

Population Dynamics of Asiatic Hard Clam, *Meretrix meretrix* (Linnaeus, 1758) in Marudu Bay, Malaysia: Implication for Fishery Resource Management

Vienna Anastasia Admodisastro¹, Joanna Wong Doinsing², Laditah Duisan¹, Sujjat Al-Azad¹, John Madin¹ and Julian Ransangan^{1*}

ABSTRACT

Hard clam, *Meretrix meretrix* is the principal bivalve resource collected by artisanal fishermen in the coastal areas of Marudu Bay, Malaysia. Population parameters of the clam in the intertidal zone of Marudu Bay, Sabah were analyzed using FiSAT software, based on monthly length and weight data collected from May 2017 to April 2018. A total of 1,745 clams with shell lengths ranging from 18.3 to 101.7 mm were analyzed. Asymptotic length (L_{∞}) and growth coefficient (K) of the von Bertalanffy growth formula (VBGF) for *M. meretrix* were estimated at 107.63 mm and 0.47 year⁻¹, respectively. The estimated growth performance index (ϕ) was 3.736. The theoretical age at length zero (t_0) was -0.1412. The predicted maximum life span of the clam was 6.38 years. The sampled population of *M. meretrix* exhibited consistent and moderate fatness (3.88 ± 0.84) throughout the year. The total mortality (Z) was estimated at 2.65 year⁻¹, fishing mortality (F) at 1.87 year⁻¹, and natural mortality (M) at 0.78 year⁻¹. The exploitation level (E) of the *M. meretrix* population was 0.70, while the maximum allowable limit of exploitation (E_{max}) was 0.499 for the highest yield. This study clearly indicates that the *M. meretrix* stock in Marudu Bay experiences over-exploitation that warrants immediate action by the fisheries management authority.

Keywords: Condition index, Exploitation, Growth, Hard clam, Marine park, Mortality, Tun Mustapha

INTRODUCTION

Marudu Bay is located within Tun Mustapha Marine Park, in the north of Malaysian Borneo, and is part of the Coral Triangle Initiative region of Malaysia. The bay is known for its high biodiversity (Zakaria and Rajpar, 2015), but is also an important fishing ground for Sabah (Beliku and Saleh, 2013). Of the many bivalve species occurring in the bay, the Asiatic hard clam, *Meretrix meretrix* (Veneridae), also known as the great clam, receives special attention because of its commercial importance (Tan *et al.*, 2017).

Meretrix meretrix is an edible marine bivalve mollusk that is inhabiting in coastal areas of South and Southeast Asia (Liu *et al.*, 2006). The clam is widely cultured in countries like China (Tang *et al.*, 2006) and Taiwan (Huang *et al.*, 2016). However, in Malaysia, *M. meretrix* is not farmed, but rather is harvested from the natural habitat (Mohd Hamdan *et al.*, 2020).

The global landings for clam fisheries in 2017 were estimated to be about 6,193,000 metric tonnes, which contributed about 38 % to the global bivalve production (FAO, 2019). Unlike blood

¹Borneo Marine Research Institute, Universiti Malaysia Sabah, Sabah, Malaysia

²Politeknik Sandakan Sabah, Sabah, Malaysia

* Corresponding author. E-mail address: liandra@ums.edu.my

Received 11 September 2020 / Accepted 6 April 2021

clams (*Anadara* sp.), which are widely cultured and have become the main contributor to bivalve production in Malaysia (Department of Fisheries Malaysia, 2018), the *Meretrix* clam is only important as an artisanal fishery. However, many communities in coastal areas are dependent on this naturally occurring clam as a source of protein and household income (Mohd Hamdan *et al.*, 2017).

The *Meretrix* clam normally burrows itself in mudflat areas of estuaries where the sediment consists of sand and mud with high nutrient concentration (Hamli *et al.*, 2017). It is considered delicious by consumers and is cheaper than other seafood products such as fishes and crustaceans. It has become the principal protein source for coastal communities (Tan *et al.*, 2017). According to Chowdhury *et al.* (2019), *Meretrix* clams are high in protein and moisture, but low in ash, lipid, and carbohydrate. The clam also contains some essential minerals including calcium, iron, and phosphorus. Biochemical composition (e.g., protein, lipid, and carbohydrate) of the clam was reported to be influenced by body size and maturation stage (Chowdhury *et al.*, 2019). The clam was also found to have lower lipid content during its spawning season (Joshi and Bal, 1965).

In Marudu Bay, the *Meretrix* clam is usually collected by artisanal fishermen either for their own consumption or selling directly at local wet markets and seafood restaurants (Tan *et al.*, 2017). The market demand for the clam is high and expected to increase in the future in view of the blooming tourism industry in Sabah (Said, 2011). Such development may result in an increase in exploitation of the natural stocks of the clam (Tan *et al.*, 2016), and may become a threat to the sustainability of the species. Hence, a sustainable fisheries management plan for this species is needed. However, such a management plan can only be developed and implemented effectively when sufficient scientific information about the species is available (Amin *et al.*, 2009). Therefore, this study was carried out to understand the population dynamics and determine the current exploitation level of the *Meretrix* clam so that a sustainable fishery management plan for the species in Marudu Bay can be established.

MATERIALS AND METHODS

Sampling

Hard clams were collected in Marudu Bay (6°34'02.49" to 6°34'57.75" N and 116°48'49.49" to 116°45'26.20" E) from eight stations (Figure 1) during a one-year period from May 2017 to April 2018. The sampling covered an area of 500 m² (50×10 m) by using a hand dredge, called a Kerek (Tan and Ransangan, 2019). A total of 1,745 clam specimens (Figure 2) with shell lengths ranging from 18.3 to 101.7 mm were collected. The shell length and total weight of each clam specimen were measured using a Vernier calipers and an electronic balance with accuracy of 0.01 mm and 0.01 g, respectively. Monthly length-frequency distributions based on a 5-mm shell length interval were analyzed as illustrated in Figure 5.

Seawater temperature

Seawater temperature (°C) was measured in situ monthly during the sampling period at 0.5 m below the surface using a multifunction environmental sensor (YSI; Loveland, Co, USA).

