BIODIVERSITAS ISSN: 1412-033X
Volume 23, Number 5, May 2022 E-ISSN: 2085-4722
Pages: 2580-2585 DOI: 10.13057/biodiv/d230539

Effects of water parameters on population structure of mud crab from Buntal Mangroves, Kuching, Sarawak, Malaysia: A GLM analysis

ABANG MOHAMMAD HUDZAIFAH ABANG SHAKAWI[1,♥], RUHANA HASSAN[1,2], DURRAH SYAZWANI MUSTAPAH[2]

[1]Centre for Pre-University Studies,Universiti Malaysia Sarawak. 94300 Kota Samarahan, Sarawak, Malaysia. Tel./fax.: +60-82582480, ♥email : asamhudzaifah@unimas.my

[2]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak. 94300 Kota Samarahan, Sarawak, Malaysia

Manuscript received: 8 March 2022. Revision accepted: 26 April 2022.

Abstract. *Shakawi AMHA, Hassan R, Mustapah DS. 2022. Effects of water parameters on population structure of mud crab from Buntal Mangroves, Kuching, Sarawak, Malaysia: A GLM analysis. Biodiversitas 23: 2580-2585.* Buntal Mangroves, Kuching, Sarawak, Malaysia, is an area that is abundant with biological resources but contains minimal biodiversity information. Mud crab fisheries by the locals exist on small scales at Buntal Mangroves, but there is a tendency to overfish due to the increasing demand for this resource. The relationship between the population structure of mud crabs and the environmental factors in Buntal Mangroves has not been explored. Therefore, this study aimed to apply the generalized linear models (GLM) for analyzing the population structure of mud crabs with selected water parameters in Buntal Mangroves. *Scylla olivacea* (Herbst, 1796) has the highest abundance in Buntal compared to *S. tranquebarica* (Fabricius, 1798) and other types of mud crab. Three GLM with carapace length, carapace width, and body weight as dependent variables were constructed. These GLMs with gamma-distributed response variables indicated that depth, pH, salinity, and turbidity positively affected body weight, carapace width, and carapace length, while temperature had a negative impact on the dependent variables. The results emphasized the importance of adopting the GLM to describe a relationship where the response variable followed a non-normal distribution. The findings provide a basis for future studies at Buntal Mangroves, not only for conservation purposes but also to support the utilization of this valuable resource sustainably.

Keywords: Abiotic factors, carapace length and width, gamma GLM, *Scylla* spp., water quality

INTRODUCTION

Mud crab (locally known as 'ketam bakau') is a group of crab from Genus *Scylla*, comprising four species, namely *Scylla serrata* (Forsskål, 1775), *S. paramamosain* (Estampador, 1949), *S. tranquebarica* (Fabricius, 1798) and *S. olivacea* (Herbst, 1796) (Keenan et al. 1998). Mud crabs live inside burrows in the mud of estuaries and mangrove areas, where the waters are covered by currents and wave actions (Hassan and Mustapah 2019). The carapace of mud crab is smooth, oval and wider than its length, and slightly concave in shape (Keenan et al. 1998). Trivedi and Vachhrajani (2013) have mentioned that the carapace is also glabrous. The chelipeds of mud crabs are massive in size and are not of equal size for both sides; the first three walking legs are similar, while the last walking legs are natatorial (Trivedi and Vachhrajani 2013).

Adult mud crabs scavenged on almost anything. Hence, they are important in assisting the decomposition of organic matters such as detritus from dead plants and animals (Hassan and Mustapah 2019). This will further accelerate the nutrient recycling process and energy flow in the mangroves (Keenan et al. 1998). Besides its ecological importance, mud crabs are exploited by fishers due to its high value in the markets, reaching up to RM 68 per kg (for an individual crab that reaches or exceeds 250 g).

Buntal Mangroves is located near Santubong National Park and Bako National Park, Malaysia. This mangrove forest stretches between these two promontories. During neap tides, almost a third of the bay is exposed sand mud flats. Therefore, this area contains high biodiversity with only local resources utilization (Conklin et al. 2014). A small human settlement (village) in this area called Kampung Buntal benefited from this by having mud crab as one of their sources of food and economy.

