Thesis for the Degree of Master of Fisheries Science

Growth, Age Structure and Population Parameters of Pink Sea Cucumber (*Holothuria edulis*) in Tioman Island, Pahang, Peninsular Malaysia

by

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(말레이시아 Tioman섬에 분포하는 분홍 해삼 (*Holothuria edulis*)의 성장, 연령, 구조 및 개체군 매개 변수)

Advisor: Prof. Dr. Md. Aminur Rahman

by

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Abstract

The pink sea cucumber (*Holothuria edulis*) is one of the important tropical Holothurian, which occurs abundantly in the Indo-Pacific region including Tioman Island, Peninsular Malaysia. A field study was carried out for one year between March 2016 and February 2017, and the length-weight data of *H. edulis* was taken through monthly samplings, measured accordingly and analyzed using the FiSAT II (FAO-ICLARM) software. Mean total length and total weight of the population was calculated as 26.92 cm and 22.28 g, respectively. The Von Bertalanffy growth parameters such as asymptotic length (L_∞) and coefficient of growth (K) and age were estimated to be 47.78 cm, 1.00 yr^{-1} and 3 yrs, respectively. The length-weight relationship of the population was established as $W = 0.810L^{1.8}$ ($R^2 = 0.812$). The growth of the *H. edulis* was negatively allometric ($b<3$) as revealed from the length-weight relationship. The estimated total mortality (Z), natural mortality (M) and fishing mortality (F) were 2.81 yr^{-1}, 1.54 yr^{-1} and 1.27 yr^{-1} in that order.

The result demonstrated that the fishery was underexploited as the present exploitation rate, E = 0.45, which was less than the optimum exploitation rate, E_{opt} = 0.5. This exploitation rate (E) also suggested that only 45% of the available stock biomass was being harvested yearly. The estimated recruitment pattern was bimodal, with peak recruitment of 19.66% occurred in July, 14.02% in June and 12.7% in September, respectively. This study represents the first successful investigation on the population structure and growth parameters of pink sea cucumber (*H. edulis*) in Malaysia, the findings of which will immensely be helpful not only for the understanding of population status of this species but also for their biodiversity conservation and aquaculture development to a greater extent.

Key words: Sea cucumber, *Holothuria edulis*, population parameters, growth, mortality, Tioman

1 Introduction

1.1 Distribution and Habitat

Sea cucumbers are sessile marine invertebrates belonging to the class Holothuroidea and phylum Echinodermata, which are usually found in the shallow benthic areas and deep seas all over the world's ocean. They have a significant role in the components of food chain and detritus recycling (Hauksson, 1979; Uthicke, 1999; MacTavish et al., 2012). Kerr et al., (2001, 2004) identified around 2,000 species of Holothurian with seven major orders including Apodida, Aspidochirotida, Dendrochirotida, Elasipodida, Molpadida, Persiculida, and Synallactidae. This classification was made on the basis of the shape of ossicles and number of tentacles as the major priorities in morphological species identification. It is a known fact that Aspidochirotida is not only the most abundant group with great number of species (Allen et al., 2002), but also the overexploited sea cucumber in the world (Bruckner, 2006; Purcell et al., 2012) because of their high commercial and medicinal value around the globe (Purcell et al., 2012).

Holothuria edulis, preferably known as the edible sea cucumber or pink sea cucumber, is a member of Holothuriidae family and belongs to the order Aspidochirotida. It is widespread around the Indo-Pacific in shallow waters from south to northern Australia, throughout the Indo-Malay Philippine Archipelago, India, Southeast Asian Peninsula, French

Polynessia, Marshall Islands, Arabian Peninsula (plus the Red Sea), and Africa including the East and North (Conand et al., 2013). Based on country-wise distributions, it is found in Australia, Bangladesh, China, Egypt, Eritrea, Guam, India, Israel, Japan, Kenya, Madagascar, Malaysia, Oman, Papua New Guinea, Tanzania, Thailand, USA, Viet Nam, Yemen etc. (Conand et al., 2013).

In general, *H. edulis* is mostly found on silty-sand mixed with coral rubbles. It stays between 0 and 20 m of depth, and occupies the reef flats and lagoon patch reefs (Purcell et al., 2012). It can also be found on hard reef surfaces and seagrass beds (Kinch et al., 2008). For those that inhabit the barrier reefs has a whitish trivium and brown bivium (Conand et al., 2013). However, the habitat of *H. edulis* varies from one location to another. Within the Indian Ocean and the African region, the species lives in lagoons between 0 and 30 m over sandy substrate and seagrass (Conand et al., 2013). It also inhabits the microatoll and the meadows of seagrass at the highest density of about 0.612 kg/ha around the inner slope (Conand, 2008). In the Western Central Pacific, it lives in the lagoon-islet and fringing reefs or in the inner reef flats within the shallow waters of coastal lagoons between 0 and 30 m (Kinch et al., 2008). It reproduces in the months of December and January within the Great Barrier Reef (Kinch et al., 2008). Furthermore, Purcell (2004) reported that there is no known information on change of habitat during the development history of the species, but the juveniles are both small individuals and cryptic that may likely migrate later to adult habitats.

1.2 Sea cucumber fisheries

Sea cucumber fisheries have been in existence since the 16th century within the Indo-Pacific region (Akamine, 2004). It extended to Indonesia, Philippines, and Malaysia around the 17th century (Choo, 2008). In Asia, the commonly fished sea cucumbers such as the *Holothuria*, *Bohadschia* and *Actinopyga*are from the Order Aspidochirotida. In total, 125 species of sea cucumbers as recorded from different references are existed in Asia (Choo, 2008). However, only about 52 species among the total found in Asia are commercially important (Uthicke et al., 2004). There have been documented around 62 species of sea cucumber that belongs to three Orders and five families from the Peninsular Malaysia (Forbes et al., 1999; Zaidnuddin, 2002). Furthermore, about 20 species out of the total species found in the country are commercially important (Choo, 2008).