Length-weight relationship

The weight and length relationship was estimated using the log transformation equation ($W = aL^b$; W = weight (g); L = length (mm); a = condition factor; b = the coefficient of the length weight relationship) suggested by Le Cren (1951). The “ a ” and “ b ” parameters were estimated using regression analysis on log-log transformed data:

$$\text{Log}W = \text{Log}a + b\text{Log}L$$

If $b = 3.0$, growth is isometric. However, growth is positive allometric if $b > 3.0$, and growth is negative allometric when $b < 3.0$.

Growth parameters

The length-frequency data were analyzed by using FAO-ICLARM Stock Assessment Tools (FiSAT). The asymptotic length (L_∞) and growth coefficient (K) of the von Bertalanffy growth

function (VBGF) were estimated by using Electronic Length Frequency Analysis (ELEFAN-1) following Pauly and David (1981). The approach used in estimating the L_{∞} and K values and correction of length frequency data was similar to that of Amarasinghe and De Silva (1992), Sparre and Venema (1992) and Amarasinghe (2002). The steps of the approach are briefly described here. First, the estimation of the preliminary values of L_{∞} and K values was carried out by using ELEFAN-1. Second, probabilities of capture were estimated from a detailed analysis of the left ascending part of the catch curve using the preliminary values of asymptotic length (L_{∞}), growth coefficient (K) and computed t_0 . Third, correction of the original length frequencies was done by dividing each frequency value by the probability of capture corresponding to its length (Pauly, 1986). Finally, optimized estimates of L_{∞} and K values were found using ELEFAN-1 from the corrected length frequency data.

The L_{∞} and K values can be obtained from the ELEFAN-1 routine via four options of curve fitting: by eye, response surface analysis, K -values scan and automatic search. In this study, optimized L_{∞} and K values were obtained by the K -values scan (Sivashanthini, 2009). The growth performance index (ϕ) was estimated by using the optimized L_{∞} and K values (Pauly and Munro, 1984) according to the equation below:

$$\phi = 2\log_{10}L_{\infty} + \log_{10}K$$

The average length of clams at a given age was estimated using the inverse von Bertalanffy growth function (VBGF) equation (Sparre and Venema, 1992) as follows:

$$L_t = L_{\infty} (1 - e^{-k(t-t_0)})$$

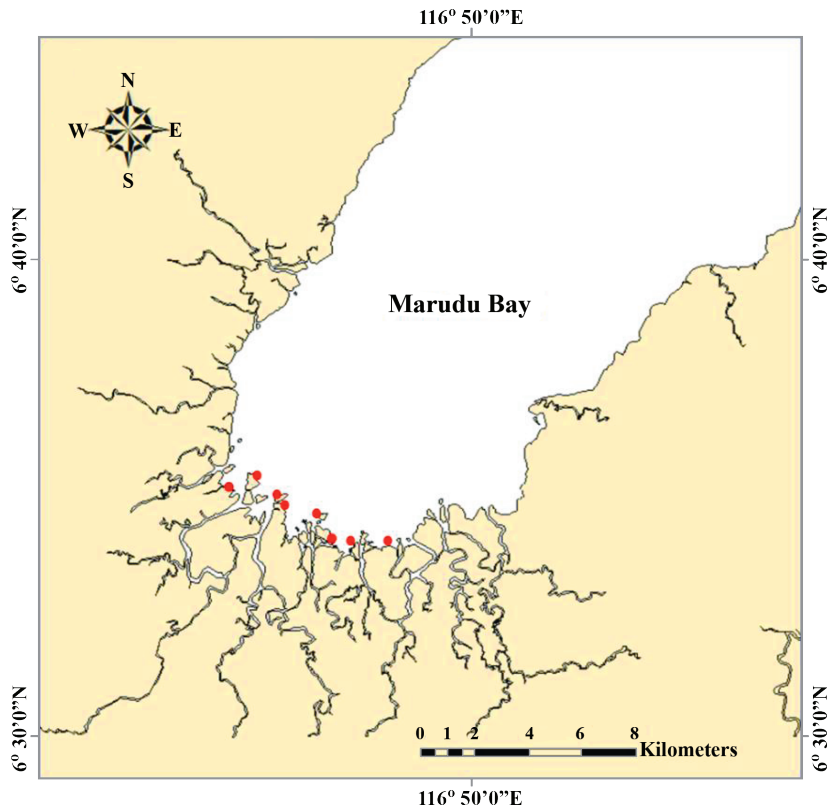


Figure 1. Sampling sites (marked by red dots) of *Meretrix meretrix* within the inner area of Marudu Bay.

Where L_t is the mean length at age t , and t_0 is the hypothetical age at which the length is zero (Newman, 2002). The t_0 value was estimated by substituting the L_∞ and K into the inverse of the VBGF. The average length of 14.5 mm for clams at two months old, as reported by Narasimham *et al.* (1988) was used in the t_0 calculation. The potential longevity (t_{max}) of the clam was obtained using the formula $t_{max} = 3/K$.

Recruitment and condition index

The annual recruitment pattern was estimated by analyzing the monthly shell length-frequency distributions. The symmetry and the uniformity of the shell length distribution was then judged by the skewness and kurtosis values following Groeneveld and Meeden (1984). Five specimens of hard clam were collected randomly each month for condition index determination ($n = 60$). Dry tissue weight and dry shell weight were measured after drying clam specimens individually for 24 h at 105 °C in a muffle furnace. The condition index (CI) was then calculated from the ratio of dry tissue weight (DTW) and dry shell weight (DSW) following Davenport and Chen (1987) and Rahim *et al.* (2012) as follows:

$$CI = (DTW/DSW) \times 100$$

The condition indices are divided into three fatness categories according to Rahim *et al.* (2012):

$$CI \leq 2 \text{ (thin); } CI = 2 \text{ to } 4 \text{ (moderate); } CI \geq 4 \text{ (fat).}$$

The condition indices were tested for significance by using the SPSS Windows Statistical Package (version 26, Chicago, USA) at 0.05 level. All variables were tested for normality and homogeneity of variances prior to further analysis.