Despite its economic importance, the current population structure of the mud crab population in Buntal Mangroves remains unknown. Lack of data eventually hindered sustainable management of mud crab resources. There are studies dealing with morphological data and certain descriptions of the wild mud crab populations in Malaysian Borneo, for example, by Ikhwanuddin et al. (2011), Hassan and Mustapah (2019), and Fazhan et al. (2017; 2021), but no studies have been conducted in Buntal Mangroves.

The growth of mud crab is dependent on a wide range of impacting factors (Gong et al. 2015). Among the water quality, extreme fluctuation in the salinity, temperature, and high humid conditions can cause severe problems in mass mortality. In addition to that, dissolved oxygen (DO) also affects survivability and growth due to the slight changes in temperature (Pedapoli and Ramudu 2014). Catchability and abundance of *Scylla* spp. are likely to influence by physical environmental factors such as currents, tides, wind and the lunar cycle (Green et al. 2014; Johnston et al. 2021). The mangroves and mudflats inhabited by mud crabs are often rich in organic material and microorganisms, hence contributing to high biochemical oxygen demand. The shallow water of these areas, together with flooding tides, suggests low DO amounts (Dubuc et al. 2017).

The impacts of environmental factors on aquatic animals can be estimated by running a regression of parameters (Sun et al. 2019; Leoville et al. 2021; Zhang et al. 2021; Ha 2022). This method has been applied successfully to several studies (Schmidt et al. 2012; Rees et al. 2014; DeForest et al. 2017; Su et al. 2017) and can describe the initial relation between physical or chemical parameters towards the abundance, catch as well as risk to the aquatic life. Linear regression is a model to forecast an outcome (called the dependent variable) as a function of one or more predictors (called independent variables) correlated with the outcome. However, outcomes from ecological studies are not always normally distributed, often binary, and contain proportions or counts (Nakagawa and Schielzeth 2012; Levy et al. 2014; Harrison et al. 2018). Therefore, a more effective approach is needed. Thus, the main improvements of generalized linear models (GLM) over linear regression are their ability to handle a larger class of error distributions and provide an efficient way of ensuring linearity and constraining the predictions to be within a range of possible values the link function. Furthermore, GLM provides an alternative means for analyzing relationships instead of transforming the data into the classical statistical framework by using nonparametric tests or relying on the robustness of classical ANOVA followed by achieving normality and homogeneity of variance (Levy et al. 2014; Harrison et al. 2018). Therefore, this study aimed to describe the population structure of mud crabs at Buntal Mangroves and formulate GLM to describe the interaction between the water quality and the population structure of mud crabs.

MATERIALS AND METHODS

Field sampling

Collection of mud crab samples from Buntal Mangroves, Kuching, Sarawak, Malaysia (Figure 1) was performed from March 2019 to January 2020, with about one to two months between each sampling based on spring tides, at three sites in the mangrove area near to Buntal Bay. Buntal mangrove covering deltas of approximately 3 km^2. This area receives water flow from Sungai Buntal (one of the tributaries of Sungai Santubong) with a river mouth facing north and meets the South China Sea. Station 1 (N01°41'09.5", E110° 22' 26.7") and Station 2 (N01° 41'33.8", E110°21'56.2") were located in the rivers amongst mangrove forests with *Rhizophora* sp. and nipa vegetation could be observed along the riverbanks. Station 3 (N01° 41'31.7", E110°22'17.6") was located near a human settlement, where one could see the villagers anchored their small boats in between mangrove vegetation (Figure 1).

