Thesis for the Degree of Master of Fisheries Science

Age, growth and population parameters of the tropical sea urchin (*Tripneustes gratilla*) from the coastal waters of Sabah, Eastern Malaysia

by

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Pukyong National University

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(동부 말레이시아 사바(sabah) 연안에 분포하는 열대 성게 (*Tripneustes gratilla*)의 연령, 성장 및 개체군 매개 변수)

Advisor: Prof. Dr. Rahman Md. Aminur

by

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Abstract

An investigation on the population parameters (growth, mortality, exploitation rate etc.) of the tropical sea urchin (*Tripneustes gratilla*) was carried out for one year from the monthly samples collected between January and December 2016 in Bum Bum Island, Sabah, Eastern Malaysia. A total of 615 live samples were collected during the experimental period and the mean length and weight were measured to be 8.36 ± 5.0 cm and 238.83±30 g, correspondingly. The relationship sandwiched between the total body weight and the total length of the species was estimated as TW=0.9563x2.5634 (R2=0.8407) from the linear regression graph. The estimated value of the total mortality at the end of the research was 4.94/yr, slightly exceeding the final result estimated for natural mortality which yields 3.24/yr at an average ambient temperature of 28℃ in the study area. The exploitation rate (E) estimated for *T. gratilla* was 0.35, which was below the optimum exploitation level (E=0.50). The Gulland and Holt plot, as well as Von Bertalanffy non-linear least square regression methods were used to estimate growth parameters. Monthly length-frequency numeric data were analyzed using FAO FISAT II software for generating and estimating the population parameters such as asymptotic (∞)) length, growth coefficient (K) and age; which were 12.38 cm, 1.7/yr, and 2 yrs, respectively. However, the recruitment pattern was observed to be increased gradually with the maximum recruitment peak between the months of October and November 2016. This is the first approach to study the detailed population dynamic of the economically important tropical sea urchin (*T. gratilla*) endemic to the region. However, the result so far obtained from this research would greatly be useful towards the understanding of the detailed population structure and growth patterns that will undoubtedly help us to develop captive breeding, seed production, culture protocols and conservation strategies of this high-valued species incommensurate with national and international perspectives.

Keywords: Sea urchin, *Tripneustes gratilla*, population parameters, stock assessment, Malaysia

1 Introduction

1.1 Background

Tripneustes gratilla (Linnaeus, 1758), commonly known as 'Collector Sea urchin' or short-spined echinoid due to its morphological behavior of gathering fragments of algae, coral rubble or rocks in their benthic environment during forages as camouflage against predation (Westbrook et al., 2015). This high-valued commercial species is mostly found throughout the intertidal tropical region of the Indo Pacific Ocean. It also abundantly occurs in some parts of Asian countries including Eastern Malaysia.

The gonad of collector urchin (*T. gratilla*) is a rich source of nutrients for human diet and also has profound pharmaceutical properties for human health (Rahman et al., 2013). It provides subsistence revenue to the local coastal communities in Sabah (Siti. et al., 2016) where the present study was conducted. In some parts of Asia, it is considered a great delicacy to the aristocratic society. According to Siti et al. (2016), Sabah is the exclusive state in Malaysia that has the tradition for consuming sea urchin roe (processed gonad) as it is often considered as a treasured fishery resource. The empirical parameters of sea urchin in their peripheral habitat are very crucial for the understanding of both developmental sustainability and species abundance. Studies suggest that uncertainty in stock assessment can simulate the consequence of various management strategies and their interactions (e.g., Amirali et al., 2016). Therefore, the parameters of species are of estimable concern for the sustainable fishery in Sabah since no studies have been conducted prior to this study on *T. gratilla* to evaluate growth performance and exploitation rate.

Inevitably, there is continuous harvest and marketing of *T. gratilla* in Sabah but no records on their landings are available. Therefore, a proper documentation is needed to avoid the threat to natural stock. Moreover, the increasing global demand for such high-quality urchin gonad will result in exploitation and overfishing of *T. gratilla* in the near future if proper initiatives and statistics are not put in place. Therefore, to maintain sustainable stock biomass in their ecological habitat, stock assessments and population dynamics of this economically important sea urchin is urgently needed. In view of this, the present study has attempted to estimate population parameters including exploitation rate, growth performance etc. for the development of an integrated management strategy and species conservation of *T. gratilla*. Furthermore, it will provide the necessary information to the Malaysian fisheries to guarantee some sorts of ecological and economic sustainability of *T. gratilla* harvest in the study area for both current and future generations.

