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POPULATION DYNAMICS OF MANGROVE CLAM, *Geloina expansa* (MOUSSON, 1849) (MOLLUSCA, BIVALVIA) IN A MALAYSIAN MANGROVE SYSTEM OF SOUTH CHINA SEA

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Abstract: Mangrove clam, *Geloina expansa* is a common harvested resource in the Malaysian mangroves. Although the local communities extensively collect the species throughout the year, information on the population dynamics of the species in Malaysia is limited. Population dynamics study is essential to help in adequate stock management during potential future commercial exploitation. The population dynamics of *G. expansa* from Setiu Wetlands were determined by shell length and wet weight for 18 months (from January 2016 to June 2017). The estimated growth parameters using von Bertalanffy growth equation were; $L\infty = 76.1$ mm and $K = 0.7$ year^{-1}. The total mortality *(Z)* rates were expected to be 2.1 year^{-1}. The fishing mortality *(F)* rates (1.0 year^{-1}) are almost similar to natural mortality *(M)* rates (1.1 year^{-1}), whilst observed exploitation *(E)* rates (0.5 year^{-1}), fall under optimised position in the stock with exploitation rates of $E_{max} = 0.5$. Therefore, there is a need to regulate rules such as time limit, legal harvesting size and licence implementation of this organism to avoid population from declining. This study suggests possible step to be taken to ensure the sustainability of *G. expansa* to thrive in the future.

KEYWORDS: Benthic invertebrates, *Geloina expansa,* growth, mangrove clam, Malaysia, Setiu Wetlands

Introduction

Mangrove forests consist of salt-tolerant plants, mainly distributed between latitudes 30°N and 30oS along intertidal coasts or estuaries in the tropical and subtropical regions (Kathiresan & Bingham, 2001; Giri *et al.,* 2011). Mangrove forests have ecological importance to the ecosystems and economic significance to the local communities. They are essential to stabilise and protect shorelines from erosion as the root system of the trees helps in reducing current velocities and hold the sediments (Selvam & Karunagaran, 2004). The sediments create habitat for benthic invertebrates and spaces between the roots provide shelter and nursery ground for juvenile fish and invertebrate species (Nagelkerken *et al.,* 2008; Saenger *et al.,* 2013). Mangrove forests provide habitat for birds, insects, mammals and reptiles (Nagelkerken *et al.,* 2008) which make them among the highly biodiversity ecosystems in the world covering marine, freshwater and terrestrial species (Aksornkoae, 2012; Suresh *et al.,* 2012). Among the animal found in this ecosystem include commercial fisheries species such as fish, prawns, crabs and shellfish (Sasekumar & Chong, 1998).

Mangrove clam, *Geloina expansa* (Mousson, 1849) (Figure 1) is among the common shellfish found in the mangrove forests and widely distributed in the Indo-West Pacific region covering from India (west), Vanuatu (east), Vietnam (north) to Queensland (south) (Poutiers, 1998). *G. expansa* is also known as *Geloina erosa* auct. non Lightfoot (as in Printrakoon *et al.,* 2008; Stephen *et al.,* 2008; Sanpanich, 2011; Saroeng & Razali, 2013; Peralta & Serrano, 2014; Sarong *et al.,* 2015), *Polymesoda expansa* (Mousson, 1849) (as in Hamli et al., 2012; Rahim *et al.,* 2012; Idris *et al.,* 2017; Ong *et al.,* 2017) and *Polymesoda erosa* (Lightfoot, 1786) (as in Morton, 1976; Morton, 1985; Gimin *et al.,* 2004; 2006; Hartati *et al.,* 2005; Clemente & Ingole, 2009a; 2009b;

Edward *et al.,* 2009; Nuryanto & Susanto, 2010; Suryono, 2012; Hamli *et al.,* 2012; Nuryanto & Sastranegara, 2013; Argente *et al.,* 2014; Dolorosa & Dangan-Galon, 2014; Yap *et al.,* 2014). This species is reported to be highly tolerant; survive in the wide range of salinities and inhabits muddy, brackish and almost freshwater areas of mangrove swamps (Morton, 1976). It is a filter feeder which can remove particles from water current by bio-filter mechanism accomplished by the gills (Ruppert & Barnes, 1994).