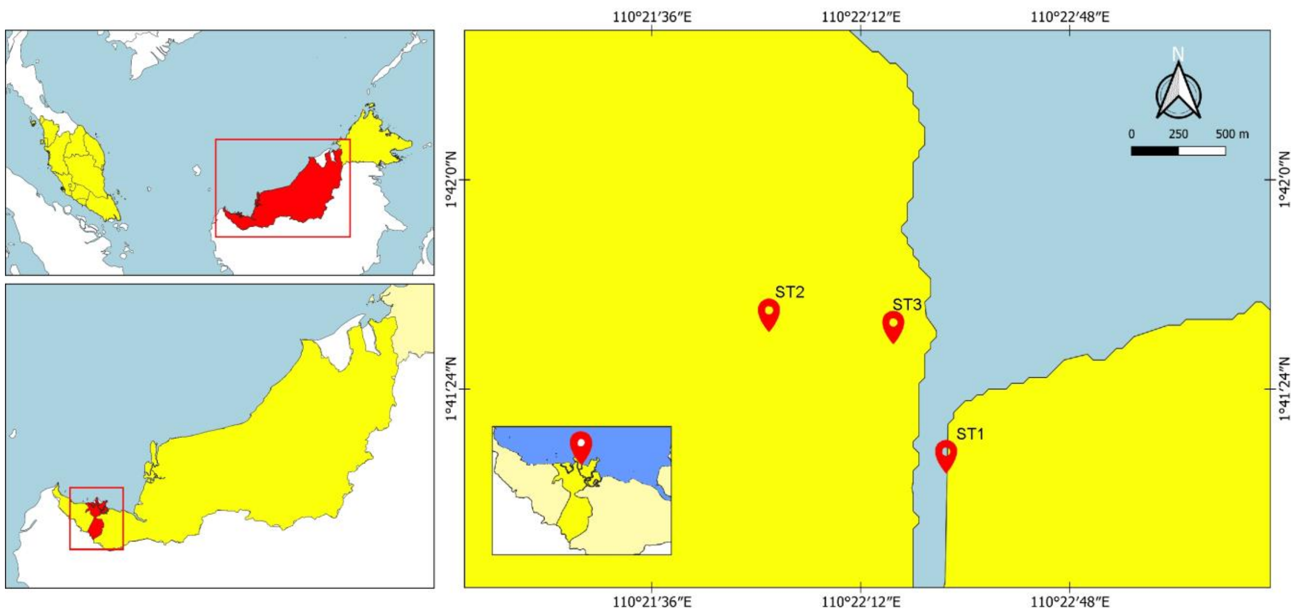

Figure 1. Sampling stations at Buntal Mangroves, Kuching, Sarawak, Malaysia

A total of 276 mud crabs were captured using baited custom-made traps with help from local fishers. Each specimen was given an ID number followed by a morphological assessment, and pictures of each specimen were captured as a record. At the sampling sites, the measurements taken were carapace length (CL), carapace width (CW), and body weight (BW) of the crabs. CL and CW were measured using a digital caliper (Precision, Digital caliper) with precision up to 3 decimal points. CL (cm) is taken vertically in the midline of the carapace from the frontal lobe spine to the posterior margin of the carapace. CW (cm) is taken horizontally along the carapace of the mud crabs from the end to the end of the tip of the lateral spine. BW of each individual sample was taken using a portable digital balance (Shimadzu, ELB3000) with precision up to the nearest 0.1 g. To ensure that the weight measurements are uninterrupted by miscellaneous factors, all individuals were cleaned from mud using tap water and dried with tissue paper before the weighing process. Only meaty crabs (hard-shelled crabs) and no water crabs (newly molted crabs) were included in this study to reduce biased on body weights. The species and gender of all individuals are recorded. Species identification followed the identification key for this genus (Keenan et al. 1998).

Water quality

Selected water quality was measured at approximately 0.5 meters below the surface water during flooding tide at every station and triplicate readings were recorded. DO, temperature, turbidity, pH, and salinity were measured in situ using DO meter (HI9146, Hanna Instrument), turbidity meter (TU-2016, Lutron), pH meter (HI 991003, Hanna Instrument), and refractometer (300011, Sper Scientific).