1.2 Taxonomic Description

The sea urchin (*Tripneustes gratilla*) is an orbicular tube like animals of a spiny like a sea cookie or the snapper biscuit as called in New Zealand. It belongs to the order Camarodonta. It is also clustered into genus *Tripneustes*, consisting of three sea urchin species with the remaining species being *Tripneustes ventricosus* (Lamarck, 1816) and *Tripneustes depressus* (Abdul et al., 2014, 2015). It is one of the most exploited urchins in the world including the coastal waters of Sabah, Eastern Malaysia. The species lives in sandy and muddy bottom reef areas and algae flourishing habitats in some parts of Indonesian waters (Toha et al., 2012).

The taxonomic classification of *T. gratilla* (Linnaeus, 1758) is systematically arranged below:

Kingdom: Animalia

Phylum: Echinodermata

Subphylum: Echinozoa

Class: Echinoidea

Subclass: Euechinoidea

Infraclass: Carinacea

Superorder: Echinacea

Order: Camarodonta

Infraorder: Echinidea

Superfamily: Odontophora

Family: Toxopneustidae

Genus: *Tripneustes*

Species: *Tripneustes gratilla*

Sea urchin was originally called *Echinus gratilla* Linnaeus. It has more than twenty-five synonymized names. The *T. gratilla* has a white dark-brown surface in the ambulacral and interambulacral areas with the exception of the foot-feet where it appears with mid-brown. Echinodermata is further dichotomized into five marine invertebrates including starfish, sea lily, sea cucumber, brittle-star and *T. gratilla* (Rahman et al., 2013, Matsuoka, 1993). Sand dollar can never be excluded in the Echinodermata groupings.

1.3 Habitat and Distribution

The short–spined *T. gratilla* is a tropical echinoid occurs in the Indo-Pacific region. It can be found in Hawaii, Bahamas and Red sea (Miskelly, 2002). They are commonly inhabited shallow- water coral reefs in the benthic region of the sea floor, making up over 50% of the overall number of urchins in the rocky area and over 90% on the calcareous pavement as it reaches an average peak density of 70.3 m^{-2} and grooves on the calcareous pavement at water depth of 1.5 m (Nancy et al., 1989). However, some urchins can occur at a depth ranging between 0 to 90 m in shallow water amongst seagrass meadows and muddy sublittoral zone (Tan and Ng, 1989). The purple sea urchin, for instance, thrives well in the midst of strong wave surge and churning aerated water (Woley, 2001). In Malaysia, the species is predominant in warm temperature regions including Semporna between Sabah and the Philippines (Rahman et al., 2014; Parvez et al., 2016). Fig. 1 shows a distribution map of *T. gratilla* in the study area. Distribution of the species mainly occurs across the tropical and temperate regions of the marine ecosystem. Due to its high nutritive value, and tasty qualities, it has attracted a national and international demand that has associated with the exportation of the mature species to neighboring cities and other countries. High demand accelerates heavy exploitation and hence, the gradual disappearance of the species will happen in the future if pragmatic management precautionary approaches are not put in place.

Figure 1. Distribution of *T. gratilla* in Semporna, Sabah, Eastern Malaysia

1.4 Morphological characteristics and anatomy of sea urchin

Tripneustes gratilla is chiefly black but most habitually possesses a pentaradial bluish to reddish hue as its tube-like feet retracted close to its physique (Westbrook et al., 2015). It has an amalgamated color of spines ranging from cream, black or white. They are mostly found in shallow waters (Kay, 1994). They are herbivorous grazers and use its extruded Aristotle’s lantern to feed or scrape algae from any available substrates. In general, the anatomy of sea urchin is divided into an oral portion (on the left side) and the aboral portion (on the right side) having 36 known internal structures (Fig. 2).