Mortality, exploitation level and yield per recruit

The natural mortality rate (M) was estimated from Pauly's equation (Pauly, 1980) by using the mean annual seawater temperature (T , 29.7 °C) at the study site:

$$\log M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

The total mortality (Z) was estimated by the length-converted catch curve method (Pauly, 1984) based on the following equation:

$$\ln \left(\frac{N_i}{\Delta t_i} \right) = a + bt$$

Where N_i is the number of individuals in length class i ; Δt_i is the time needed for the clams to grow through length class i ; t_i is the age or the relative age of individual clams corresponding to the midlength of class i ; a is the intercept; and b , with sign changed, is an estimate of Z . Fishing mortality (F) was estimated by subtracting M from Z . The exploitation level (E) was then estimated following Gulland (1965) as follows:

$$E = F/(F+M)$$

Relative yield per recruit (Y/R) and biomass per recruit (B/R) were derived from the method of Beverton and Holt (1993) using knife-edge selection. The relative yield per recruit was calculated using the following formula:

$$Y'/R = EU^{M/K} \left\{ 1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)} \right\}$$

$$B'/R = (Y'/R) / F$$

Where $U = 1 - (L_c/L_\infty)$, in which L_c is the average length at first capture and L_∞ is the asymptotic length; $m = (1-E)/(M/K) = (K/Z)$, in which E is the exploitation level; M is natural mortality; K is the growth coefficient; and Z is total mortality.

The values of E_{max} , $E_{0.1}$ and $E_{0.5}$ were then estimated by using the first derivative of this function, where E_{max} is the maximum sustainable exploitation rate, $E_{0.1}$ is the exploitation rate at which marginal increase of relative yield-per-recruit is 10 % of its value at $E = 0$, and $E_{0.5}$ is the value of E under which the stock has been reduced to 50 % of its unexploited biomass.

RESULTS

Length-weight relationship

The length and weight of the collected *Meretrix meretrix* specimens ranged from 1.83 to 10.17 cm and from 1.95 to 288.5 g, respectively. The equation representing the length-weight relationship is $W = 0.4920L^{2.774}$, which was obtained by plotting the length values against weights (Figure 2). The computed coefficient (b) of the length-weight relationship was 2.77 and the condition factor (a) was 0.4920.

Growth parameters

Initial estimates of L_{∞} and K values obtained from K -scan in ELEFAN-1 were 107.63 mm and 0.47 year^{-1} , respectively. After the correction of the original length frequencies, the optimized values for L_{∞} and K remained the same (Figure 3). The restructured length distribution according to the length-frequency data is shown in Figure 4. The estimated growth performance index (ϕ) was 3.736 and the theoretical age at length zero (t_0) was estimated to be -0.1412.

The observed maximum length of the *Meretrix meretrix* in Marudu Bay was 102.50 mm, but the predicted maximum length was 104.04 mm, with confidence interval of 95.32 to 112.76 mm at 95 % probability of occurrence. The mean lengths of the hard clam were estimated to be 14.50, 21.52, 28.01, 34.00, 39.55 and 44.68 mm at the end of 2, 4, 6, 8, 10 and 12 months of age, respectively. The estimated maximum life span (t_{max}) of the clam was 6.38 years.

Recruitment and condition index

The *Meretrix meretrix* stock in Marudu Bay exhibited a unimodal population structure throughout the study and was predicted to have constant recruitment throughout the year (Figure 5). It is interesting to note that length-frequency distributions in all the sampling months showed a clear right-skewed distribution. However, shell lengths of *M. meretrix* in June, September, October of 2017 and in January of 2018 showed less skewness.

The condition indices of *M. meretrix* in Marudu Bay ranged from 3.09 to 5.61, with a mean \pm SD of 3.88 ± 0.84 . The condition index was significantly higher ($p < 0.05$) in April 2018 than in the other months (Figure 6).

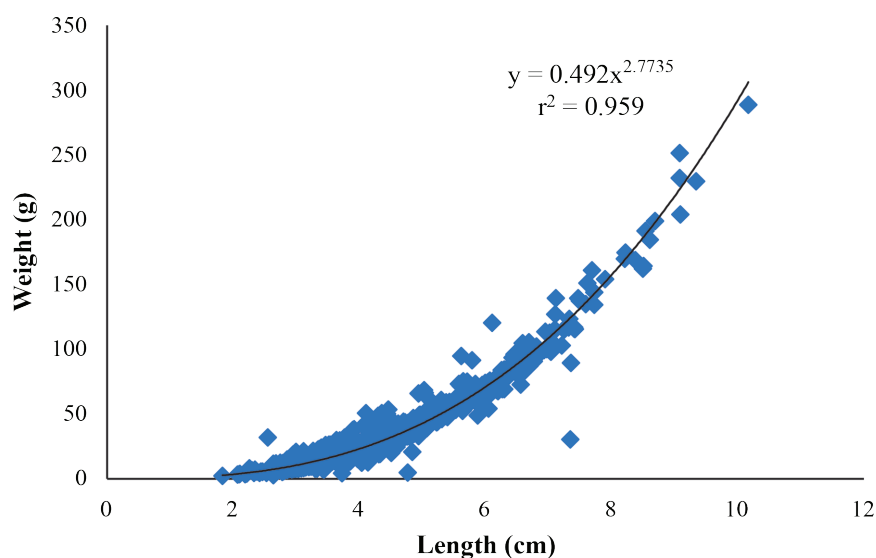


Figure 2. Length-weight relationship of *Meretrix meretrix* in Marudu Bay.