Carapace width-body weight relationship

The equation BW = aCWb was applied to describe each species's carapace width-body weight relationship according to sex. To calculate carapace width-body weight relationships, data were log-transformed to achieve linearity and calculated by linear regression based on the formula log BW = log a + b log CW. The constant *a* represents the BW at a unit length, whereas constant *b*, also known as the allometry coefficient, represents the slope (rate of increase) of BW against CW (Fazhan et al. 2021). Growth allometry was deduced based on the b value. For instance, b = 3 implies isometric growth, b > 3 implies positive allometric growth and b < 3 implies negative allometric growth. Student's t-test was used to determine the significance of the *b* values against b = 3.

Generalized linear model

GLMs are constructed based on an assumed relationship, called a link function, between a linear predictor function of the explanatory variables and the mean of the response variable. Data are assumed to fall within one of several families of probability distributions, including Normal, Binomial, Poisson, negative Binomial, or Gamma. 3 GLMs using Gamma distribution (CL, CW, and BW as dependent variables and water quality as independent variables) as its probability function and log link were constructed in this study. The Gamma distribution is a 2-parameter frequency distribution given by the equation:

$$f(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)} x^{\gamma-1} e^{-\frac{x}{\beta}};\ \beta > 0, \gamma > 0$$

The gamma distribution is widely used in modeling continuous, non-negative, and positive-skewed data. In evaluating the model's parameters, the GLMs were fitted using maximum likelihood (ML) estimation rather than the sum of squares through ordinary least squares regression. ML estimation uses an iterative approach to determine estimates for population parameter values (i.e., estimates of the slopes, standard errors, etc.) that maximize the likelihood that the sample data came from a population with these parameter values. A useful measure of comparative model fit is the Akaike Information Criterion (AIC), with smaller values of the AIC being preferred. A major advantage of the AIC is that it is valid for comparing non-tested models, allowing models with a different link and distributional assumptions to be compared.

RESULTS AND DISCUSSION

Composition, size distribution, and sex ratio

Four species of mud crabs were identified in Buntal Mangroves; *S. tranquebarica, S. paramamosain, S. olivacea*, and *S. serrata*. A total of 276 crabs were collected throughout the study period. The two most abundant species were *S. olivacea* and *S. tranquebarica*, making up approximately 42.75% (n = 118) and 30.43% (n = 84) of the total caught crabs, respectively. The *S. serrata* was the least frequently encountered (3.62%, n = 10), while 23.20% (n = 64) of the crabs collected were *S. paramamosain* (Table 1). Overall, the total number of male crabs (n = 190) was nearly two times higher than that of females (n = 86), with an overall sex ratio of male: female of 1:0.45. Similarly, Sharif et al. (2019) reported that all species of mud crabs in Marudu Bay, Sabah was male-biased, with a ratio 1:0.5.

The size range (CW and CL) of male *S. olivacea* was larger than that of females, as shown in Table 1. However, the opposite situation occurred for *S. tranquebarica* and *S. paramamosain*. There was a significant difference in CW for *S. olivacea*, *S. tranquebarica* and *S. paramamosain*. Similar fluctuation dynamics were also observed for CL across these 3 species. Another study in Malaysia by Fazhan et al. (2017) reported that the CW of males was significantly larger than that of females for *S. tranquebarica* and *S. paramamosain* but not *S. olivacea*. Analysis for *S. serrata* was not conducted due to its small size sample. On the other hand, Kumalah et al. (2017) reported that in the west of Java Island, Indonesia, more small size female *S. serrata* were caught during field sampling than male crab, suggesting that male crabs had been overexploited over time in the area. The body-weight of male *S. olivacea* and *S. paramamosain* were larger than that its female, while the bodyweight of female *S. tranquebarica* was larger than its male. There was also a significant difference in BW for *S. olivacea* (F = 151.2, p<0.001), *S. tranquebarica* (F = 183.5, p<0.001), and *S. paramamosain* (F = 31.9, p<0.001).

Carapace width-body weight relationship

The coefficient of correlation (r^2) obtained was high regardless of sexes and species, indicating that the values had a high degree of positive correlation existed between carapace width and body weight in these crabs (Table 2). Compared to the isometric growth pattern where b = 3, only male *S. serrata* recorded positive allometry, but this finding should be read with caution due to the low sample size. In Java, Indonesia, Kumalah et al. (2017) reported that *S. serrata* showed positive allometry suggesting the environment is suitable for the wild mud crab population to flourish.