Geloina expansa has been regularly harvested in the commercial fishery industries in India, northern Australia, the Philippines and East Malaysia due to its high protein content and it is considered a delicacy in some communities (Gimin *et al.,* 2004; Clemente & Ingole, 2009a; Hamli *et al.,* 2012; Argente *et al.,* 2014; Sarong *et al.,* 2015). This species has been used as bioindicator species to monitor heavy metals pollution in Malaysia's water because of its filter feeding behaviour (Edward *et al.,* 2009). Due to its ecologically and economically important, previous studies of this species were focusing on the ecology (Gimin, 2006), distribution (Printrakoon *et al.,* 2008), population genetic (Nuryanto & Susanto, 2010), reproduction (Morton, 1985; Hartati *et al.,* 2005; Clemente & Ingole, 2009a; Saroeng & Razali, 2013; Sarong *et al.,* 2015), heavy metal accumulation (Edward *et al.,* 2009; Yap *et al.,* 2014; Ong *et al.,* 2017), status of polycyclic aromatic hydrocarbons level (Peralta & Serrano, 2014), filtration rate (Argente *et al.,* 2014) and stable isotopes (Stephens *et al.,* 2008), but study on the population dynamics is poorly known.

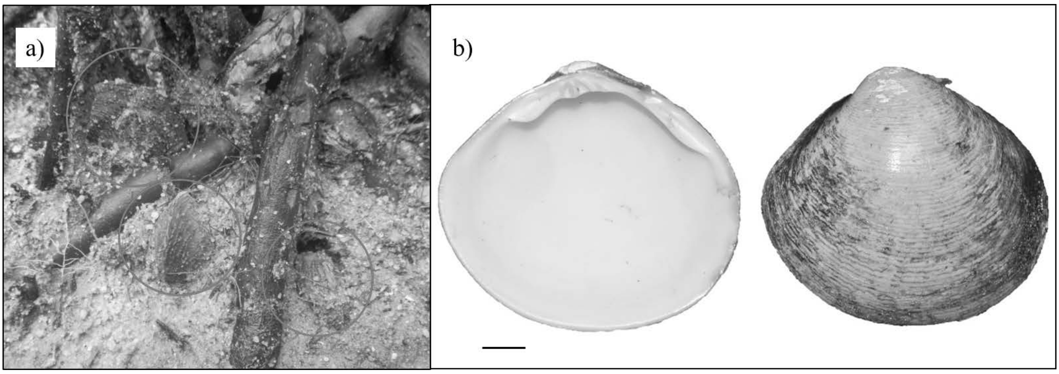

Figure 1: *Geloina expansa* found in mangrove forests of Setiu Wetlands, Terengganu. a) *G. expansa* at the natural habitat of mangrove forest, b) The shells of *G. expansa* (scale bar = 10 mm).

A part of population dynamics studies are determining the age and growth rate of organisms (Gosling, 2003). There are few common methods been described to estimate age and growth rate of molluscs such as study of annual growth rings on the external surfaces of shells, determining micro growth bands in the inner shell layer and mark-recapture experiments (Mirzaei *et al.,* 2015). However, common method used to determine growth rate is using length frequency of clams over a time. From the length frequency data, statistical programme by FAO-ICLARM Stock Assessment Tools (FiSAT) can be used to estimate growth rate parameters including growth, longevity, mortality and exploitation status (Amin *et al.,* 2005; Al-Barwani *et al.,* 2007). Growth rate information is important in understanding the population dynamics as the data are crucial to help in adequate stock management during potential future commercial exploitation (Lomovasky *et al.,* 2005). Therefore, this study is aimed to determine the allometric (length-weight relationship) and population dynamics of *G. expansa* in mangrove forests of Setiu Wetlands, Terengganu, a Malaysian mangrove system of South China Sea.

Materials and methods

Study Area

Setiu Wetlands is a natural wetland located in the northeast of Terengganu in Setiu district, east coast of Peninsular Malaysia (Alipiah *et al.,* 2018). This wetlands' area covered approximately 880 ha and about 22 km long from Kampung (village) Penarik to Kampung Beting Lintang. Salinity changes in the area are influenced by estuary opening facing the South China Sea and freshwater inlet from Sungai Setiu (river) and Sungai Chalok. Collection sites were located at approximately 5°41'N and 102°43'E (Figure 2). Mangrove vegetation such as *Rhizophora apiculata, Avicennia* spp., *Sonneratia* spp., *Bruguiera* spp. and *Nypa fruticans* can be found around the study area.