The fisheries in Pulau Payar (Payar Island) marine park, in the northwest coast of the Peninsular, has an abundant number of *Holothuria atra* followed by *H. leucospilota*, *Stichopus chloronotus* and *S. horrens* (Zaidnuddin et al., 2000). They also reported the abundance of low-value *Paracaudina* sp. in the muddy habitats found in Balik Pulau (Batik Island), which are been eaten raw by the peoples living in the island. He suggested that the species has been widely publicized as a food source. However, Forbes et al. (1999) carried out a survey in Sabah, East Malaysia between July 1996 and December 1998 and found that majority of the high valued stocks such as *H. Scabra* are now less in population. This scenario has resulted to increased pressure on the middle and low-valued stocks like *Stichopus* spp., *T. anax* and *T.ananas.*

Reports from the west coast of Peninsular Malaysia indicated that the Langkawi Island was once the fishery hot spot for *Stichopus* spp. but have been so depleted due to overfishing to the extent where fishing at the island is somewhat a part time. Choo (2004) recorded that the sea cucumber fisheries were concentrated in the west coast of Sabah regions such as Sandakan and Semporna, and also in the East coast area including Kota Kinabalu, Kota Marudu, Kudat and Kota Belud.

Furthermore, the Pangkor Island within the West Peninsular faces the same condition as reported by Choo (2008) in the past that a diver could collect a large bucket of gamat in an hour, but this feat is impossible nowadays. Historically, Langkawi Island in the west coast of Kedah, Peninsular Malaysia was the major landing site for sea cucumber in the early 1980s. This made the island to be popularly known as Kota Gamat or Gamat City and which provided a source of livelihood to merchants that trades on gamat related industrial goods (Choo, 2004).

1.3 Economic importance

Holothurians belonging to the order Aspidochirotida are considered to be the most important sea cucumber fisheries that are treaded globally in the form of dry processed body-wall called beche-de-mer (sea worms) or trepan (sea slug) and are regarded as an essential international sea food commodity. Beche-de-mer is an important highly demanded delicacy in China, Hong Kong, Singapore, Korea, and Taiwan for their curative ingredients and as food (Ferdouse, 2004; Toral-Granda et al., 2008). Due to increasing prices and strong market demand since the 1950s, Holothurians have experienced a rapid global expansion and its contribution to economies and means of livelihood within the coastal communities increased (Rahman, 2014; Purcell, 2014).

Holothuria edulis is fished throughout the world in low levels and relatively intensive in some places. Its commercial importance also varies from place to place, for example, it is not of commercial importance in Seychelles (Aumeeruddy and Conand, 2008). In Fiji and Solomon Island it has a low commercial value (Kinch et al., 2008). On the other hand, in Asian countries like Malaysia, China, Thailand, Japan, Philippines, Indonesia, and Viet Nam, the specie has a high commercial value (Conand et al., 2013). Choo (2008) reported that the species is heavily exploited in Indonesia. *Holothuria edulis* is one of the two species that was priced very low in Sri Lanka due to its abundance, and later attracted a high price as the supply decreased (Conand, 2008).

In Malaysia, Holothurians are popularly known as ‘timun laut’, ‘balat’ or‘gamat’, with gamat being very popular in the traditional medicine industry. The gamat include species belongs to the genus *Stichopus* like *Stichopus chloronotus*, *S. harmanii* and *S. horrens*. It improves the economy of Malaysia through trade and also plays an important role in the manufacturing industries in that it is highly needed as beche-de-mer and gamat related uses. The extracted ‘gamete oil’ and ‘gamete water’ are being utilized by the gamat industries in so many uses, for example, for producing household commodities like toothpaste, and medicines for wound healing, antitumor, neuroprotective, antimicrobial, antioxidant and anticoagulant activities (Ridzwan, 1995; Kerr, 2000). Furthermore, it is also used as an ingredient for producing a popular Hurix cough syrup and Safi face cleanser (Akamine, 2014). However, beche-de-mer is the main economic product, which is very popular within the Chinese communities. With 30% of the Chinese population in Malaysia, beche-de-mer gained more value in the commodity market (Choo, 2008).

From the total export and import values of sea cucumber as shown in Fig.1, the traded products are live frozen, dried, smoked, and salted cucumber prepared and preserved in airtight containers. Trade volume from the year 2001 to 2012 for export values was constant at an average value of 258 tonnes, with revenue earnings of about RM 4.4 million, respectively. Also, the import within the same year stood at an average of 196 tonnes, costing about RM 2.3 million. There was an increase in the trade volume of sea cucumber between 2012 and 2015. For instance, in 2015, the import stood at 624 tonnes with a total cost of about RM 15,883,400, while the export was 957 tonnes and generated a revenue of about RM 24,771,294. This scenario however, changes the status of Malaysia from the past five years and presented her among the net importer of sea cucumber and its related products.

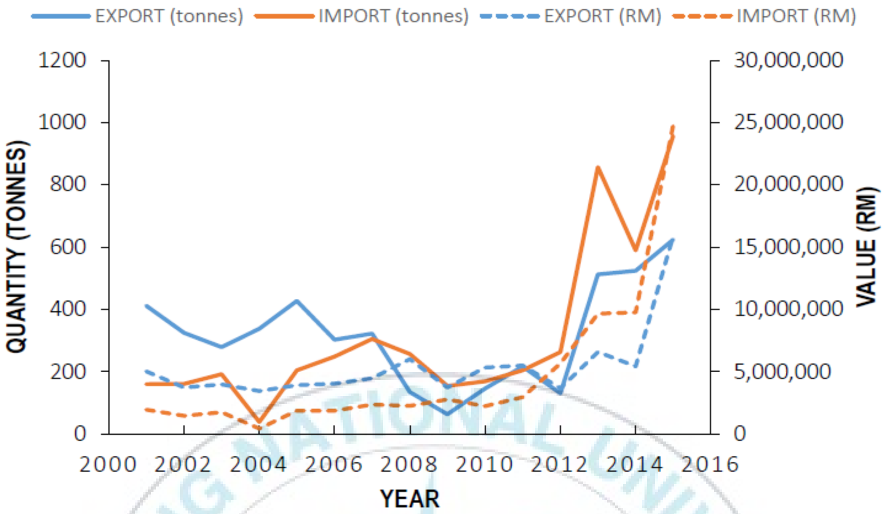

Figure 1. Export and import graph showing quantities (tones), cost and revenue (RM) for beche-de-mer products (2001-2012), Malaysia