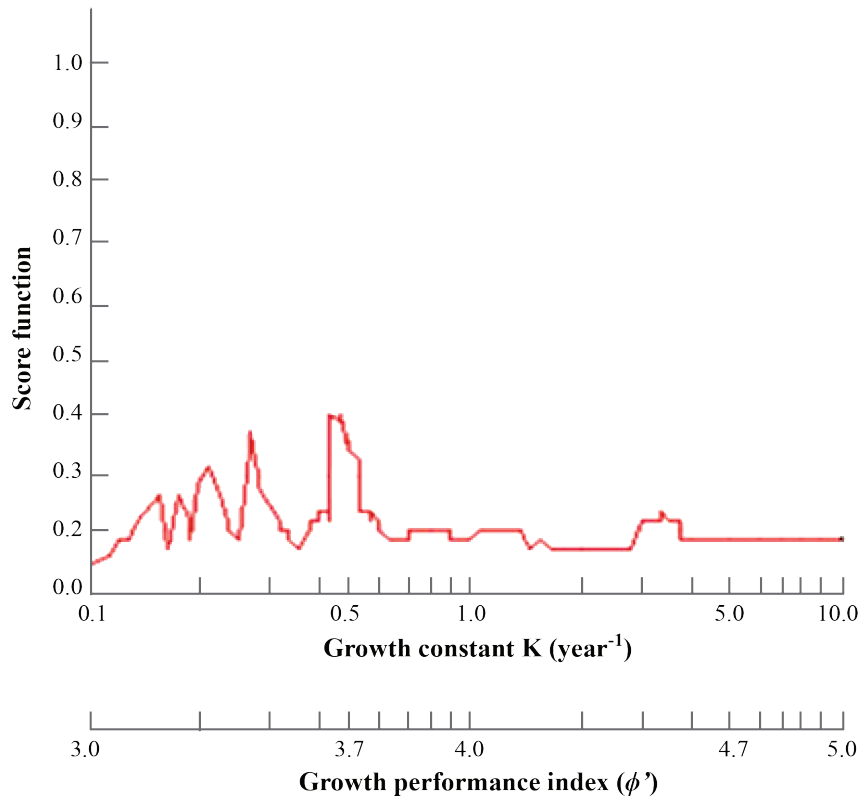


Figure 3. Estimated growth constant (K) of *Meretrix meretrix* in Marudu Bay ($K = 0.47 \text{ year}^{-1}$).

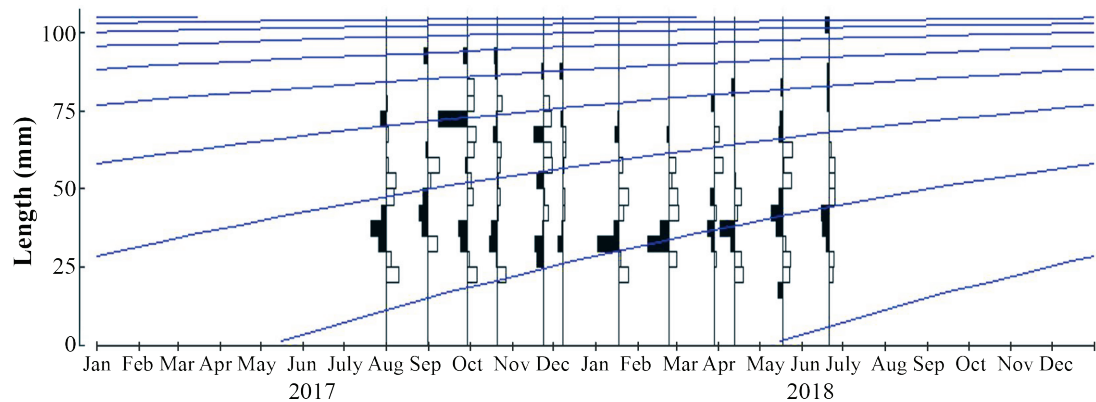


Figure 4. Growth of hard clam, *Meretrix meretrix* in Marudu Bay based on length-frequency data analyzed using ELEFAN-1 ($L_{\infty} = 107.63 \text{ mm}$ and $K = 0.47 \text{ year}^{-1}$).

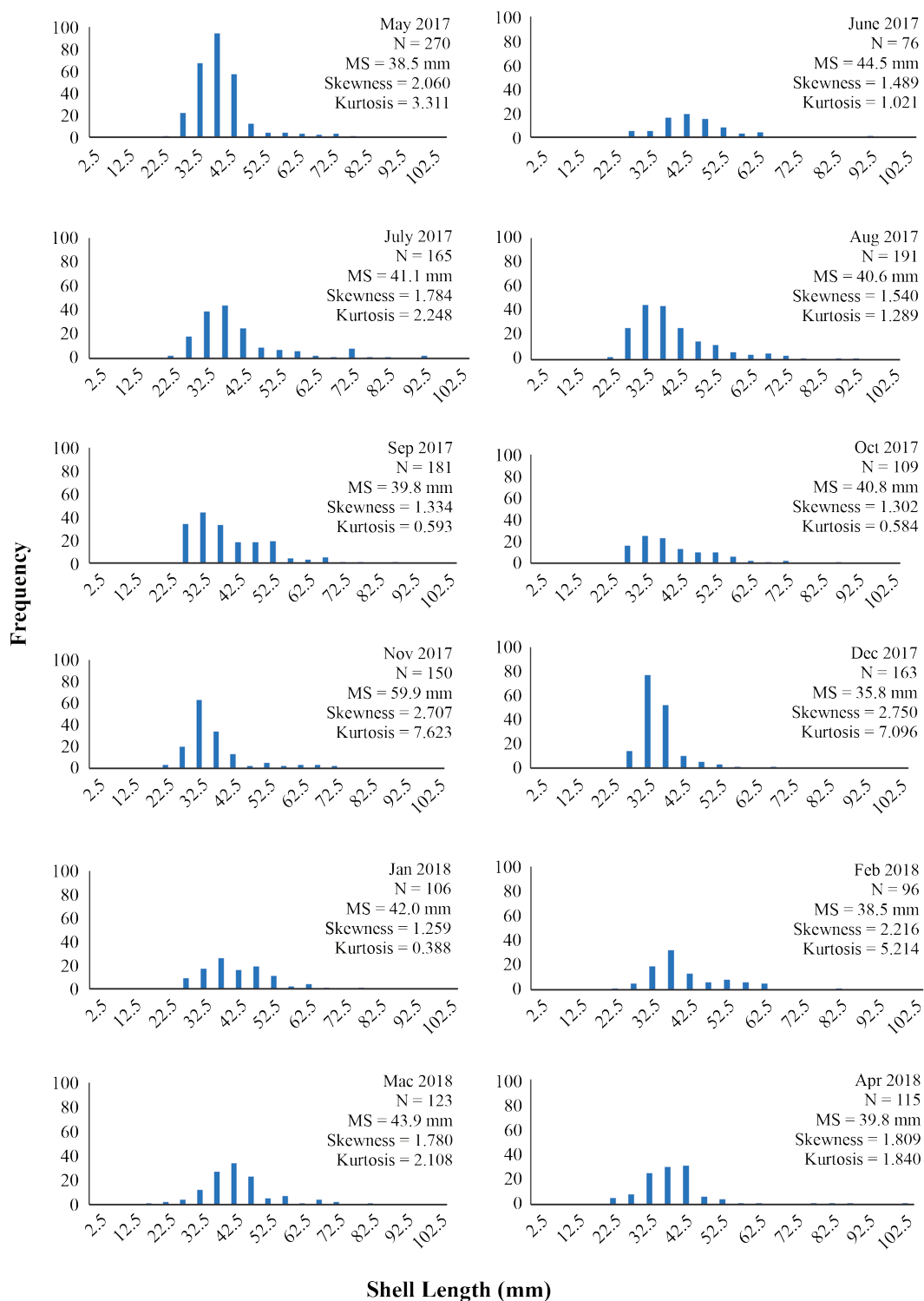


Figure 5. Length-frequency distribution of *Meretrix meretrix* in Marudu Bay on each sampling date. N = number of individuals; MS = mean size of individuals.