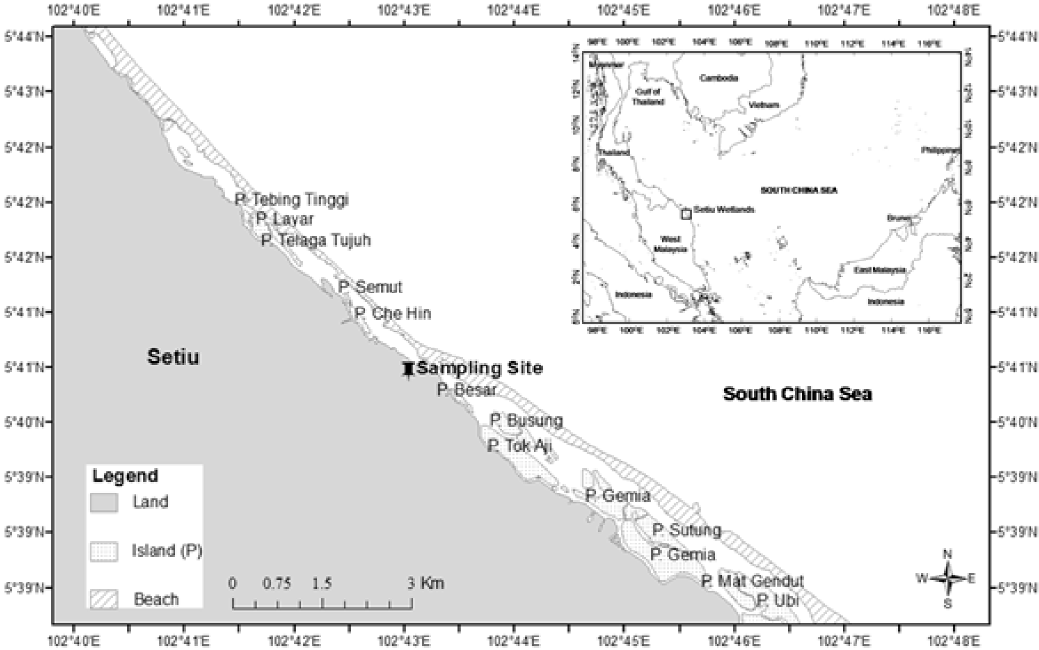

Figure 2: Sampling site at the mangrove forests of Setiu Wetlands, Terengganu.

Field and Laboratory Procedures

Various sizes of 150 to 200 individuals of *G. expansa* were randomly hand-picked monthly from January 2016 to June 2017 (Degraer *et al.,* 2007). Samples were left overnight in an aquarium filled with filtered seawater to clean their guts or mantle cavities from sediment particles. Shell length of each individual was measured to the nearest 0.01 mm (the longest anterior-posterior distance of the shell) using digital vernier caliper (Mitutoyo) and grouped into 5 mm size classes (Figure 3). Total weight was measured using an analytical balance (Sartorius CP224S) of 0.001 g accuracy.