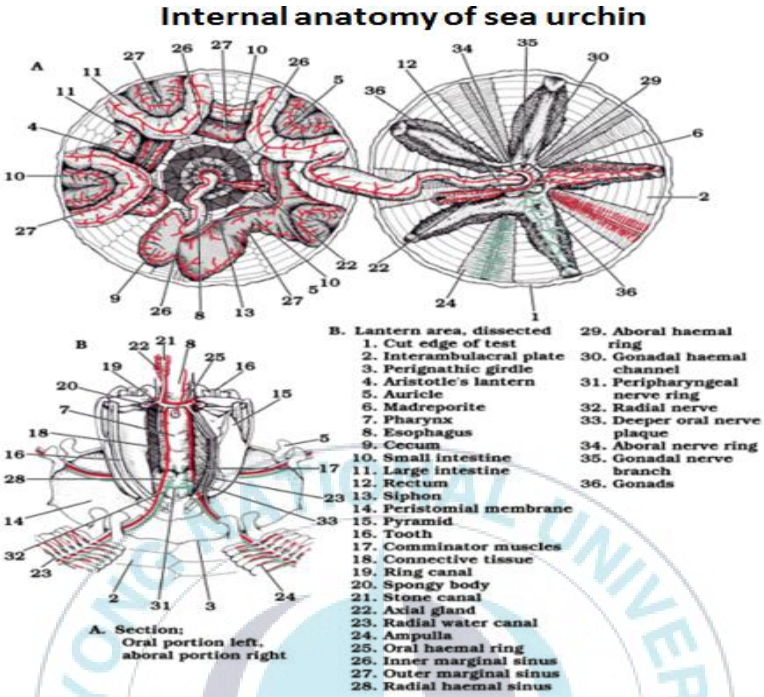

Figure 2. Sea Urchin Dissection Protocol (Whalen, 2008)

1.4.1 Description of sea urchin reproductive cycle

Understanding of reproductive stages is vital to the aquaculturist for the development of induced breeding, quality seed production and sustainable aquaculture of sea urchins in captivity. The sea urchins spawn annually and their eggs are released into water column for mixing and fertilization to take place and this process is known as broadcast spawning (Philip et al., 2012). Formation of reproductive cells in *T. gratilla* usually begins from mid-winter. Studies on temperature tolerances of early larval as well as embryonic development stages have shown that zygotes showed imbalanced cleavage at 13◦C whereas maximum hatching rates were observed at 22–29◦C meaning; the larval temperature tolerance capability is stage dependent for *T. gratilla* (Saifur

Rahman et al, 2009). A study conducted in the University of Cape Town (South Africa), revealed that some phytoplankton species such as *Chaetoceros muelleri, Skeletonema pseudocostatum* as well as *Isochrysis* sp. were the most suitable algae and thus recommended for nurturing of *T. gratilla* larvae (Schotz et al., 2013). Normally, the breeding pattern of *T. gratilla* is dependent on the seasonal changes of sea temperature (Chen et al., 2012; Saifur et al., 2009). Japan is not only the most noted country for high consumption of sea urchin as but also a leading country of production of this species. Predominant species, cultured in Japan are *Tripneustes gratilla, Anthocidaaris crassipina, Strongylocentrotus intermedius, Heterocentrotus pulcherrimus, Pseudocentrotus depressus, and strongylocentrotus nudus.* The reproductive cycle is clustered into two phases: the planktonic and benthic adults phase. From spawning egg, fertilization, cell formation to echinopluteus larval stage through pelagic embryos development usually take 30 days to settlement and metamorphosis. Juvenile development takes about 9 days to 3 weeks. And finally, it takes a year for major ontogeny shift from juveniles to maturity or adults sea urchins.