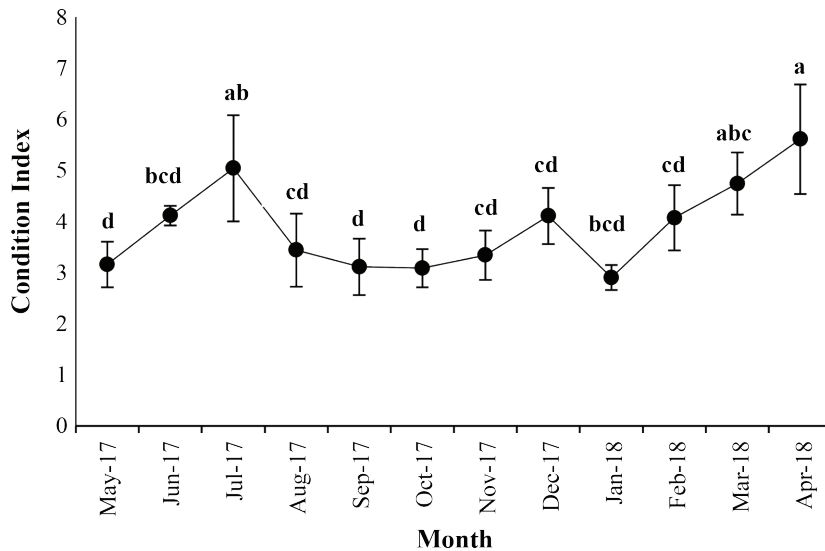


Figure 6. Condition index of *Meretrix meretrix* in Marudu Bay recorded from May 2017 to April 2018. Different lowercase letters above the line indicate significant ($p < 0.05$) difference between months.

Mortality, exploitation level and yield per recruit

The total mortality of *Meretrix meretrix* in Marudu Bay was 2.65 year^{-1} . Higher fishing mortality (1.87 year^{-1}) was observed as compared to natural mortality (0.78 year^{-1}) (Figure 7).

The exploitation level (E) of the hard clam in Marudu Bay was estimated to be 0.70. Figure 8 shows the results of the relative Y/R and B/R analysis for *M. meretrix*. The $E_{0.1}$, $E_{0.5}$ and E_{max} were found to be 0.419, 0.297 and 0.499, respectively.

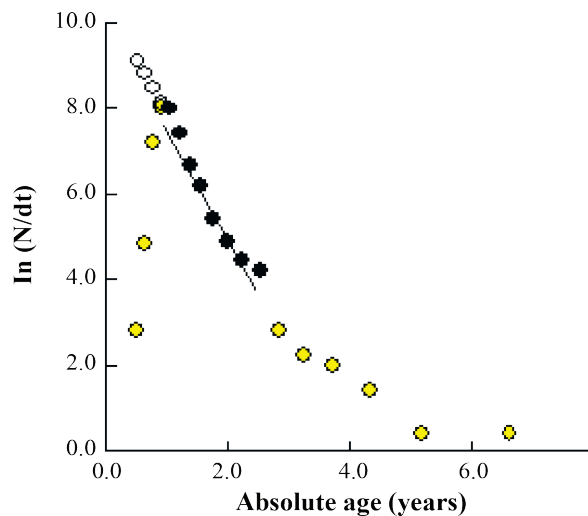


Figure 7. Length-converted catch curve ($Z = 2.65$, M (at 29.7°C) = 0.78 , $F = 1.87$, $E = 0.70$) of *Meretrix meretrix* in Marudu Bay.

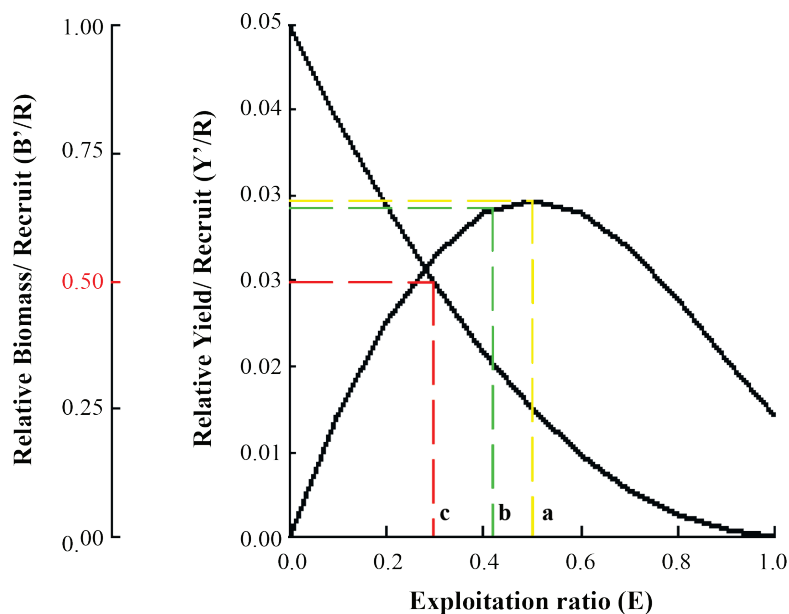


Figure 8. Relative yield per recruit and biomass per recruit of *Meretrix meretrix* in Marudu Bay (a – E_{max} ; b – $E_{0.1}$; c – $E_{0.5}$).

DISCUSSION

Length-weight relationship

In most bivalves, the coefficient b of the length-weight relationship generally ranges between 2.4 and 4.5 (Isham *et al.*, 1951). The computed coefficient b of this relationship for *Meretrix meretrix* in Marudu Bay was 2.77. This demonstrates that the relative growth of the clam in length was higher compared to body weight. This value was also higher than that of the *M. meretrix* population in Bangladesh ($b = 2.02$), and suggests that physiological and habitat conditions affect clam growth (Ramesha and Thippeswamy, 2009).