Due to its great significance to the country's economy, a lot of researches have been undertaken to study various aspects of sea cucumbers in Malaysia. However, the studies have been concentrated only on several research areas with some areas still remains largely understudied. The majority of sea cucumber researches in Malaysia have been conducted on the characterization and analysis of their bioactive constituents (Hawa et al., 1999; Ridzwan et al., 2003; Che Badariah et al., 2011; Zohdi et al., 2011; Forghani et al., 2012; Shahrulazua et al., 2013; Siddiqui et al., 2013; Subramaniam et al., 2013; Lukman et al., 2014; Ridzwan et al., 2014; Forghani et al., 2016). The second major area of researches are on the distribution and diversity of sea cucumber species in Malaysia (Zulfigar et al., 2007; Kamarudin et al., 2009, 2015;

Woo et al., 2010), followed by some taxonomical studies (Massin et al., 2002).

Recently, new studies on genetics and aquaculture of sea cucumbers have also been published (Kamarudin and Rehan, 2015; Vaitilingon et al., 2016). However, little information on the basic biological and ecological aspects of sea cucumbers such as study on the larval development (Mazlan and Hashim, 2015), population structure (Rahmad and Zulfigar, 1993; Nuraini, 1995) and reproductive biology (Sallehudin, 1992; Yang, 1997; Rodzi, 2001; Tan and Zulfigar, 2001; Sim, 2005) are prevailing in Malaysia. Furthermore, most of the studies such as study on the population dynamics and reproductive biology are often not very comprehensive, particularly in respects of sample size or sampling duration. In view of declining status of holothurian stocks and natural habitats worldwide, studies on the biology and ecology of these species are urgently required to conserve and preserve the current population in the wild.

The gaps in knowledge on the study of population parameters of *H. edulis* in Toman Island as presented in this study are worth exploring, especially for species protection, biodiversity conservation, and sustainable management of emerging high-valued sea cucumber fishery in Malaysia. Therefore, it is urgently needed for taking utmost precaution to prevent overexploitation of *H. edulis* because of the depletion of the population of higher commercially important and valued species like *H. scabra*, as has been the case in Viet Nam (Choo, 2008).

1.4 Objectives of the Study

Based on the above discussions in mind, it is very important to determine the detailed population parameters of *H edulis* in Tioman Island with the following objectives:

I. To determine the size structure and biometric relationship of *H. edulis* population

II. To estimate the population parameters of *H. edulis*

2 Materials and Methods

2.1 Study site

Tioman Island is located on the Southeastern Peninsular, Pahang State, Malaysia, and lies between $104^{0}10'29.3''$E and $02^{0}48',52.1''$N, and 32km far away from the coast of the Peninsular (Fig.2). Tioman Island is the biggest, popular, and most beautiful among other Islands with a total area of about $136km^{2}$. The Island was designated as a marine park in 1994 under the 1985 Fisheries Act in order to protect its biodiversity (DMPM, 2011). It has 13 coral reef sites within the west coasts area (Tomok Island, Terdau Bay, Renggis Island, Soyak Island and Genting Village), east coast area (Benuang, Dalam Bay and Benuang Bay) and isolated area (Labas Island, Bayan Bay, Gado Bay, Tulai Bay and Sepoi Island) (Shahbudin et al., 2017).

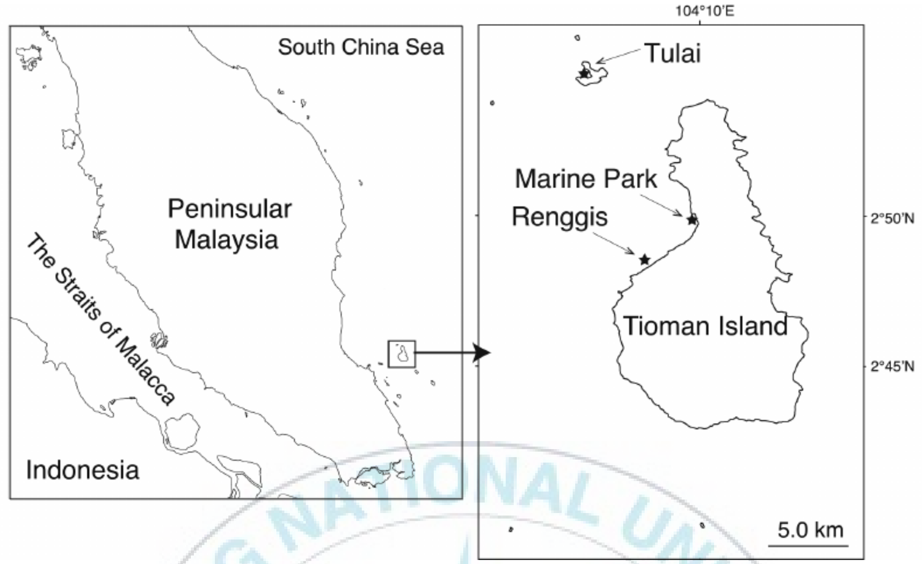

Figure 2. Map of Peninsular Malaysia showing the Tioman Island and the location of the sampling site

Tioman Island is the ideal habitat of large number of sea cucumbersmainly from the order Aspidochirotida and around 20 species under the Holothuriidae family are found in the island, such as*Stichopus chloronotus*, *Bohadschia vitiensis*, *Holothuria atra*, *S. vastus*, *Thelenota ananas*, *Actinopyga lecanora*, *S. hermanni*, *S. ocellatus* and *H. edulis* (Kamarudin et al., 2015).