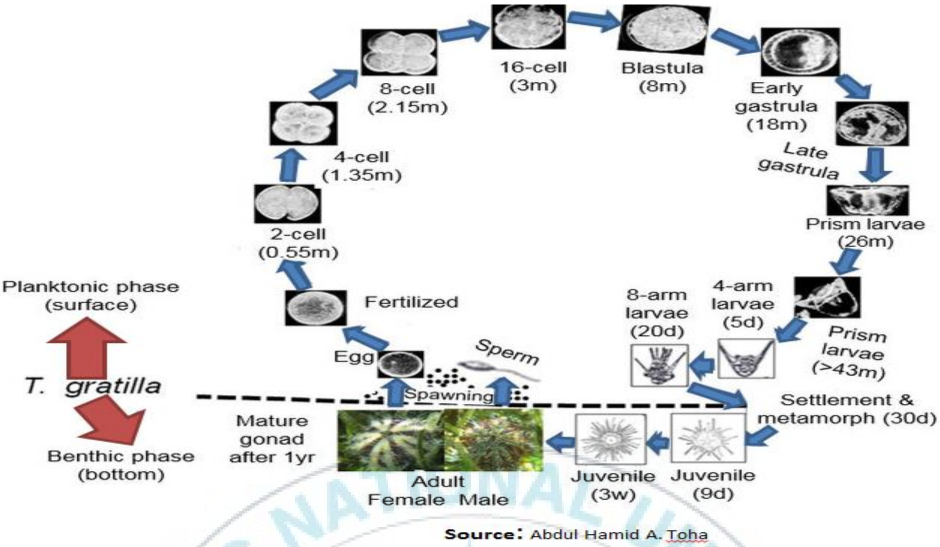

Figure 3. A complete schematic life cycle of the schematic life cycle of the tropical sea urchin (*T. gratilla*)

1.5 Development of Sea urchin fisheries

Development of sea urchin fisheries had been started from long times ago. World landings of sea urchins increased from 31,000 metric tons in 1975 to 120,000 metric tons in 1995 (Fig. 4) that showed an increase of 37% within 20 years (Mark, 2013). However, it further decreased to 82,000 metric tons in 2009 with an alarming declining rate of around 32% until today (Rahman et al., 2017). Undoubtedly, the development of sea urchin industry has increased so greatly throughout the world in recent years that, the population of urchins, especially *T. gratilla* have been overfished to meet up the increasing global demands (Andrew et al., 2002; Rahman et al., 2017). Obviously, the continued strong demand and the declining state in supply led to a strong increase in awareness for aquaculture of sea urchins, predominantly, in those parts wherein their natural populations have been depleted (Lawrence et al., 1997, 2001; Robinson, 2004). However, until now, insufficient scientific works have been done in Malaysia in regards to the investigation on the population dynamics and exploitation status of this highly endemic sea urchin species.

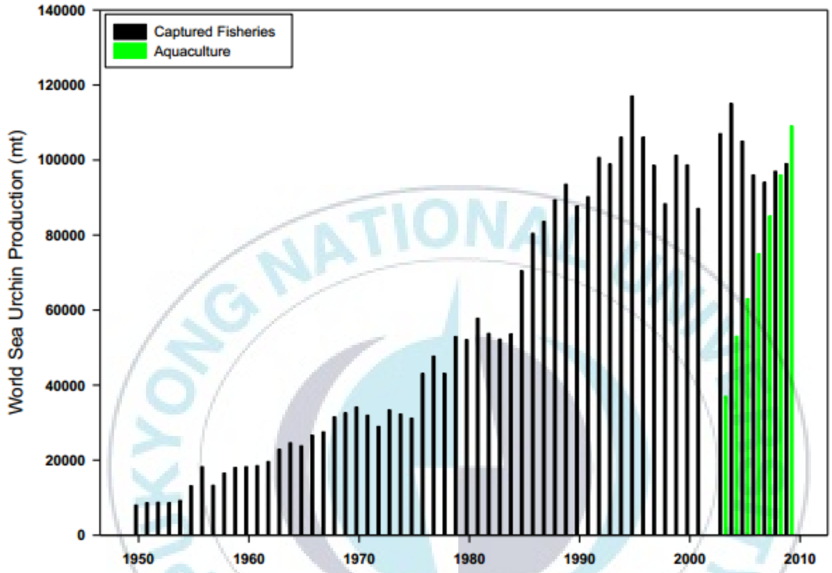

Figure 4. World sea urchin production from capture fisheries and aquaculture from 1949 to 2009 (FAO, 2009, 2012)

1.5. Feeding behavior of *T. gratilla*

Sea urchin plays important roles in decomposition and nutrient cycling in a seagrass bed (benthic region of the sea) through excretion of ammonium and metabolism of feces (Koike et al., 1987). It feeds mainly on seaweed and seagrass but its major feed is seagrass (Rahim and Nurhasan, 2016; Hamid et al., 2017. Some researchers have been conducted for alternative feed in culturing the species, and *Ulva lactuca* (sea lettuce, an edible green alga in the family of Ulvaceae) was used as a feed supplement in the development of an artificial diet and feeding regimes to produce export quality roe (Mark, 2012). Also according to Rodolf (2012), the species can consume coralline algae, macro algae, endolithic algae and turf algae in Hawaiian waters. However, green macro alga (*Ulva lactuca)* was found to be the best feed among the others (Dafni, 1992).