Growth parameters

The asymptotic length (L_{∞}) and growth coefficient (K) of *Meretrix meretrix* in Marudu Bay were estimated at 107.63 mm and 0.47 year^{-1} , respectively. Comparison with growth and mortality parameters from other studies shows that differences exist for the species from different areas of the world. The size variation could be due to geographical

location and level of exploitation (Dolorosa and Dangan-Galon, 2014). The L_{∞} (107.63 mm) of *M. meretrix* in Marudu Bay was higher than was found for the same species in Thoothukudi, India (99.1 mm) (Narasimham *et al.*, 1988), Moheshkali Island, Bangladesh (81.4 mm) (Amin *et al.*, 2009), and Maharashtra, India (58.8 mm) (Sawant and Mohite, 2013). The K value (0.47) recorded for *M. meretrix* in Marudu Bay was higher than recorded in India, where values ranged between 0.04-0.32 (Narasimham *et al.*, 1988; Sawant and Mohite, 2013), but were much lower compared to that recorded in Bangladesh (0.97) (Amin *et al.*, 2009). On the other hand, the L_{∞} of *M. meretrix* in Marudu Bay was higher, but the K value was lower than those recorded for *M. casta* ($L_{\infty} = 34.0\text{-}43.1$; $K = 0.84\text{-}1.44$) in the Dutch canal of Sri Lanka (Jayawickrema and Wijeyaratne, 2009).

Recruitment and condition index

The current study suggests that the recruitment of *Meretrix meretrix* in Marudu Bay occurs throughout the year (Figure 5). According to Rai (1932), under favorable conditions *M. meretrix*

can spawn throughout the year. A similar observation was reported for *Perna viridis* in Marudu Bay (Tan and Ransangan, 2016). This could be explained by the continuous gametogenesis of tropical bivalves due to low interannual temperature variability in tropical waters (Urban, 2001). Salinity appears to play a more important role in the reproductive cycle of clams in tropical waters than temperature (Jayabal and Kalyani, 1987). Also, the development of the reproductive cycle in the genus *Meretrix* is found to be significantly correlated with chlorophyll *a* availability, which suggests that the clams need high amounts of food to promote gametogenesis (Hamli *et al.*, 2015).

The observation of a clear right-skewed distribution in all the sampling months may be attributed to the selective effect of the fishing gear used during sampling. Previously, Tan *et al.* (2017) reported that the fishing gear used locally is not only destructive to smaller *Meretrix* clams but also to other bivalve species. Also, the lower value of skewness in June, September, October 2017, and January 2018 could indicate higher recruitment activity during these months.

Condition index (CI) is usually used to evaluate the flesh quality of fishery stocks under the given environmental conditions (Li *et al.*, 2009). According to Davenport and Chen (1987) and Rahim *et al.* (2012), bivalves can be divided into three fatness categories based on their CI values: $CI \leq 2$ (thin); $CI = 2$ to 4 (moderate); $CI \geq 4$ (fat). Based on this categorization, the *M. meretrix* stock in Marudu Bay is characterized with moderate fatness. The drastic decrease in condition index of the clam in May and August is most likely associated with the spawning season. This observation is supported by the higher recruitment of the clam in the proceeding months (June, September and October), whereas the high condition indices in July and April suggest that the clams are undergoing maturation. According to Sahin *et al.* (2006), spawning can cause a significant loss in tissue weight or reserves due to release of gametes. Likewise, Peharda *et al.* (2006) suggested that the condition index can be used as a sensitive measure of changes in the reproductive development and it is correlated well with the mean gonad index.

Condition index not only corresponds to reproductive changes, but it can also be affected by environmental variables such as water quality. Lagade and Mulley (2014) reported that the condition index of *Meretrix meretrix* is sensitive to high temperature. On the other hand, Hamli *et al.* (2017) reported that high ammonia nitrogen concentration negatively affects the condition index of hard clams. Extreme environmental conditions are stressful and can cause bivalves to become inactive (e.g., closure of valves and reduced feeding rate) which can lead to poor growth (Gosling, 2003).

Mortality and exploitation level

Mortality rate is an important parameter for understanding the stock status in a natural environment. An exploitation rate of 0.5 has been recommended by Gulland (1983) for an ideal yield, where the fishing mortality is equal to natural mortality (Al-Barwani *et al.*, 2007). In this study, the higher fishing mortality rate ($F = 1.87 \text{ year}^{-1}$) compared to the natural mortality rate ($M = 0.78 \text{ year}^{-1}$) suggests that the fishing activity contributes a major cause of death for the stock. The high exploitation level ($E = 0.70$) compared to the recommended exploitation rate at maximum sustainable yield ($E_{max} = 0.499$) suggests that the clam is indeed experiencing overfishing. This agrees with the finding of Ransangan and Tan (2018), who noted that fishermen tend to explore areas far from common fishing grounds with extended fishing effort to improve their catch. Besides overfishing, the use of destructive fishing gear that have been reported to damage small and juvenile clams (Tan *et al.*, 2017) may potentially deplete the clam population (Moschino *et al.*, 2003) and lead to recruitment failure of the clam in Marudu Bay.

CONCLUSION

The current study demonstrates that the natural stock of the Asiatic hard clam (*Meretrix meretrix*) in Marudu Bay is characterized by negative allometric growth (2.77), but satisfactory condition index (3.88 ± 0.84) and year-round recruitment. However, the high exploitation level (0.70) and fishing mortality (1.87 year^{-1}) suggest that it is

currently overexploited. Hence, a sustainable fishery management plan for the clam through ecosystem-based management approaches is highly recommended. This can be done via several strategies such as avoiding overfishing; ensuring reversibility and rebuilding of the clam population; minimizing impact of fishing operations on the structure, productivity, function and biological diversity in the clam habitat; understanding and maintenance of ecological relationships between the clam and dependent and related species; and finally, broadening stakeholder participation in data collection, knowledge building, option analysis, decision making and implementation of the management strategies.

ACKNOWLEDGEMENTS

This research work was financially supported by the Fundamental Research Grant Scheme (FRG0467-2017) from the Ministry of Higher Education, Malaysia. The authors would like to thank the Fisheries Department of Sabah for the kind assistance provided throughout the field work.