Studies conducted on the island including collection of live samples, and collection of data on population parameters such as mortality, growth, and asymptotic length which are important for stock assessment. There exist many stock assessment tools, however, the FiSAT II (FAO-ICLARM Stock Assessment Tools) has widely been used to estimate population dynamics of holothurians because it only requires the length-frequency data to determine the population parameters to assess the stock level of *H. edulis* within the coastal waters of Tioman Island (Poot-Salazar et al., 2014; Olaya-Retrepo, 2014).

2.2 Sampling protocols

In total,701 individuals of *H. edulis* (Fig. 3) of different sizes were collected from the month of March 2016 to February 2017. Around 40-90 live samples per month were picked by SCUBA diving on the reef of the east coast of Tioman Island from a depth of about 3 to 4 m at a seawater temperature of about 27-30^{o}C. Measurement was taken as soon as possible by using the tailor tape and digital weight balance, and then releases the samples back into the sea water. At full tide, the average depth of sampling area was 9 m, which can be exposed when the tide becomes so low, and at that time individuals were handpicked from the dead coral reefs, sandy bottom and rocky surfaces.

Figure 3. Collected live samples of pink sea cucumber (*Holothuria edulis*) from Tioman Island, Peninsular Malaysia

2.3 Morphometric measurements

The length, width and weight of all the collected *H. edulis* individuals were measured with the aid of measuring tools such as tailor tape to the nearest 0.1 cm and an electronic balance to the nearest 0.1 g. The length was obtained by measuring from the mouth to the anus; the width was measured by dividing the body into 3 points. Firstly, it was measured in-between the anus and the mid body, secondly, between the mid body and lastly, between the mid body and the anus.

2.4 Size structure and biometric relationships

The data on size distributions of *H. edulis* in terms of length (cm) were grouped into 1.0 cm length-frequency classes. The coefficient of variance of each distribution was also estimated. The length-weight relationship (LWR) was established using the formula: $W = aL^b$, where "a" is a constant and b is the growth coefficient. The growth is isometric when the metric of growth b = 3, while b < 3 and b > 3 represents the negative and positive allometric growth, respectively. The parameters of the relationship were also estimated using the least squares linear regression of the log-transformed data with the equation, $\log_{10} W = \log_{10} a + b \log_{10} L$. A student t-test was used to check the hypothesis of isometry (b = 3).

2.5 Estimation of population growth and age

This step follows immediately after data entry and manipulation in order to estimate the population parameters. The data were grouped with a class interval of 1 cm, and analyzed using FiSAT II (FAO-ICLARM) software in line with Gayanilo et al. (2005). ELEFAN 2 method was used to estimate Asymptotic length (L_∞) at various age, and growth coefficient (K) of the von Bertalanffy growth function (VBGF) respectively. ELEFAN 2 works by reconstructing data to generate troughs and peaks as presented by Pauly (1987). The growth parameters of VBGF is estimated using the following equation: $L_t = L_\infty [1 - e^{-k(t - t_0)}]$. Where, L_t = mean length at age t; L_∞ = asymptotic length; K = growth co-efficient (yr^{-1}); t = age of the species; t_0 = the hypothetical age at which the length is zero, and expressed as $Log_{10}(-t_o) = -0.3922 - 0.2752 Log_{10} L_\infty - 1.038 Log_{10} K$. The growth performance index (φ) was calculated from the estimated value of L_∞ and K using the equation as presented by Pauly and Munro (1984): $\varphi = 2 \log_{10} L_\infty + \log_{10} K$. Potential longevity ($t_{max}$) of the species was calculated from the equation of Pauly (1984) as follows: $t_{max} = 3/K$

Parameters combination that produced the highest score function was selected at each series of estimation. This score function describes the degree of goodness of fit of the growth curve to the observed length frequencies as observed from the data, and to the expected growth if it follows the chosen parameters (Kirkwood, 2001). He also stated that the core function of ELEFAN 2 is depended on the function of proportionality of the available troughs and peaks that is expected by a VBGF curve with the corresponding L_∞, K, and t_0. The age-at-length curve of the population was then constructed by substituting the selected estimated parameters into the above equation.

2.6 Estimation of mortality and exploitation level

Total mortality (Z) of the population was calculated through the use of steady-state-sample of the length-converted catch curve (where annual oscillation of growth does not exist) by applying the equation of Pauly (1984) as follows: $\ln(Nt/\Delta_t) = a + b_t$

Where, N is the number of individual in length class at age (t), Δ_t is the amount of time needed for the individual to grow through a particular length class, t is the relative age corresponding to class mid-length, b is the slope with sign changed gives an estimation of total mortality (Z).Natural mortality (M) was estimated using the empirical relationship of Pauly (1984) as below:

$Log_{10}(M) = -0.0152 - 0.279Log_{10}(L_\infty) + 0.6543Log_{10}(K) + 0.463 Log_{10}(T)$

Where, M is the natural mortality, L_∞ is the maximum asymptotic length, K is the growth rate (yr^{-1}) and T is the average habitat temperature (^oC).

From the estimation of M and Z above, the fishing mortality F was then estimated from the equation: $F = Z - M$. Gulland (1985) gave the first expression on the exploitation level (E), which was obtained from the following equation of Ricker (1975): $E = F/Z = F/(F + M)$. When $E = 0.5$, it was considered as an optimum exploitation level, while $E < 0.5$ represents an underexploited stock, and $E > 0.5$ indicates an overexploited stock.