Tripneustes gratilla are most attractive and beautiful among the numerous kinds of sea urchins. They are usually located rocky shorelines or coral reefs habitats where their daily activities are carried out. Moreover, some are also found in sandy substrates, seagrass and algal beds dwelling at depth of about 2 to 3 m (Lesser et al., 2011) in the intertidal Indo-Pacific region. It appears with diverse and momentous coloration patterns but most common ones are the orange. *Tripneustes gratilla* possesses ambulacrum, a vascular system that aid locomotion, chemoreception, and respiration with the support of uncountable tube feet. The locomotive mechanism makes them a unique echinoderm with tube feet measuring about 3 to 7 cm. Even though, their spines on their bodies which sometimes refer to pedicellariae are used for protection against predators.

Its “Aristotle’s lantern” also called the jaw have five sharp teeth, is strong enough to drill a stone. *Tripneustes gratilla* is an omnivore and mainly consumes both animal and plant food such as algae, sea weed, plankton and other food items. The larval stage of *T. gratilla* produces a fragile calcite skeleton or rod in the Echinoplutei that support their body for swimming and feeding (Sheppard, 2010). Most sea urchin roe (Fig.

5), known as uni in Japan, is sold at sushi bars as topping with cooked rice and wrapped in seaweed (Sheppard, 2010).

Figure 5. Roe (mature fresh gonad) of *Tripneustes gratilla* (Philip, J. and Sten, S. 2012).

1.6 Feeding habits of *T. gratilla*

Primarily *T. gratilla* feeds using its unique jaw-like structure called Aristotle lantern consisting of five pointed jaws for feed crushing (Rahman et al., 2010; Rahman et al., 2013). The success behind feeding is through unanimity work of teeth rasping against its surface. This echinoid basically consumed sea algae, and also significantly contributes towards the natural biocontrol of invasive alien algal species in Pulau Bum Bum Island, Eastern Malaysia. Moreover, they consume bryzoans, seaweeds and detritus (Rahman et al., 2015) and a variety of seagrass and microalgae (Klumpp et al., 1993). Moreover, Lession, Kane and Robertson, 2003, research on the Phylogeography of the species, came out with a generalized diet and habitat requirement for extremely wide pantropical distribution of the species potential.

1.7 Prospect and potentials *T. gratilla*

Global demand for sea urchin has increased which has coupled with the expansion of various species of sea urchins in the world. Recently, Global sea urchin fisheries have expanded in Japan, Chile, France, the west coast of North America, northeastern United States etc., that the economically important species have been overfished due to high demand (Lawrence et al., 2001; Rahman et al., 2005; Rahman et al., 2012; Rahman et al., 2013). The world harvestings of sea urchin in 2009 showed clear declining patterns of sea urchin industry from 120,000 mt in 1995 to 82,000 mt (Rahman et al, 2017). This huge decline indicated a clear overexploitation of the species that needs conservational strategies and policies for both fishery management and aquaculture development.

According to Raymie and Siti, (2011), sea urchin fishery in Malaysia was once available, and Bajau and Philipino tribes in Sabah used *T. gratilla* as local delicacy food as well as the source of subsistence income. However, the natural populations of this species have been decline from the intertidal and subtidal of Sabah. The declined status is as a result of environmental and man-made interventions in the spawning and feeding grounds where the species is endemic (Rahman et al., 2014; Rahman et al, 2017). Besides these challenges, there is still much potential for sea urchin aquaculture in the study area such as availability and abundance of natural resources as well as conducive environmental conditions for culturing *T. gratilla*.