LITERATURE CITED

- Al-Barwani, S.M., A. Arshad, S.M.N. Amin, S.B. Japar, S.S. Siraj and C.K. Yap. 2007. Population dynamics of the green mussel *Perna viridis* from the high spat-fall coastal water of Malacca, Peninsular Malaysia. **Fisheries Research** 84(2): 147–152. DOI: 10.1016/j.fishres.2006.10.021.
- Amarasinghe, U.S. 2002. The fishery and population dynamics of *Oreochromis mossambicus* and *Oreochromis niloticus* (Osteichthyes, Cichlidae) in a shallow irrigation reservoir in Sri Lanka. **Asian Fisheries Science** 15: 7–20.
- Amarasinghe, U.S. and S.S. De Silva. 1992. Population dynamics of *Oreochromis mossambicus* and *O. niloticus* (Cichlidae) in two reservoirs in Sri Lanka. **Asian Fisheries Science** 5: 37–61.
- Amin, S.M.N., M. Zafar and M. Barua. 2009. Population dynamics of Venus clam *Meretrix meretrix* from the Moheshkali Island in the Cox's Bazar coast of Bangladesh. **Asian Fisheries Science** 22: 1031–1043.
- Beliku, J. and E. Saleh. 2013. Threats of fishing gears on turtles in proposed Tun Mustapha Park, Kudat, Sabah. **Borneo Science** 33: 31–39.
- Beverton, R.J.H. and S.J. Holt. 1993. **On the Dynamics of Exploited Fish Populations**. Chapman & Hall, London. 535 pp.
- Chowdhury, J., M.S.I. Sarkar, M.A.A. Khan and M.S. Bhuyan. 2019. Biochemical composition of *Meretrix meretrix* in Bakkhali river Estuary, Cox's Bazar, Bangladesh. **Annals of Marine Science** 3(1): 18–24.
- Davenport, J. and X. Chen. 1987. A comparison of methods for the assessment of condition in the mussel (*Mytilus edulis* L.). **Journal of Molluscan Studies** 53: 293–297. DOI: 10.1093/mollus/53.3.293.
- Department of Fisheries Malaysia. 2018. **Perangkaan Tahunan Perikanan 2018-Import/Eksport Jilid 2**. <https://www.dof.gov.my/index.php/pages/view/4071>. Cited 21 Mar 2021.
- Dolorosa, R.G. and F. Dangan-Galon. 2014. Population dynamics of the mangrove clam *Polymesoda erosa* (Bivalvia: Corbiculidae) in Iwahig, Palawan, Philippines. **International Journal of Fauna and Biological Studies** 1(16): 11–15.
- Food and Agriculture Organization of the United Nations (FAO). 2019. **FAO Year Book. Fishery and Aquaculture Statistic 2017**. FAO, Rome. 80 pp.
- Gosling, E. 2003. **Bivalve Molluscs: Biology, Ecology and Culture**. Blackwell Science, Oxford. 443 pp.
- Groeneveld, R.A. and G. Meeden. 1984. Measuring skewness and kurtosis. **The Statistician** 33: 391–399.
- Gulland, J.A. 1965. Survival of the youngest stages of fish and its relation to year-class strength. **NAFO Special Publication** 6: 365–371.
- Gulland, J.A. 1983. **Fish Stock Assessment. A Manual of Basic Method**. FAO/Wiley Series on Food and Agriculture, Rome. 241 pp.

- Hamli, H., M.H. Idris, A.H. Rajae and A.H.M. Kamal. 2015. Reproductive cycle of hard clam, *Meretrix lyrata* Sowerby, 1851 (Bivalvia: Veneridae) from Sarawak, Malaysia. **Tropical Life Sciences Research** 26(2): 59–72.
- Hamli, H., M.H. Idris, A.H. Rajae, A.H.M. Kamal and M. N. Hoque. 2017. Condition index of *Meretrix lyrata* (Sowerby 1851) and its relationship with water parameter in Sarawak. **Sains Malaysiana** 46(4): 545–551.
- Huang, J., M. Chou, J. Lee and Y. Cheng. 2016. Effects of culture area, stocking density, and shrimp and fish polyculture on the cost efficiency of hard clam, *Meretrix meretrix*, culture: A case study of hard clam farms in Yunlin, Taiwan. **Journal of the World Aquaculture Society** 47(4): 481–495. DOI: 10.1111/jwas.12289.
- Isham, L.D., H.B. Moore and F.G.W. Smith. 1951. Growth rate measurement of shipworms. **Bulletin of Marine Sciences of the Gulf and Caribbean** 1(2): 136–147.
- Jayabal, R. and M. Kalyani. 1987. Reproductive cycle of the estuarine bivalve *Meretrix meretrix* (Linn) of the Vellar Estuary. **Indian Journal of Fisheries** 34(2): 229–232.
- Jayawickrema, E.M. and M.J.S. Wijeyaratne. 2009. Distribution and population dynamics of the edible bivalve species *Meretrix casta* (Chemnitz) in the Dutch canal of Sri Lanka. **Sri Lanka Journal of Aquatic Sciences** 14: 29–44.
- Joshi, M.C. and D.V. Bal. 1965. Observations on the chemical composition of the clam *Katelysia marmorata* Lamarck. **Journal of the Zoological Society of India** 17 (1–2): 108–113.
- Lagade, V.M. and D. Muley. 2014. Effect of short term temperature on physiological body indices of two estuarine Venerid clams *Katelysia opima* and *Meretrix meretrix* (Mollusca: Bivalvia). **Journal of Ecophysiology and Occupational Health** 14(3&4): 167–174. DOI: 10.18311/joeh/2014/1661.
- Le Cren, E.D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the Perch (*Perca fluviatilis*). **Journal of Animal Ecology** 20(2): 201–219.
- Li, Y., J.G. Qin, X. Li and K. Benkendorff. 2009. Monthly variation of condition index, energy reserves and antibacterial activity in Pacific oysters, *Crassostrea gigas*, in Stansbury (South Australia). **Aquaculture** 286: 64–71. DOI: 10.1016/j.aquaculture.2008.09.004.
- Liu, B., B. Dong, B. Tang, T. Zhang and J. Xiang. 2006. Effect of stocking density on growth, settlement and survival of clam larvae, *Meretrix meretrix*. **Aquaculture** 258: 344–349. DOI: 10.1016/j.aquaculture.2006.03.047.
- Mohd Hamdan, D.D., L. Udin, F. Musa and R. Tair. 2020. Consumption of *Meretrix meretrix* (Linnaeus 1758) by selective shell size reduces heavy metal toxicity risk and overfishing in Tawau, North Borneo. **Environmental Quality Management** 29 (4): 15–22.
- Mohd Hamdan, D.D., L. Udin, R. Tair and M.H. Adnan. 2017. Communication gap of heavy metals knowledge among community in Batu Payung, Tawau and its impact on food safety, security and livelihood sustainability. **Jurnal Komunikasi Borneo Edisi Khas** 3(1): 1–25.
- Moschino, V., M. Depieri and M.G. Marin. 2003. Evaluation of shell damage to the clam *Chamelea gallina* captured by hydraulic dredging in the Northern Adriatic Sea. **ICES Journal of Marine Science** 60: 393–401. DOI: 10.1016/S1054-3139(03)00014-6.
- Narasimham, K.A., P. Muthiah, D. Sundararajan and N. Vaithinathan. 1988. Biology of the great clam *Meretrix meretrix* (Linnaeus) in the Korampallam creek, Tuticorin. **Indian Journal of Fisheries** 35(4): 288–293.