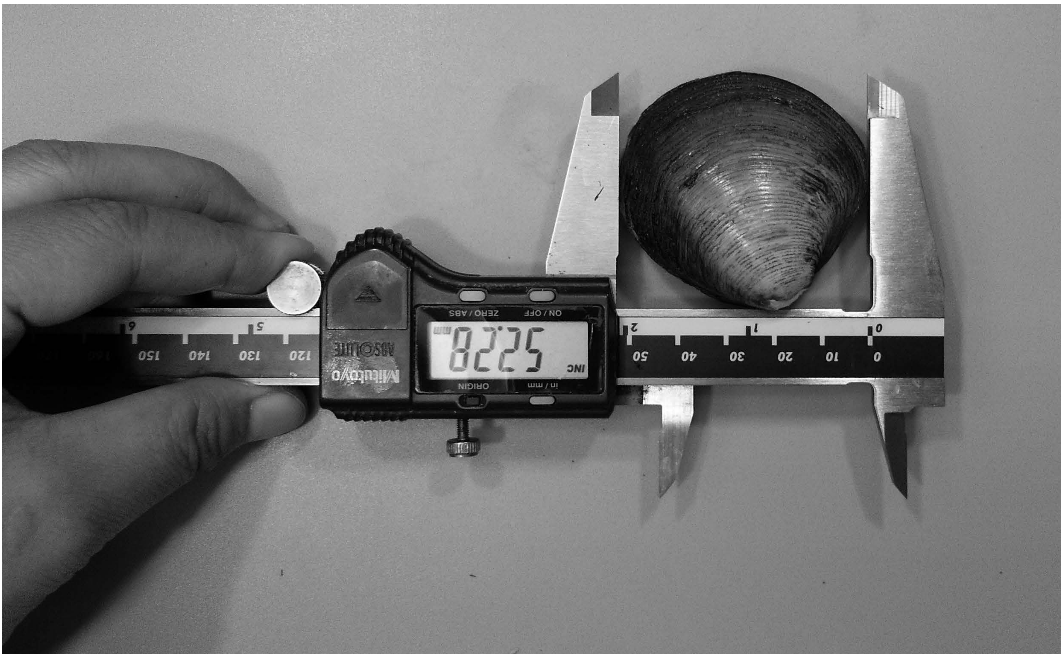

Figure 3: Shell length measurement a using digital vernier caliper to the nearest 0.01 mm (the longest anterior-posterior distance of the shell)

Data Analysis

Length-weight relationship was estimated using allometric equation $W = aL^b$ (Ricker, 1975), where W is the weight (g), L is the total length (mm), *'a'* is the intercept (initial growth coefficient) and *'b'* is the slope and relative growth rates of the variables. The *'a'* and *'b'* parameters were calculated using regression analysis of log-log transformed data as below:

$$\log_{10} W = \log_{10} a + b \log_{10} L$$

Monthly data on length frequency of *G. expansa* was grouped into 5 mm size classes to determine population parameters (e.g. mortality, growth coefficient and recruitment) using FAO-ICLAM stock assessment tool (FiSAT II) (Gayanilo *et al.,* 2005). The advantage of using FiSAT II is the accessibility of bivalves stock that can be estimated using a year length frequency information (Al-Barwani *et al.,* 2007).

The von Bertalanffy Growth Function (VBGF) equation was fitted to calculate the length-at-age curve by using the non-linear squares estimation method (Pauly *et al.,* 1992). The annual growth rates of the bivalve were fitted to the von Bertalanffy growth equation as below:

$$L_t = -(L_\infty - L_0)\, e^{-kt}$$

where L_t is the length at age t, L_0 is a constant and represents length at age 0, L_∞ is the asymptotic length and K is the growth coefficient (year^{-1}) at which growth approaches the asymptotic length.

The L_∞ value was then inserted in the ELEFAN-1 routine (Gayanilo *et al.,* 1989; 2005) to scan K values with variable starting points (i.e. starting length and starting sample). These values were used as inputs in the ELEFAN-1 routine to produce a curve of the normal and restructured length frequency graphs. The growth performance index *(ϕ')* is a length-based index of growth that shows the interaction of K and L_∞ and is important for the evaluation within similar species. The growth performance index ϕ' was determined using the formula as below:

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

where K is the growth coefficient of the VBGF and $L\infty$ is the asymptotic length.

Recruitment is defined as successful colonization of the substrates by bivalves and implies the passage of time with survival and post-settlement mortality (Seed & Suchanek, 1992). The Hasselblad's NORMSEP (Pauly, 1986) method was used to estimate normal distributions to produce peaks for the recruitment patterns. However, in this model two assumptions are considered: 1) that all animals in a given set of data grow by a single set of growth parameters; and 2) that recruitment occurs in 11 months only (Gayanilo *et al.,* 1989).

Longevity (t_{max}) of the species was obtained using as below:

$$t_{max} = 3 / K$$

where K is the growth coefficient of the von Bertalanffy growth formula.

Length-converted catch curve (Pauly, 1984) in FISAT II was used to estimate total mortality *(Z),* natural mortality *(M)*, fisheries mortality *(F)* and exploitation rate *(E)*. The calculation was based on the $L\infty$ and K from the VBGF data and average temperature during sampling (29.6 °C). The exploitation rate *(E)* is the portion of total mortality, calculated by the equation as below:

$$E = F / Z.$$

Results

A total of 2,977 individuals of *G. expansa* were collected throughout the sampling period. Length of individuals ranged from 10.5 to 72.5 mm and weighed from 0.25 to 92.87 g. The allometric relationship of *G. expansa* is expressed in Figure 4. The calculated length-weight equation was $\log_{10} W = -4.0734 + 3.1987 \log_{10} L$, in exponential form the equation is $W = 0.00008L^{3.1987}$ ($R^2 = 0.958$, $p < 0.05$). The computed growth coefficient *(b)* was 3.1987. The exponential form was formed into a linear regression to obtain the allometric relationship equation, $y = 3.1987x - 4.0734$, $R^2 = 0.958$. Table 1 shows the allometric relationship of *G. expansa* for each month. The *b* values ranged from 2.7832 to 3.5235 at 95% confidence limit.

