986). Arc shells, including the blood cockle, have haemoglobin (Bao et al. 2013, 2011) as an adaptation to the hypoxic environment (Kladchenko et al. 2020, Wang et al. 2021). However, reoccurring hypoxia would hamper their growth, because bivalves submerged in unsuitable water conditions, under conditions such as hypoxia and hypo-salinity, tightly close their valves, thereby pausing food intake and aerobic respiration. In brackish water, blood cockles showed the highest growth increment in high salinity areas (26.92 ± 4.79), whereas the lowest growth was seen in low salinity areas (17.65 ± 5.73) (Md Joni et al. 2019). This may indicate that salinity plays a vital role in the growth of the blood cockle. In Sg. Buloh, Selangor, ammonia concentration had exceeded the maximum tolerance level of the blood cockle, suggesting that high ammonia concentration was one of the factors that caused decline in cockle population (Ramli et al. 2014, 2013). Additionally, acidic water, with pH as low as 4.3-5.3, has been reported to be discharged into the mouth of Sg. Buloh river (Shimoda et al. 2016).

Furthermore, different ground levels on a mudflat cause different durations of inundation during which benthic organisms take in oxygen-rich water and food in suspension. Additionally, different lengths of daytime desiccation induce different stress levels on those living under extreme solar radiation (Unsworth et al. 2012). Thus, the hydro-geomorphology of the mudflats creates complex spatial patterns of stress exposure and supportive factors that interplay with each other, thereby causing complex spatio-temporal variations in bivalve growth and shell shape.

The conventional sharpness index is a simple ratio between the short and the long axes of a shell. This index was tailored for the manila clam, *Ruditapes philippinarum*, which exhibits higher condition factors with elongated shells (Kakino 1996, Saito et al. 2007). Although contrary to our linguistic intuition, a low sharpness index value means that the shell is flat and elongated. However, this type of sharpness index has a potential size dependency. One way to handle this problem is to use the shell shape indices only for individuals of the same size (Watanabe & Katayama 2010); however, this precondition is difficult to fulfil in natural habitats. Therefore, we proposed the adjusted sharpness index, SI_{adj}, to improve the utility of sharpness index for shells with mixed sizes (Saito & Teoh 2020). By calculating shell weight from its allometry with shell width, estimated condition factor (CF) can be estimated from shell width and total body weight without shucking cockles, where CF replaces the measurement of soft tissue weight relative to total body weight. In the present study, SI_{adj} and CF values of blood cockles in Kg. Bukit Kecil showed an annual oscillation that matched the maturation cycle. Notably, CF was higher than that in Kuala Sepetang and Sg. Buloh. Low

ORP in the sediment in this locality indicated poor oxygen supply at the sea bottom. However, low SI_{adj} and high CF indicated good growth, suggesting greater dietary benefit from eutrophication than risk of sub-lethal hypoxia. Even when the sub-surface layer of organically rich sediment is anoxic, it does not mean that the water touching the sediment surface is always hypoxic. Moreover, anaerobic respiration in tightly closed shell valves can support the tolerance of bivalves under extreme conditions (Ahmad & Chaplin 1984, Babarro & Zwaan 2008, de Zwaan & Wijsman 1976, Taylor 1976).

Estimated condition factor (CF) values in Kuala Sepetang from May to July 2018 showed a contrasting trend to that of CF in Kg. Bukit Kecil, which increased during the same months. Because these months followed the spawning period, which is from November to March, as reported by Yurimoto et al. (2014a), cockles in Kuala Sepetang might die in the process of recovering from the loss in body mass after spawning. Low ORP in the sediment in Kuala Sepetang indicated that eutrophication there is as intense as that in Kg. Bukit Kecil. Food deficiency for cockles was unlikely in this locality; therefore, other stress factors should be examined to explain the reason behind decline in CF values after the spawning period. SI_{adj} in Kuala Sepetang showed no noteworthy temporal fluctuation throughout the study period, presumably because there was no substantial seasonal impact that affected the long-term growth pattern of the shell. In Sg. Buloh, number of dredge samples was not enough to detect a clear seasonal trend in SI_{adj} and CF. Estimated condition factors no smaller than 0.475 were frequent in the second half of all the 3 years of the study, but the coincidence with maturation was not apparent. On 12 November 2019, in an exceptional case, high SI_{adj} values occurred with high CF values. Perhaps, this was a case when cockles with slow growth experienced a sudden improvement in dietary conditions that supported a rapid growth of soft tissue.

The two-axis data plot of SI_{adj} and CF provide a convenient illustration of the long- and short-term growth history of cockles. The negative correlation between SI_{adj} and CF was a common trend in three of the localities studied (Kg. Bukit Kecil, Kuala Sepetang, and Sg. Buloh), suggesting that the elongated shell is an indicator of superior growth conditions (Fig. 3). Presumably because the combined effects of long- and short-term factors on cockle growth were site-specific, the response of CF to increase in SI_{adj} differed between localities. The growth performance of cockles in Kg. Bukit Kecil outperformed that in Kuala Sepetang and Sg. Buloh, showing low SI_{adj} and high CF values, except in the cases of three samples, which had mean CF values that were lower than 0.45. Significant standard errors associated with these three samples suggested that the response of CF to unsuitable conditions was individual-specific. The cockles in Kuala Sepetang and Sg. Buloh showed higher SI_{adj} values, from approximately −0.04 to 0, and lower CF values than those in Kg. Bukit Kecil. In Sg. Buloh, CF remarkably declined as SI_{adj} increased, except for the case in November 12, 2019, indicating that the environmental factors that negatively affected long-term shell growth also inhibited soft tissue recovery. In Teluk Kumbar, cockles showed the highest CF values in this study while SI_{adj} values were in the middle range; however, only one data subset does not represent the range of temporal variation.

Mudflats with few environmental stresses do not always bring about superior cockle growth. Hence, high primary production in eutrophic water is necessary for the adequate soft tissue growth and maturation of cockles, even if some portions of the population experience risk of oxygen deficiency. A two-year observation (2011-2013) of digestive glands of blood cockles in Selangor showed stable phytopigment concentration throughout the year without a positive correlation with seawater chlorophyll-*a*. This implies that the food availability was sufficient for cockle growth (Yurimoto et al. 2021). The present study, in contrast, showed spatial variations in shell morphology and condition factor of blood cockles. The estimated condition factor (CF) of cockles in Sg. Buloh decreased notably as SI_{adj} increased, suggestive of some factors that interrupted rapid growth of the shell and recovery of soft tissue. We should consider turnover and assimilation rate of gut contents to explain the discrepancy between the two studies. Changes in CF and SI_{adj} are the consequences of instantaneous metabolic conditions represented by the quality of gut contents.

As stated above, the adjusted sharpness index (SI_{adj}) and the estimated condition factor (CF) are convenient and easily obtained indices used to evaluate growth of blood cockles in local environments. Measuring 25-30 individual cockles for one sample set should be recommended to obtain credible mean values and errors. As only three variables are required for an individual (shell length, shell width, and total body weight), the time required to measure an individual would be around 10 s, which is approximately 5 min for 30 cockles. The accumulation of this kind of accessible data will help us in chronological analyses of effect of long-term environmental change and in large-scale geographical comparisons. The simplicity of this method enables local fishers to frequently check the growth condition of their cultured cockles without killing, therefore it could be popularly utilized in cockle farming areas in Southeast Asia.

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