1.8 Economic importance of *T. gratilla*

Tripneustes gratilla is considered as one of highly delicacy species consumed by rich peoples in the society. Its extraordinary demands have led to a high price on the market. One mature urchin has usually been selling at 10.00 to 25.00 dollars in some local markets in Busan, South Korea, while in Malaysia, one mature urchin goes for 5.00 to 15.00 dollars. In Japan, the market value of urchin ranged from 2.20 dollars per tray to 43.00 dollars and they imported 6,130 metric tons per annum at an estimated total cost of 251 million dollars (Worley, 2001). In Sabah, exportation of this echinoid has generated revenue, employment and means of support to local fisherman and the community to a greater extent. In California, primary sea urchin harvesting company export 75% of their harvest to Japan as it has become one of the highest value-added fisheries, generating $80 million worth of money per year (sea urchin harvesters association, 2000). According to Richard, 2004, the gonad of sea urchin either in the form of fresh or processed food is classified as one of the most expensive and luxury seafood in the world and are used for various food recipes (Fig. 6). Sea urchin gonads are rich in a valuable bioactive compound such as polyunsaturated fatty Acid and ß-Carotene (Dincer and Cakli, 2007). This polyunsaturated fatty acid particularly eicosapentaenoic acid and docosahexaenoic acid have great significant preventive effects on arrhythmia, cardiovascular diseases and cancer (Pulz and Gross, 2004). Aside from economic importance, it has profound ecological functions including nutrient recycling in the intertidal areas, coral ecosystem, and seagrass. They reduced the biomass of *Kappaphycus* spp. in an experimental enclosure and may be functioned as a useful bio-control agent (Eric, 2005). The only known negative impact of sea urchin is its continuous gnawing away of remnant scraps of vanishing kelp forest which serves as a luxuriant coastal ecosystems habitat for a wide range of marine biodiversity (Alastrair, 2017). In Japan, the species is considered as commercially traded sea urchin (Rahman et al., 2009). In Sabah, *T. gratilla* is mostly harvested by local fishermen with traditional fishing gears. However, the economic importance of the species in the community has led to continuing exploitation and harvesting of the species.

Figure 6. Processed gonads of *T. gratilla* (Tohru Minowaa collections)

1.9 Objective of the study

The knowledge gaps on the study of sea urchins in Malaysia presented here are worth exploring, especially in aiding effort to promote conservation, sustainable fishery, and aquaculture effort of commercially important sea urchin species in Malaysia. One of such species is *T. gratilla* as discussed in detail above. This species is one of the key target species and has currently been exploited in Malaysia. However, the knowledge on population dynamics of *T. gratilla* is very scarce both in Malaysia and in the world. Based on these gaps, we have conducted a research on the population of *T. gratilla* in Bum Bum Island, Sabah in order to delineate aspects of their population structure and growth parameters. The specific objectives of the research are as follows:

I. To determine the population structure and length-weight relationships of *T. gratilla* population.

II. To estimate some of the population parameters including growth, age, recruitment, and mortality.

2 Materials and Methods

2.1 Study area

The study was conducted in Pulau Bum Bum, an island geographically located near to Semporna (Fig. 7 and Fig. 8), Eastern part of Malaysian State Sabah in Northern Borneo. It lies between the latitude of 3°46'00"N and longitude of 100° 59' 00"E. It is located about one kilometer towards the eastern part of Semporna and also separated from the mainland by a navigable channel known as Terusan Tanda Bulong (Ziegenhorn, 2016). In Eastern Malaysia, Sabah is the only State, where there is a custom of consuming sea urchins roe and exploits the species without knowing the status of natural stock (Ziegenhorn, 2016). Sabah has an astonishing array of most beautiful islands off its coastlines. Such an attractive marine research area makes it regularly sought after by divers, as the seas are copious in coral reefs and marine life. It is a partly forested island that covers an area of 45 km^2. It measured 12.8 km from the North-South and 19.7 km from the East–West.