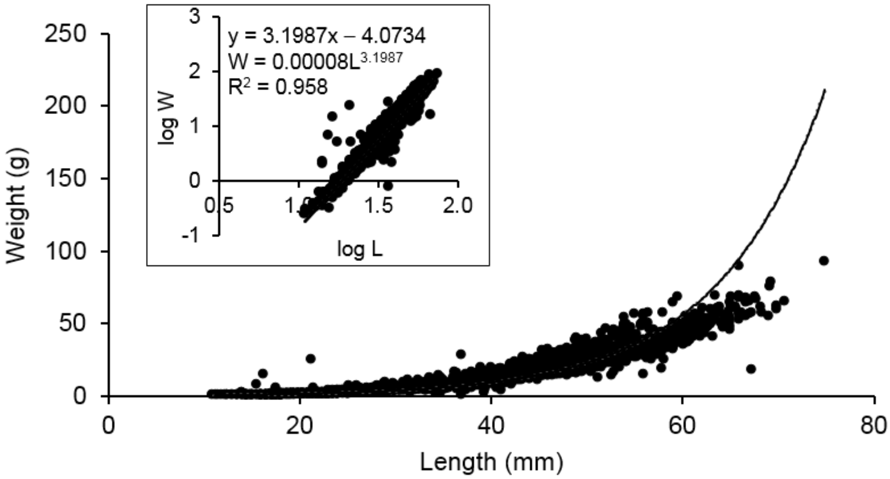

Figure 4: Allometric relationship of *Geloina expansa* collected in the mangrove forests of Setiu Wetlands, Terengganu. Inset shows the natural logarithms ($\log_{10}$) of allometric relationship of *G. expansa.*

Table 1: Result of allometric relationships for *Geloina expansa* from January 2016 to June 2017 (18 months of sampling period).

Date	**R2**	**Log10 W = log10 a + b log10 L**		**Intercept (a)**	**Equation**
		(W = aLb)	**Slope (b)**		
January 2016	0.9194	-3.6667	2.9434	0.00022	W = 0.00022L2.9434
February 2016	0.9679	-4.5262	3.5235	0.00003	W = 0.00003L3.5235
March 2016	0.6123	-3.3995	2.7832	0.00040	W = 0.00040L2.7832
April 2016	0.9745	-3.8924	3.1965	0.00013	W = 0.00013L3.1965
May 2016	0.9789	-4.4214	3.3970	0.00004	W = 0.00004L3.3970
June 2016	0.9638	-3.9663	3.1199	0.00011	W = 0.00011L3.1199
July 2016	0.9654	-4.3991	3.3905	0.00004	W = 0.00004L3.3905
August 2016	0.8923	-3.9448	3.0903	0.00011	W = 0.00011L3.0903
September 2016	0.9840	-4.4048	3.3917	0.00004	W = 0.00004L3.3917
October 2016	0.9453	-3.9968	3.1246	0.00010	W = 0.00010L3.1246
November 2016	0.9474	-4.0158	3.1401	0.00010	W = 0.00010L3.1401
December 2016	0.9194	-3.8536	3.0601	0.00014	W = 0.00014L3.0601
January 2017	0.9896	-3.8996	3.0872	0.00013	W = 0.00013L3.0872
February 2017	0.9683	-3.9938	3.1439	0.00010	W = 0.00010L3.1439
March 2017	0.9910	-4.0717	3.1967	0.00008	W = 0.00008L3.1967
April 2017	0.9928	-4.1203	3.2210	0.00008	W = 0.00008L3.2210
May 2017	0.9901	-4.2143	3.2820	0.00006	W = 0.00006L3.2820
June 2017	0.9835	-4.0930	3.2083	0.00008	W = 0.00008L3.2083

Asymptotic length ($L\infty$) of the VBGF was 76.1 mm and growth coefficient (K) was 0.7 year^{-1}. Monthly length-frequency distribution is shown in Figure 5. Observed maximum length was 72.5 mm and predicted maximum length was 73.6 mm with 95% confidence interval between 70.7 to 76.5 mm (Figure 6). Best-estimated value of K was 0.7 year^{-1} and the growth performance index ϕ' was 3.6 (Figure 7).