3 Results

3.1 Size Structure

In total, 701 individuals of *H. edulis* were collected over a sampling period of 12 months. The frequency distribution of weight and length were presented in Fig. 1. The weight and length has a range of values between 26.10 and 807.60 g, and 2.0 to 44.0 cm, respectively. A steeper decline of small classes was observed in the length. The observation indicates that young individuals were not easily found during the sampling. The body width appeared multimodal and difficult to be used for the prediction of growth. Instead, the length was used because it has monthly length frequencies of the modal progression as was observed. This feat suggests the possible measurement of growth through the use of length frequency data.

3.2 The biometric relationship

The measurements of length and weight of all collected specimens of *H. edulis* were utilized to establish the length-weight relationship using the mathematical expression of $W = aL^b$. The linear regression of the log transformation data were established and used to estimate the constants “a” and exponent b through the linear regression: $Log_{10}W = log_{10}a + blog_{10}TL$ (Fig. 4). The biometric relationships showed a positive correlation between L and W ($r^2 = 0.812$). The growth coefficient (b) from the length–weight regression analysis was statistically different from 3 (Student’s t-test; $P < 0.05$), indicating that the growth pattern of *H. edulis* in Tioman island was negatively allometric ($b < 3$).

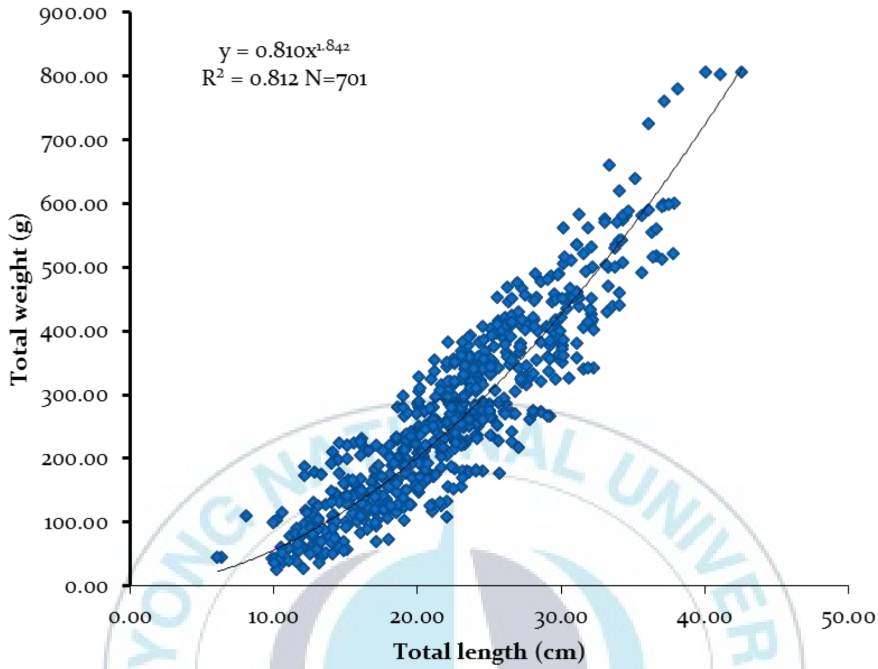

Figure 4. Length-Weight relationship of *Holothuria edulis* in arithmetic scale.

3.3 Estimation of growth parameters and age

The ELEFAN method of FiSAT II (ICLARM-FAO) software was used to estimate the best optimized non-parametric scouring of Von Bertalanffy Growth Function (VBGF) fitted as: asymptotic length(L_∞) = 47.78 cm, growth coefficient (K) = 1.00 yr^{-1}, growth oscillation © = 0.00, winter point (season when there is slow growth rate) (WP) = 0.00, response surface (Rn) = 0.131. Fig. 5 showed the growth curve was superimposed on length frequency data. In this context, the mean theoretical maximum length that species could achieve within its natural habitat is the asymptotic length (L_∞). K, is the coefficient of growth that reveals the rate at which species grows in size in relation to its years. Hence, the length sizes reached by *H. edulis* were 28.35 cm, 40.27 cm, 45.02 cm and 46.76 cm at the end of 0.5, 1, 2, and 3 years of age, in that order. The hypothetical age t_o = -0.85 years. The maximum age t_{max} = 3 years.

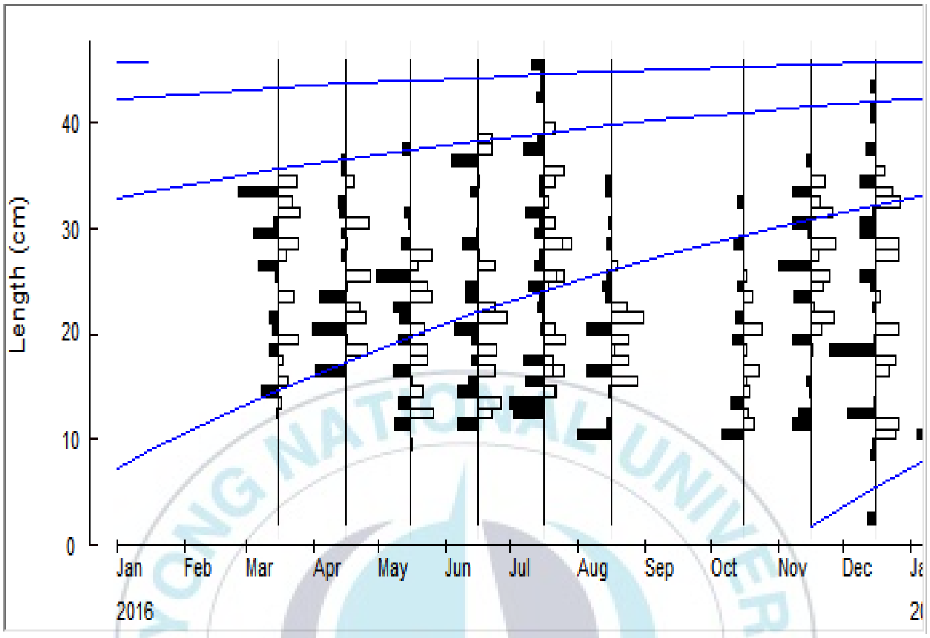

Figure 5. The calculated VBGF curve superimposed on the restructured monthly length frequency data. The shaded bar represented the theoretical cohorts within each monthly distribution (Asymptotic length (L_∞) = 47.78 cm, Growth coefficient (K) = 1.00 yr^{-1} and Age = 3 yr)