Water quality

Various water quality recorded during the sampling period is presented in Table 3. The data obtained during this study matched Class E (Estuary) by Malaysian Marine Quality Standard and Index (2019). The mean values at each station did not significantly differ among depths and temperature (Table 3). However, the salinity at Station 1 is significantly higher (p<0.001) than at other stations. Turbidity and pH at Station 2 are significantly higher (p<0.001) than at other stations. DO was highest at Station 2, followed by Station 1 and Station 3.

Generalized linear models

Six models were constructed where models were constructed using ordinary linear regression and the other 3 with GLM (Table 4). The independent variables for all models were depth (χ_1), DO (χ_2), pH (χ_3), salinity (χ_4), temperature (χ_5) and turbidity (χ_6).

The AIC and an examination of residuals from the fitted model showed that a Gamma GLM with a log link function was the most appropriate model for expressing additive relation between response and predictor variables.

There was a positive relationship between depth, pH, salinity, and turbidity towards BW, CW, and CL. High fluctuation in salinity, one of the characteristics of estuary environment, is among the factors that could influence the growth of crabs (Avianto et al. 2013; Gong et al. 2015; Monteiro et al. 2021). In this study, stations were located in shallow waters (depths are between 2 to 3 meters), therefore, a positive relationship between depth and crab size needed further study.

Table 1. Species composition, carapace width, carapace length and body weight of mud crabs caught in the Buntal Mangroves, Kuching, Sarawak, Malaysia

Species	N	Average CW (cm)	Average CL (cm)	Average BW (g)
S. olivacea (male)	83	8.5±1.37	5.7±1.06	142±68.95
S. olivacea (female)	35	8.1±1.52	5.6±1.12	106.6±54.66
S. tranquebarica (male)	38	8.3±1.34	5.6±0.99	124.8±53.65
S. tranquebarica (female)	46	9.1±1.6	6±1.48	138±61.54
S. paramamosain (male)	39	8.3±1.37	5.5±1.0	124.3±53.11
S. paramamosain (female)	25	8.6±1.44	5.7±1.0	117.4±55.05
S. serrata (male)	5	10±1.22	6.6±1.0	212.8±94.76
S. serrata (female)	5	9.7±2.39	7.2±1.03	171.2±84.76

Table 2. Regression equations representing the carapace width-body weight relationships of mud crabs

Species	a	b	Regression equation	R^2	r	Allometry
S. olivacea (male)	0.0004	2.8732	$\log BW = \log 0,0004 + 2,8732 \log CW$	0.8287	0.9103	–
S. olivacea (female)	0.0011	2.5893	$\log BW = \log 0,0011 + 2,5893 \log CW$	0.8974	0.9473	–
S. tranquebarica (male)	0.0006	2.7552	$\log BW = \log 0,0006 + 2,7552 \log CW$	0.8899	0.9434	–
S. tranquebarica (female)	0.0079	2.1543	$\log BW = \log 0,0079 + 2,1543 \log CW$	0.8066	0.8981	–
S. paramamosain (male)	0.0054	2.2602	$\log BW = \log 0,0054 + 2,2602 \log CW$	0.8035	0.8964	–
S. paramamosain (female)	0.0004	2.8221	$\log BW = \log 0,0004 + 2,8221 \log CW$	0.9814	0.9907	–
S. serrata (male)	0.00002	3.4986	$\log BW = \log 0,00002 + 3,4986 \log CW$	0.9140	0.9561	+
S. serrata (female)	0.0147	2.0309	$\log BW = \log 0,0147 + 2,0309 \log CW$	0.9173	0.9578	–

Table 3. Water quality recorded during the sampling period at Buntal Mangroves, Kuching, Sarawak, Malaysia

Water quality	Station 1	Station 2	Station 3
Depth (m)	2.08±0.45	2.31±0.74	2.29±0.63
Temperature (°C)	30.96±1.74	29.65±2.07	30.59±1.59
Salinity (PSU)	27.42±8.15	27.02±8.83	27.38±5.08
Turbidity (mg/L)	38.18±15.77	42.33±38.41	30.24±7.43
pH	7.31±0.49	7.31±0.50	7.30±0.52