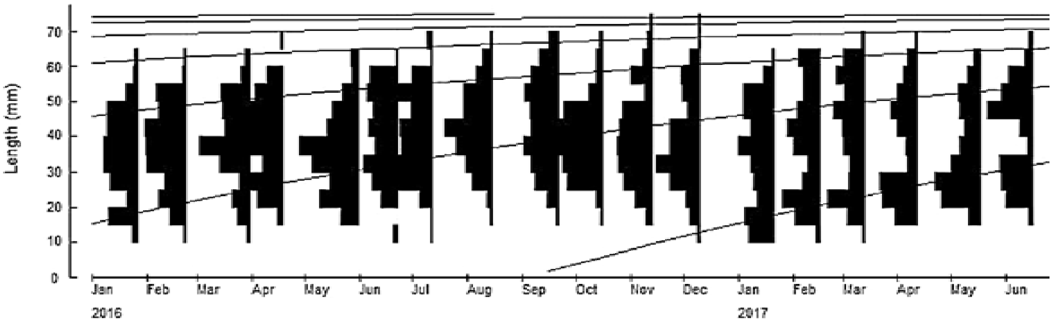

Figure 5: Length frequency distribution of *Geloina expansa* from January 2016 to June 2017.

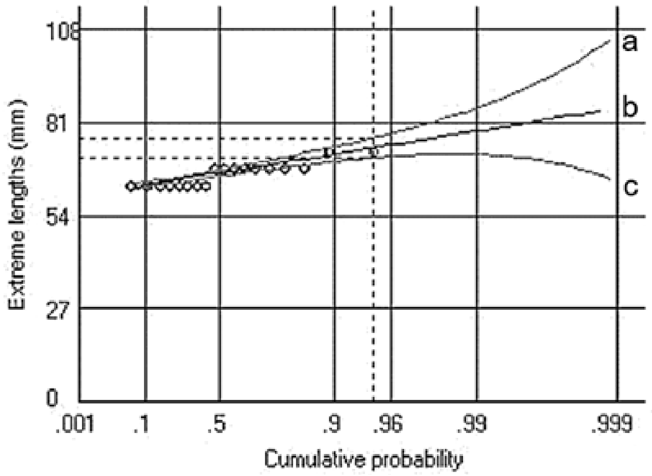

Figure 6: Estimation of maximum length of *Geloina expansa* and 95% confidence interval obtained from the intersection of overall maximum length with lines *b* and *a, c* respectively.

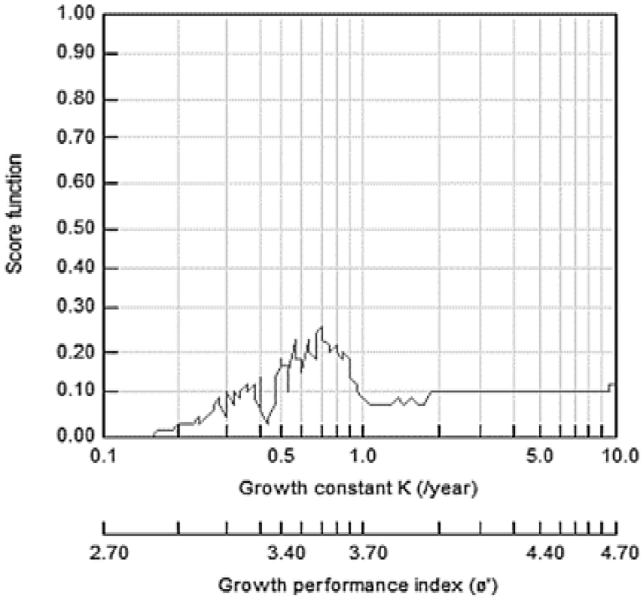

Figure 7: *K*-scan routine for determining the best growth curvature which gives the best value of asymptotic length with growth performance indices of *Geloina expansa.*

Length-converted catch curve analysis computed total mortality, natural mortality, fishing mortality and exploitation rate is shown in Figure 8. The total mortality *(Z)* was 2.1 year^{-1}, natural mortality *(M)* was 1.1 year^{-1}, fishing mortality *(F)* was 1.0 year^{-1} and exploitation level *(E)* was 0.47. Longevity ($t_{max} = 3 / K$) of the species is estimated to be 4.3 years. The recruitment pattern of *G. expansa* was continuous throughout the year with a major peak occurred from July to August 2016 (Figure 9).