Fig. 6 revealed that recruitment of *H. edulis* in the sea cucumber fishery at Tioman Island was occurred throughout the year but the pattern was bimodal, with peak recruitment of 16.29% in July, followed by 14.99 % in June, 14.70 % in May and 13.18 % in September, respectively. Table 2 shows the identified recruited age group from the length-frequency data, analyzing through Bhattacharya's method (Gayanilo et al., 2005).

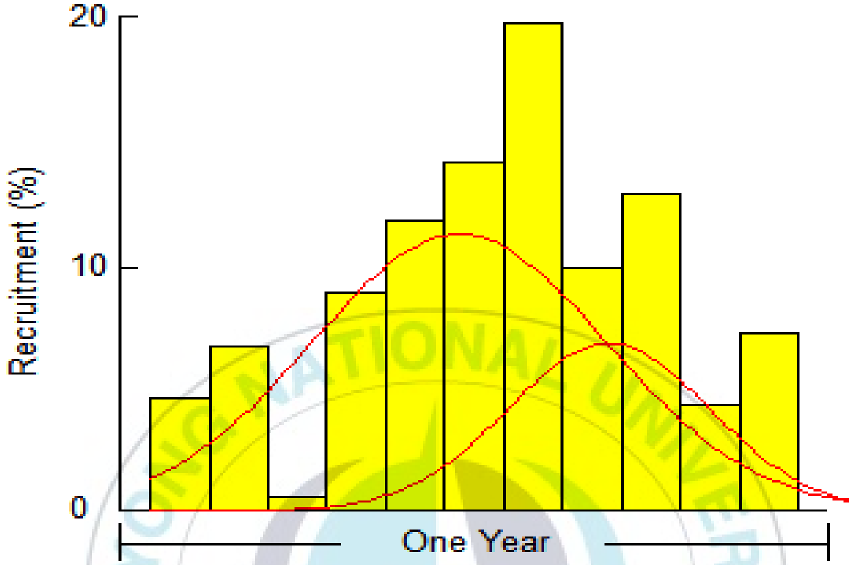

Figure 6. The recruitment patterns of *H. edulis* at Tioman Island

Table 1. Identified age group from length-frequency analysis of sea cucumber, *H. edulis* during the 12 months sampling (March 2016 to February 2017), using the Bhattacharya's method; n = number of samples per each length group, SD = standard deviations, SE = Standard Error

Months	mean	SD	n	SE
March	14.50	0.770	14	-
	18.24	0.690	10	5.120
	26.00	1.360	19	7.570
	33.0	0.790	17	6.510
April	20.19	0.900	15	-
	23.72	0.920	15	3.880
	27.84	1.400	21	3.550
May	13.67	0.690	7	-
	16.34	0.980	10	3.200
	21.12	1.580	25	3.730
	25.91	1.000	10	3.710
June	15.22	0.980	12	-
	19.80	0.930	13	4.800
	27.02	3.090	20	3.590
	34.16	1.640	13	3.020
July	15.50	0.670	5	-
	23.03	1.710	35	6.330
	26.46	1.210	12	2.350
August	18.50	1.660	23	-
	24.58	1.630	25	3.700
September	25.50	3.580	22	-
	23.34	2.600	15	2.798
October	14.00	1.610	14	-
	20.75	3.60	50	2.890
November	19.71	1.110	11	-
	24.75	2.090	28	3.150
	30.74	2.580	21	2.570
December	12.64	0.630	8	-
	19.00	0.930	9	8.150
	28.73	3.070	27	4.870
January	13.36	0.840	11	-
	18.31	1.150	10	4.970
	22.33	1.220	14	3.430
	29.52	2.230	7	4.140
February	4.73	0.820	7	-
	19.53	1.200	13	14.650
	23.30	0.800	13	3.770
	33.67	4.160	18.00	4.180

3.4 Estimation of mortality and level of exploitation

The total mortality (Z) was estimated to be 2.81 yr^{-1}, using the length-converted catch curve (Fig. 7). Natural mortality (M) was estimated at 1.54 yr^{-1} and the fishing mortality (F) at 1.27 yr^{-1} (Fig. 7).The exploitation level (E) was estimated at 0.45.The growth performance index (Φ) was calculated to be 3.358 and the total mortality (Z) was calculated from the darkened spots by using the least square linear regression. From the regression analysis, the estimated correlation coefficient (r) was 0.812 (a = 0.810, b = -1.842). The calculated fishing mortality was found to be 1.27 by subtracting M from Z.

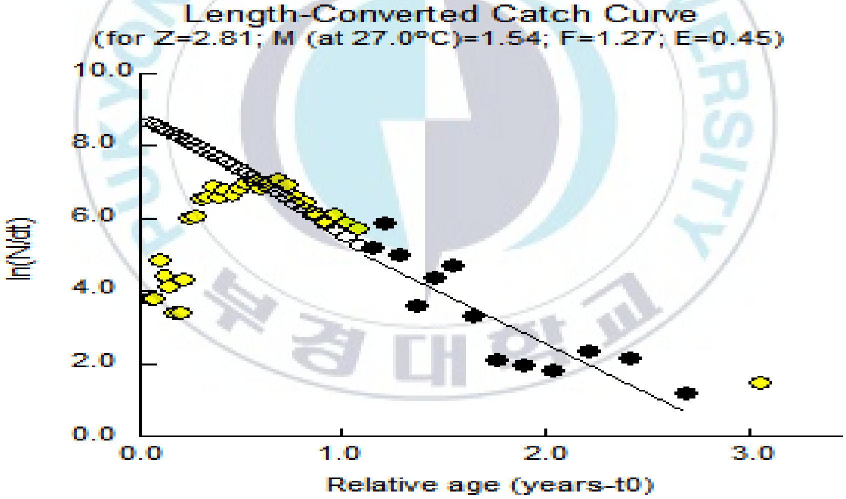

Figure 7. Linearized length converted catch curve for *H. edulis*. The yellow dots represented the omitted points, while the black dots are points used for the regression analysis