Dissolved Oxygen (mg/L)	4.62±1.62	4.66±1.54	4.44±1.59

Table 4. The estimated equation for GLM and linear regression model

Dependent variables	Type	Estimated Equation	AIC value
BW	GLM	$\log y = 0,2174x_1 + 0,0936x_2 + 1,1622x_3 + 0,3577x_4 - 0,4083x_5 + 0,0274x_6$	11.0074
BW	Linear regression	$y = 11,1018x_1 + 26,8396x_2 + 186,1664x_3 + 51,1617x_4 - 92,7602x_5 + 4,0315x_6$	11.1622
CW	GLM	$\log y = 0,1660x_1 - 0,0654x_2 + 0,1898x_3 + 0,0898x_4 + 0,0148x_5 + 0,0067x_6$	8.2836
CW	Linear regression	$y = 4,2431x_1 + 3,1157x_2 + 37,3562x_3 + 10,5111x_4 - 16,7689x_5 + 0,8566x_6$	8.3276
CL	GLM	$\log y = 0,1539x_1 - 0,0549x_2 + 0,2225x_3 + 0,0735x_4 + 0,0073x_5 + 0,0064x_6$	8.2219
CL	Linear regression	$y = 2,9387x_1 + 2,0113x_2 + 25,2623x_3 + 5,8739x_4 - 10,2444x_5 + 0,5371x_6$	8.2535

Note: *significant coefficient at 5% level

The current study showed a negative relationship between temperature towards BW, CW, and CL. Pedapoli and Ramudu (2014) claimed that temperature affects growth in the culture of mud crabs, however, when assessing the wild population of mud crabs in Malaysia, Fazhan et al. (2017) reported that there is no relationship between temperature and the abundance of wild mud crab populations. This is mostly due to unseasonal rains, very high temperatures, and humid conditions during the sampling period.

The relationship between DO towards CW and CL was similar (negative relationship) but exhibited an opposite relationship compared to BW. Mud crabs breathe through gills; they can breathe on land as long as the gills are moist (Wang et al. 2018). Therefore, the concentration of DO is not a major factor that influences the growth of the animals, whereby crabs could show satisfactory growth, although lack DO in the environment.

In conclusion, a total of four species of mud crabs were identified in Buntal mangroves, namely *S. tranquebarica*, *S. paramamosain*, *S. olivacea*, and *S. serrata*. *S. olivacea* has the highest proportion compared to other species. It was observed that depth, pH, salinity, and turbidity were the major variables that positively influenced body weight, carapace width, and carapace length, while temperature negatively impacted the dependent variable. The GLM constructed has shown significant improvement in fitting the data and can be useful in forecasting the future impact of the water quality on the mud crab population. Despite the achievements made using these models to identify an interaction between the water quality and mud crabs, future research is required to provide a more accurate and integrated assessment. Other variables that should be included are detritus composition, mangrove vegetation diversity, total organic carbon concentration, and soil characteristics.

ACKNOWLEDGEMENTS

This work is supported by Universiti Malaysia Sarawak, Malaysia (UNIMAS) CDRG Grant Scheme C09/CDRG/1834/2019. In addition, the authors would like to thank the local people of Buntal Village and Universiti Malaysia Sarawak, Malaysia, postgraduate students for their kind assistance during sampling trips.

REFERENCES

Avianto I, Sulistiono, Setyobudiandi I. 2013. Karakteristik habitat dan potensi kepiting bakau (*Scylla serrata*, *S. transquaberica*, dan *S. olivacea*) di hutan mangrove Cibako, Sancang Kabupaten Garut Jawa Barat. Bonorowo Wetlands 3 (2): 97-106. DOI: 10.13057/bonorowo/w030201. [Indonesian]

Conklin JR, Verkuil YI, Smith BR. 2014. Prioritizing migratory shorebirds for conservation action on the East Asian–Australasian Flyway. WWF-Hong Kong, Hong Kong.