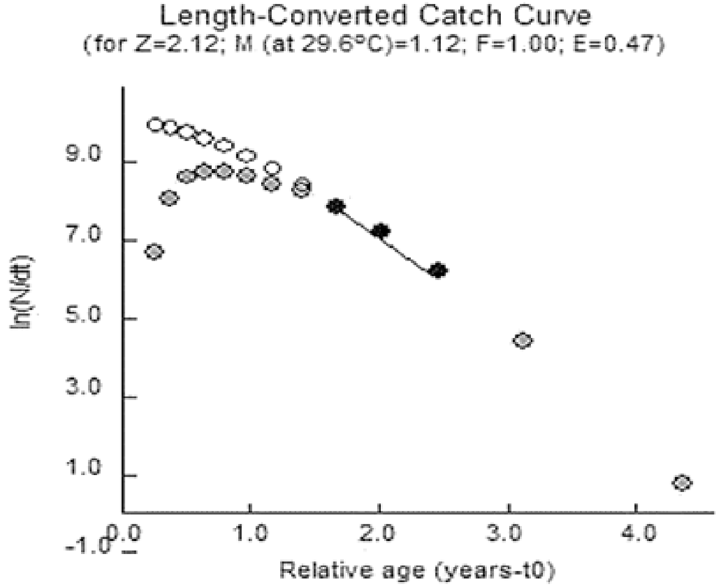

Figure 8: Length-converted catch curve of *Geloina expansa* based on pooled monthly length-frequency data samples (from January 2016 to June 2017) and calculated with the ELEFAN II program. Solid symbols: used for the calculation of Z (mortality); grey and open symbols: excluded from calculation. Linear regression equation and estimated *Z*-values are given.

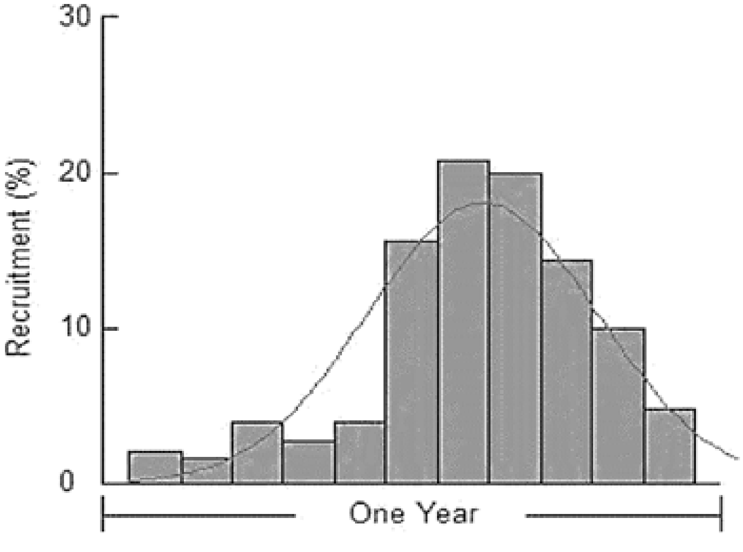

Figure 9: Monthly recruitment pattern of *Geloina expansa.* The histogram shown relative percentage of recruits per month whilst bell-shaped curves show the one recruitment peak

Discussion

Most studies on population dynamics in Malaysia focus on the commercial and domesticated bivalves such as cockles (Mirzaei *et al.,* 2015) and mussels (Al-Barwani *et al.,* 2007). Cockles are widely used in aquaculture activities due to its fast growth rate, continuous reproduction throughout the year, high population abundance and high level of tolerance to many environmental parameters (Prakoon *et al.,* 2010; Mirzaei *et al.,* 2015). Mussels and cockles have dominated the global bivalve trade as Malaysia supplies to Thailand for reprocessing (canned) and to Singapore for local consumption (Pawiro, 2010). Information on the population dynamics of mangrove clams especially in Malaysia is limited because these clams are not domesticated as compared to mussels and cockles. Most related study on *G. expansa* in Southeast Asia region was conducted by Dolorosa and Dangan-Galon (2014) in the Philippines. Dolorosa and Dangan-Galon (2014) recorded higher observed (102.0 mm) and predicted extreme length (102.1 mm) as compared to this study which recorded 72.5 mm observed maximum length and 73.6 mm predicted maximum length. Additionally, the asymptotic length *($L\infty$)* of the VBGF and the growth coefficient *(K)* in was higher (107.1 mm & 1.0 year^{-1}) as compared to this study that has 76.1 mm and 0.7 year^{-1} respectively. Poutiers (1998) stated that maximum length of *G. expansa* in the wild is 100.0 mm, while 70.0 mm is a common length. Additionally, recent studies by Clemente and Ingole (2009b) has found length size varies from 1.5 to 102.0 mm, with a majority of 70.0 to 80.0 mm. Variation in sizes of *G. expansa* are varied between different regions, different patches of mangroves or environmental factors such as salinity, pH and sediment characteristics that possibly affect growth (Dolorosa & Dangan-Galon, 2014).