- Newman, S.J. 2002. Growth, age estimation and preliminary estimates of longevity and mortality in the Moses perch, *Lutjanus russelli* (Indian Ocean form), from continental shelf waters off North-Western Australia. **Asian Fisheries Science** 15: 283–294.
- Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. **ICES Journal of Marine Science** 39(2): 175–192.
- Pauly, D. 1984. **Fish Population Dynamics in Tropical Waters: A Manual for use with Programmable Calculators**. ICLARM Studies and Reviews 8, Manila. 325 pp.
- Pauly, D. 1986. On improving operation and use of the ELEFAN programs. Part III. Correcting length-frequency data for the effects of gear selection and/or incomplete recruitment. **Fishbyte** 4: 11–13.
- Pauly, D. and J.L. Munro. 1984. Once more on the comparison of growth in fish and invertebrates. **Fishbyte** 21(1): 1–21.
- Pauly, D. and N. David. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. **Meeresforschung** 28(4): 205–211.
- Peharda, M., I. Mladineo, J. Bolotin, L. Kekez and B. Skaramuca. 2006. The reproductive cycle and potential protandric development of the Noah's Ark shell, *Arca noae* L.: Implications for aquaculture. **Aquaculture** 252: 317–327. DOI: 10.1016/j.aquaculture.2005.07.007.
- Rahim, A.A., M.H. Idris, A.H.M. Kamal, S.K. Wong and A. Arshad. 2012. Analysis of condition index in *Polymesoda expansa* (Mousson 1849). **Pakistan Journal of Biological Sciences** 15(13): 629–634. DOI: 10.3923/pjbs.2012.629.634.
- Rai, H.S. 1932. The shell fisheries of the Bombay Presidency. **Journal of Bombay Natural History Society** 35: 826–847.
- Ramesha, M.M. and S. Thippeswamy. 2009. Allometry and condition index in the freshwater bivalve *Parreysia corrugata* (Muller) from river Kempuhole, India. **Asian Fisheries Science** 22: 203–214. DOI: 10.33997/j.afs.2009.22.1.019.
- Ransangan, J. and K.S. Tan. 2018. Occurrence and distribution of marsh clam, *Polymesoda* spp. in Marudu Bay, Sabah, Malaysia. **Open Journal of Marine Science** 8: 314–322. DOI: 10.4236/ojms.2018.82017.
- Sahin, C., E. Düzgünes and I. Okumus. 2006. Seasonal variations in condition index and gonadal development of the introduced blood cockle *Anadara inaequalis* (Bruguere, 1789) in the Southeastern Black Sea Coast. **Turkish Journal of Fisheries and Aquatic Sciences** 6: 155–163.
- Said, H.M. 2011. Promoting community based tourism in Bajau Laut community in kampung Pulau Gaya, Sabah [Promoting community based tourism in Sea Gypsy community in Pulau Gaya Village, Sabah]. **Universiti Tun Abdul Razal E-Journal** 7(2): 46–57.
- Sawant, P.P. and S.A. Mohite. 2013. Length frequency analysis of the great clam, *Meretrix meretrix* along south west coast of Maharashtra, India. **Discovery** 4(10): 19–21.
- Sivashanthini, K. 2009. Population dynamics of a whip-fin silver biddy, *Gerres filamentosus* Cuvier, 1829 from the Parangipettai Waters, southeast coast of India. **Asian Fisheries Science** 22(4): 1149–1162.
- Sparre, P. and S.C. Venema. 1992. **Introduction to Tropical Fish Stock Assessment, Part 1. Manual**. FAO Fisheries Technical Paper 306/1. Food and Agriculture Organization of the United Nations, Rome, Italy. 376 pp.
- Tan, K.S., D.J. Denil and J. Ransangan. 2016. High mortality and poor growth of green mussels, *Perna viridis*, in high chlorophyll-*a* environment. **Ocean Science Journal** 51(1): 43–57.

- Tan, K.S., F.S. Ong, D.J. Denil and J. Ransangan. 2017. Distribution and fishing pressure of hard clam, *Meretrix meretrix* in Marudu Bay, Sabah. **International Journal of Oceans and Oceanography** 11(2): 265–276.
- Tan, K.S. and J. Ransangan. 2016. Feasibility of green mussel, *Perna viridis* farming in Marudu Bay, Malaysia. **Aquaculture Reports** 4: 130–135. DOI: 10.1016/j.aqrep.2016.06.006.
- Tan, K.S. and J. Ransangan. 2019. Dredging-induced shell damages to hard clam (*Meretrix meretrix*): A Malaysian case study. **Aquatic Living Resources** 32(1): 1–7. DOI: 10.1051/alr/2018025.
- Tang, B., B. Liu, G. Wang, T. Zhang and J. Xiang. 2006. Effects of various algal diets and starvation on larval growth and survival of *Meretrix meretrix*. **Aquaculture** 254: 526–533. DOI: 10.1016/j.aquaculture.2005.11.012.
- Urban, H.J. 2001. Reproductive strategies in tropical bivalves (*Pteria colymbus*, *Pinctada imbricata*, and *Pinna carnea*): Temporal coupling of gonad production and spat abundance related to environmental variability. **Journal of Shellfish Research** 20: 1127–1134.
- Zakaria, M. and M.N. Rajpar. 2015. Assessing the fauna diversity of Marudu Bay mangrove forest, Sabah, Malaysia, for future conservation. **Diversity** 7: 137–148. DOI: 10.3390/d7020137.