DeForest DK, Brix KV, Tear LM, Adams WJ. 2017. Multiple linear regression models for predicting chronic aluminum toxicity to freshwater aquatic organisms and developing water quality guidelines. Environ Toxicol Chem 37 (1): 80-90. DOI: 10.1002/etc.3922.

Dubuc A, Waltham N, Malerba M, Sheaves M. 2017. Extreme dissolved oxygen variability in urbanised tropical wetlands: The need for detailed monitoring to protect nursery ground values. Estuar Coast Shelf Sci 198: 163-171. DOI: 10.1016/j.ecss.2017.09.014.

Fazhan H, Waiho K, Al-Hafiz I, Kasan NA, Ishak SD, Afiqah-Aleng N, Tola S, Ikhwanuddin M. 2021. Composition, size distribution, length-weight relationship of sympatric mud crab species (*Scylla*) and the case of presumed hybrids. Estuar Coast Shelf Sci 250: 1-7. DOI: 10.1016/j.ecss.2020.107154.

Fazhan H, Waiho K, Darin Azri MF, Al-Hafiz I, Wan Norfaizza WI, Megat FH, Jasmani F, Ma H, Ikhwanuddin M. 2017. Sympatric occurrence and population dynamics of Scylla spp. in equatorial climate: Effects of rainfall, temperature and lunar phase. Estuar Coast Shelf Sci 198: 299-310. DOI: 10.1016/j.ecss.2017.09.022.

Gong J, Yu K, Shu L, Ye H, Li S, Zeng C. 2015. Evaluating the effects of temperature, salinity, starvation and autonomy on moulting success, moulting interval and expression of ecdysone receptor in early juvenile mud crabs, *Scylla paramamosain*. J Exp Mar Biol Ecol 464: 11-17. DOI: 10.1016/j.jembe.2014.12.008.

Green BS, Gardner C, Hochmuth JD, Linnane A. 2014. Environmental effects on fished lobsters and crabs. Rev Fish Biol Fisheries 24: 613-638. DOI: 10.1007/s11160-014-9350-1.

Ha NTV. 2022. Evaluating impact of climate change to fishing productivity of Vietnam: An application of autoregressive distributed lag (ARDL) regression model. Global Changes and Sustainable Development in Asian Emerging Market Economies 2: 671-686. DOI: 10.1007/978-3-030-81443-4_43.

Harrison XA, Donaldson L, Correa-Cano ME, Evans J, Fisher DN, Goodwin CED, Robinson BS, Hodgson DJ, Inger R. 2018. A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 6: e4794. DOI: 10.7717/peerj.4794.

Hassan R, Mustapah DS. 2019. Morphology and genetic diversity of mud crabs (Portunidae: ScyIlla) from Teluk Sulaman, Sabah, Malaysian Borneo. ASM Sci J 12: 1-9. DOI: 10.32802/asmscj.2019.252.

Ikhwanuddin M, Azmie G, Juariah HM, Zakaria MZ, Ambak MA. 2011. Biological information and population features of mud crab, genus *Scylla* from mangrove areas of Sarawak, Malaysia. Fish Res 108: 299-306. DOI: 10.1016/j.fishres.2011.01.001.

Johnston DJ, Yeoh DE, Harris DC. 2021. Environmental drivers of commercial blue swimmer crab (*Portunus armatus*) catch rates in Western Australian fisheries. Fish Res 235: 105827. DOI: 10.1016/j.fishres.2020.105827.

Keenan CP, Davie P, Mann D. 1998. A revision of the genus *Scylla* De Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). Raffles Bull Zool 46 (1): 217-245.

Kumalah AA, Wardiatno Y, Setyobudiandi I, Fahrudin A. 2017. Biologi populasi kepiting bakau *Scylla Serrata* – Forsskal 1775 di Ekosistem Mangrove Kabupaten Subang, Jawa Barat. J Ilmu dan Teknologi Kelautan Tropis 9(1): 173-184. DOI: 10.29244/jitkt.v9i1.17928 . [Indonesian]

Leoville A, Lagarde R, Grondin H, Teichert N, Faivre R, Rasoanirina E. 2021. Influence of environmental conditions on the distribution of burrows of the mud crab, *Scylla serrata*, in a fringing mangrove ecosystem. Reg Stud Mar Sci 43 (1): 101684. DOI: 10.1016/j.rsma.2021.101684.