The optimum level of exploitation was assigned at 0.5, a value where 50 % of the total mortality was due to the fishing mortality. As such, the level of exploitation for the *H. edulis*population was at 0.45, which is lower than the optimum value. From Gulland (1982) explanation, higher values of E signify overfishing of the stock biomass within the period. The curve of the relative yield-per-recruit (Y′/R) represented as a function of exploitation rate (E) to provide an optimal level of exploitation rate (E_{max}) of 0.42. Furthermore, the exploitation rates of E_{10} and E_{50} were estimated to be 0.36 and 0.28, respectively (Fig.8).

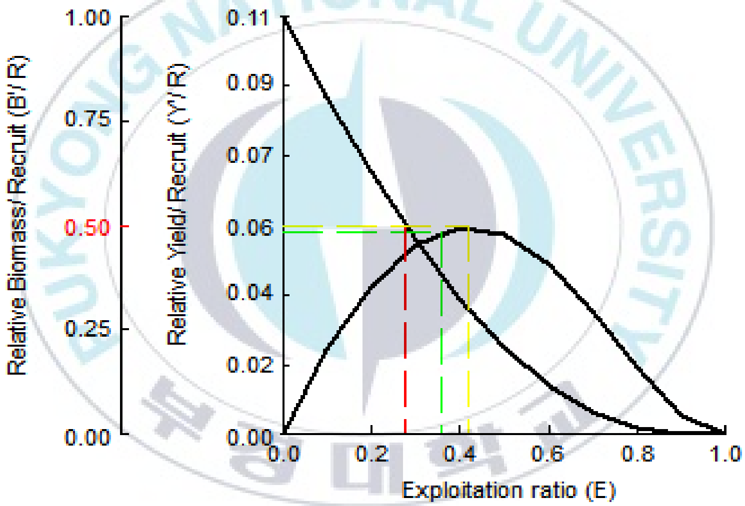

Figure 8. Relative yield per recruit(Y′/R) and biomass per recruit (B/R) (knife-edge selection) for *H. edulis* obtained from Tioman Island (E_{10} = 0.36, E_{50} = 0.28 and E_{max} = 0.42).

The results of virtual population analysis (VPA) revealed that fishing mortality at class mid-length of 23.5 cm was the highest peak, followed by 24.5 cm, 22.5 cm, and 20.5 cm with the corresponding values of the fishing mortality were 0.35 yr^{-1}, 0.32 yr^{-1}, 0.29 yr^{-1} and

0.26 yr^{-1}, respectively (Fig. 9). The fishing mortality was found to be higher over the mid-class length between 22.5 to 24.5 cm. These increasing trends indicated that recruitment occurred over this narrow mid-length range rather than the increased efficiency of the fishing gear with length.

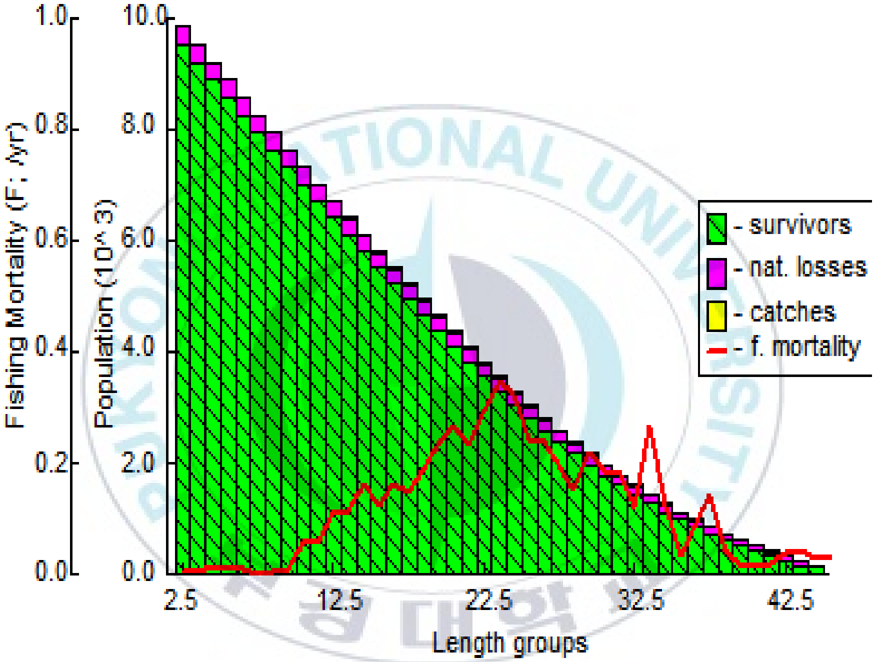

Figure 9. Length-structuredvirtual population analysis (VPA) of *H. edulis* in Tioman Island, Pahang, Malaysia

4 Discussion

4.1 Size distribution and biometric relationships

Till now, there have been no published information on population dynamics of *H. edulis* in Malaysia. However, information on taxonomy, biology, ecology, biodiversity population dynamics, genetics, reproduction, culture and bioactive constituents of other species of sea cucumber in Malaysia have been made available through previous research works (see references in introduction). This study is the first attempt to study the detailed growth parameters and length-weight relationship of *H. edulis*. The population structures of *H. edulis*, as revealed from the present study are similar to that studied for *S. horrens* in Samoa (Eriksson, 2006). However, the maximum size range was very different, relatively longer and considerably larger for *H. edulis* in the current study than that had previously been estimated for *S. horrens* in Samoa (7.0 - 23.0) and in Glapagos (9.0 - 31.0) by Eriksson (2006) and Hearn and Pinillos (2006), respectively. However, these size discriminations might be happened due to the differences in species, geographical location, natural habitat, and food availability.