Mortality of bivalves is caused by a few factors such as extreme temperature and salinity, predation, disease and fishing (Gosling, 2003). *G. expansa* in the Philippines were found to have total mortality (3.7 year^{-1}), natural mortality (1.4 year^{-1}) and fishing mortality (2.3 year^{-1}) (Dolorosa & Dangan-Galon, 2014); all of which were higher compared to the finding of the present study. Gulland (1965) stated that the yield is optimised when fishing mortality is equal to natural mortality *($F = M$)*; thus when *E* is equal to 0.5. When exploitation level *(E)* is more than 0.5, the fisheries resource is classified as over-fished or over-exploited (Gulland, 1965). However, the natural mortality (1.1 year^{-1}) in this study was slightly equal to the fishing mortality (1.0 year^{-1}) and the exploitation level was 0.5, indicating an optimised position in the stock (Al-Barwani *et al.,* 2007). Dolorosa and Dangan-Galon (2014) categorised the population status under over-exploited in the Philippines as the exploitation level was 0.62 and Idris *et al.* (2017) stated that the *G. expansa* in Sarawak waters are over-exploited by the local communities. As *G. expansa* is categorised as least concern species in the IUCN Red List of Threatened Species (Rintelen, 2011), therefore, to date no specific guideline or regulation on harvesting this species is available. Generally, countries such as Australia, New Zealand and United States applied recreational regulation on recreational shellfish harvesting which stated minimum size limit and daily bag size limit per person or per vessel allowed to collect clams, oysters, mussels and scallops (DEC, 2018; DPIPWE, 2018; FWC, 2018; MPI, 2018; WDFW, 2018). The minimum size limit ranged from 30 to 100 mm varied between countries and between groups of bivalves. However, DOF (2018) in Regulation Fisheries (Conservation and Cultured Shellfish) 2002 only restricted to cockles (*Anadara granosa, Anadara ovalis* & *Barbati* sp.). This regulation prohibits against harvesting this species before maturity, a time limit for taking cockle's seeds and adults from a natural bed and licence implementation for cockle collectors. Besides, The Fisheries (Control of Endangered Species of Fish) Regulation 1999 protected *Tridacna gigas, T. squamosa, T. maxima* and *T. crocea,* while any Malaysia regulations do not protect other bivalves. Similar action should be taken to protect the population of *G. expansa* from declining since it is not successfully cultured in Malaysia.

In the present study, the estimated longevity of this species as 4.3 years. This result is similar to the lifespan of *G. expansa* in India, which was estimated to be 4.0 years (Clemente & Ingole, 2009b), and was longer than the 3.0 years estimated for the species in the Philippines (Dolorosa & Dangan-Galon, 2014). Overall, the results provide further support that *G. expansa* is a long-lived species compared to 2.7 years for blood cockle, Anadara granosa (Mirzaei *et al.,* 2015) and 2.0 years for green mussel, Perna viridis (Al-Barwani *et al.,* 2007).

The recruitment pattern of *G. expansa* found in this study suggested that annual recruitment consisted of one seasonal peak where the highest recruitment peaks occurred in July (20.71%) and August (19.95%) which occurred during the southwest monsoon. This finding was similar to studies by Dolorosa and Dangan-Galon (2014) in the Philippines (April & September) and Clemente and Ingole (2009a) in India (August) which the recruitment period occurred during the southwest monsoon. In contrast, studies by Rahim *et al.* (2012) and Idris *et al.* (2017) in East Malaysia determined the recruitment occurred from the end of southwest monsoon to northeast monsoon (from September to December). Major recruitment peak can indicate major spawning season for *G. expansa.*

Conclusion

This study has highlighted that population of *G. expansa* in Setiu Wetlands is categorised as optimised in the stock. Even though the status has not fallen to over-exploitation, however, this could be an alarm for local fishermen and community to take action towards sustainable harvesting. Further studies on the population dynamics of this species should be expanded to other parts of West Malaysia and East Malaysia for comparison with this study. The finding could provide baseline information in finding effort for the conservation of this mangrove clam and for the population to thrive in the future.

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