Levy O, Ball BA, Bond-Lamberty B, Cheruvelil KS, Finley AO, Lottig NR, Punyasena SW, Xiao J, Zhou J, Buckley LB, Filstrup CT, Keitt TH, Kellner JR, Knapp AL, Richardson AD, Tcheng D, Toomey M, Vargas R, Voordeckers JW, Wagner T, Williams JW. 2014. Approaches to advance scientific understanding of macrosystems ecology. Front Ecol Environ 12 (1): 15-23. DOI: 10.1890/130019.

Malaysian Marine Quality Standard and Index. 2019. Ministry of Energy Science, Technology, Environment and Climate Change. https://doe.gov.my/portalv1/wp-content/uploads/2019/04/BOOKLET-BI.pdf

Monteiro JN, Pinto M, Crespo D, Pardal MA, Martinho F. 2021. Effects of climate variability on an estuarine green crab *Carcinus maenas* population. Mar Environ Res 169: 105404. DOI: 10.1016/j.marenvres.2021.105404.

Nakagawa S, Schielzeth H. 2012. A general and simple method for obtaining R^2 from generalized linear mixed-effects models. Methods Ecol Evol 4 (2): 133-142. DOI: 10.1111/j.2041-210x.2012.00261.x.

Pedapoli S, Ramudu KR. 2014. Effect of water quality parameters on growth and survivability of mud crab (*Scylla tranquebarica*) in grow out culture at Kakinada Coast, Andhra Pradesh. Intl J Fish Aquat Stud 2 (2): 163-166.

Rees HC, Maddison BC, Middleditch DJ, Patmore JRM, Gough KC. 2014. The detection of aquatic animal species using environmental DNA – A review of eDNA as a survey tool in ecology. J Appl Ecol 51 (5): 1450-1459. DOI: 10.1111/1365-2664.12306.

Schmidt TS, Clements WH, Cade BS. 2012. Estimating risks to aquatic life using quantile regression. Freshw Sci 31 (3): 15-20. DOI: 10.1899/11-133.1.

Sharif NAM, Kahar NAS, Hussein, MAS, Ransangan J, Yong AS. 2019. Species diversity and distribution of mud crab in Marudu Bay mangrove forest reserve, Sabah, Malaysia. Borneo J Mar Sci Aquac 3(1): 18-24. DOI: 10.51200/bjomsa.v3i1.1709.

Su Q, Lu W, Du D, Chen F, Niu B, Chou K. 2017. Prediction of the aquatic toxicity of aromatic compounds to *Tetrahymena pyriformis* through support vector regression. Oncotarget 8 (30): 49359-49369. DOI: 10.18632/oncotarget.17210.

Sun Z, Sokolova E, Brittain JE, Saltveit SJ, Rauch S, Meland S. 2019. Impact of environmental factors on aquatic biodiversity in roadside stormwater ponds. Sci Rec 9: 5995. DOI: 10.1038/s41598-019-42497-z.

Trivedi JN, Vachhrajani KD. 2013. First record of two porcellanid crabs from Gujarat State, India (Crustacea: Decapoda: Porcellanidae). J Mar Biol Assoc India 55 (1): 55-58. DOI: 10.6024/jmbai.2013.55.1.01756-09.

Wang H, Tang L, Wei H, Lu J, Mu C, Wang C. 2018. Transcriptomic analysis of adaptive mechanisms in response to sudden salinity drop in the mud crab, *Scylla paramamosain*. BMC Genom 19: 421. DOI: 10.1186/s12864-018-4803-x.

Zhang Z, Gao L, Zhang X. 2021. Environmental enrichment increases aquatic animal welfare: A systematic review and meta-analysis. Rev Aquac. DOI: 10.1111/raq.12641.