The size structure differences are as a result of the level of exploitation within the areas. Usually, bigger sizes are associated with lower level of exploitation. The

above explanation is typically a representation of the survey carried out by Hearn and Pilinnos (2006) in Galapagos, while they were conducting a field study on the stock for the purpose of opening a commercial fishery of *S. horrens* to serve as an alternative to the declining stock of *Isostichopus fuscus* within the area. However, the size of *H. edulis* individuals observed in Tioman Island can be due to the exploitation of the species in the area. This is also shown by the level of exploitation estimated in this study that predicted some form of exploitation has already taken place in the area in the sea cucumber fishery. Field investigations also confirmed the existence of artisanal fishing practices and small-scale gamat production facilities in the Island.

For setting up the baseline information for a particular population in a fishery, the size distribution data are very important. Due to the artisanal fishing activities, the exploitation rate is still below the optimum exploitation rate as revealed from the present study. Furthermore, there are worries such as the possibilities of intensifying fishing activities, pollution and heavy tourism attraction industries might threaten the population in this island in the near future (Baine and Choo, 1999; Yusuf et al., 2009; Sadatiseyedmahalleh et al., 2016). As such the current established baseline information is important towards helping the management, especially in monitoring the status of the wild stocks of the fisheries in the area.

The length-weight relationship of *H. edulis* indicates a negative allometric growth of 2.8. The results are in line with the growth of other holothurians as reported in the previous studies. For example, *S. hermanni* has an allometric growth coefficient of 2.5 (Connand, 1993a), *I. badionotus* has 2.7 (Poot-Salazar et al., 2014), *I. fuscus* has 1.83 (Herrero-Perezul et al., 1999), and Erikssons (2006) presented 2.7 for *S. horrens* in Samoa (Table 2).

Table 2. The growth parameters for holothurian species ($L\infty$ = asymptotic length, K = growth rate, φ = growth performance index)

Location	Latitude	Species	L∞(cm)	K(yr-1)	φ	Sources
Indonesia	5°S	*Stichopus vastus*	31.58	0.55	2.74	Sulardiono et al., 2012
New Caledonia	20°S	*Thelonota ananas*	66.30	0.20	2.94	Conand 1990
New Caledonia	20°S	*Stichopus chloronotus*	34.20	0.45	2.72	Conand 1990
Mexico	21°N	*Isostichopus badionotus*	31.60	0.50	2.77	Poot-Salazar et al., 2014
Mexico	24°N	*Isostichopus futus*	36.12	0.18	2.37	Horrero-Perezrul 1995
Mexico	31°N	*Parastichopus parvimensis*	52.50	0.30	2.91	Perez-Placentia 1995
Japan	34°N	*Apostichopus japonicas*	36.70	0.33	2.65	Hamano et al., 1989
Malaysia	4°N	*Holothuria edulis*	47.78	1.00	2.88	Present study

4.2 Population growth

The asymptotic length for *H. edulis* from the study was recorded to be 47.78 cm with a growth rate of 1.00, which was higher than that observed in *I. fuscus* at 0.18 yr^{-1} (Herrero-Perezrul et al., 1999). In general, species in lower latitude tend to has higher growth rate compared to species in higher latitudinal range. This is visibly the growth pattern for Holothurians as can be seen from the Table 2.This difference in growth rate corresponds to the fact that there is a favorable condition for growth such as higher temperature and food availabilities. Poot-Salazar (2014) noted that the possible higher growth rate of *I. badionotus* in Gulf of Mexico as compared to *I. fuscus* in the East Pacific water of Mexico was due to the relatively warmer temperature in the former location. However, there is an observable modal progression trend in the sampling. Also, there are some questions that still need to be answered like what happened to the large organisms that appeared through December and May, do they migrate to the deeper sea area or they die off? There is no explanation to this phenomenon at the moment, as survey was carried out at a higher depth. Furthermore, a sound argument could be that recruitment takes place within the shallow region, after which the matured individuals will migrate to the deeper region due to unfavorable environmental condition.

4.3 Mortality and exploitation

The natural mortality (M) of *H. edulis* from this study was much more than the fishing mortality (F). Furthermore, it revealed that the exploitation rate of *H. edulis* in the island estimated at 0.45 is still below the optimum exploitation rate at 0.5. This suggests that the species is still underexploited. The reason for this maybe due to the artisanal fishing activities going on in the island, which do not exert fishing pressure on the wild stock.

Table 3. Summary of population parameters of *H. edulis* in Tioman Island, Peninsular Malaysia

Population parameters	
Asymptotic length (L_∞) in cm	47.78
Growth coefficient (K) year^{-1}	1.00
Growth performance index (φ)	3.36
Natural mortality (M) year^{-1}	1.54
Fishing mortality (F) year^{-1}	1.27
Total mortality (Z) year^{-1}	2.81
Exploitation level (E)	0.45
Allowable limit of exploitation (E_{max})	0.42
Length range (cm)	2.0-44.0
Sample number (n)	701

5 Conclusion

Our present findings reveal that *H. edulis* is a relatively fast growing species compared to other Holothurians. The species has a high natural mortality rate, with a corresponding low rate of fishing mortality. This is because the pressure from the artisanal fishing activities is minimal, and the wild stock is still underexploited. This represents the first study to outline the baseline information on the size structures of the wild stock of *H. edulis* population. Through this study, we suggest that in order to sustain the sea cucumber fisheries in the Tioman Island, proper management strategies needed to be drafted and implemented.

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