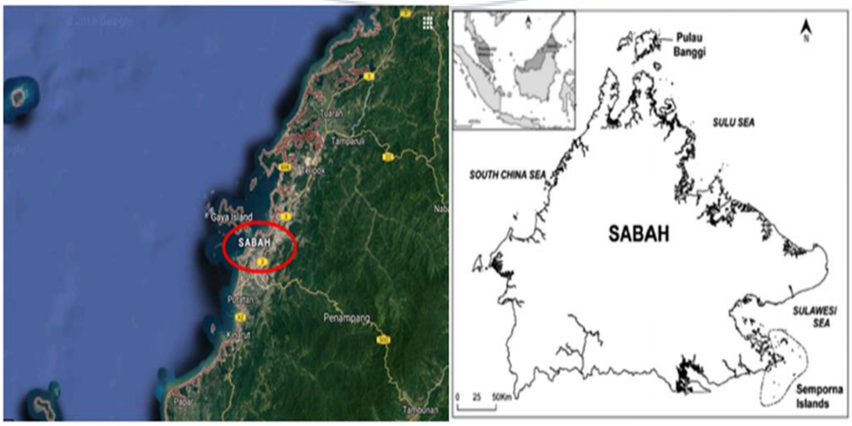

Figure 7. Satellite and sketch maps of Sabah, eastern Malaysia

Figure 8. Map of the study area and collection site of *T. gratilla* at Pulau Bum Bum (Bum Bum Island), Sabah, Eastern Malaysia

2.1 Sample collection and measurements

The length and weight data from the monthly samples of the commercially important sea urchin (*T. gratilla*) was collected from Bum Bum Island (Pulau Bum Bum), Semporna, Sabah State, Malaysia between January and December 2016. A mesh bag attached to a maypole was used by divers for collection. A total of 615 live *T. gratilla* specimens (Table 1) were collected during the entire experimental period and each individual was measured to the nearest 0.05 mm for total length (TL) using vernier caliper and weighed to nearest 0.01 g for the total weight (TW) using digital electronic balance (Fig. 9). The mean live weight was 241.09 ± 0.5 g with a range between 49.76 and 457.98 g, and the mean length was 8.66 cm ± 0.5 cm. The data were then grouped into length-frequency classes by 1.0 cm classes (Table 1).

Figure 9. The measurement of *T. gratilla* using digital electronic vernier caliper on the left and electronic weighing balance on the right

Table 1. Monthly pooled length-frequency data of *T. gratilla* from the coastal waters of Semporna, Sabah, Eastern Malaysia during the one year experimental period between January and December 2016

ML	JAN.	FEB.	MAR.	APR.	MAY.	JUN.
4.5		2				
5.5	1					
6.5		3				
7.5	3	3	5	7	13	5
8.5	21	15	15	20	32	13
9.5	20	16	21	21	6	16
10.5	4	10	10	2		10
11.5		1	2			
TOTAL	**49**	**50**	**53**	**50**	**51**	**44**

ML	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
4.5			2			
5.5	7		15		1	1
6.5	19	4	35	37		
7.5	21	17	1	17	3	3
8.5	6	17	1	4	20	21
9.5		15			21	20
10.5		1			3	4
11.5		1			1	
TOTAL	**53**	**55**	**54**	**58**	**49**	**49**

2.3 Data analysis

The data were analyzed using FiSAT (FAO-ICLARM Stock Assessment Tools) software. According to Pauly and David (1981), the best growth curve in arriving fitted curve through the maximum number of patterns of the length-frequency distribution was based on the ELEFAN I procedure. With the aid of the best growth curve, the von Bertalanffy growth function (VBGF) parameters (L_∞) and (K) were calculated and the resulting values were used to estimate the growth performance index (φ) in terms of length growth of *T. gratilla* using the following formula:

$\varphi' = Log_{10}\ K + 2Log_{10}L$ (Munro and Pauly, 1983; Pauly and Munro, 1984).

The linear relationship W = aL^b was applied to achieve the length-weight relationship (Le Cren, 1951; Riccker, 1975; Quinn and Deriso, 1999). W, L, (a) and (b) represents the weight, the total length, the intercept and the relative growth rate or the slope respectively. The least squares linear graph regression on log-log transformed data were used to estimate the values of (a) and (b) parameters as $Log_{10}W = Log_{10}a + bLog_{10}L$. The coefficient of determinant (r^2) was used as an indicator the quality of the linear regression (Scherrer, 1984). In addition, the statistical significance level r2 and 95% confidence intervals of the parameters (a) and (b) were estimated.

To find the length of the *T. gratilla* at any ages, the inverse von Bertalanffy growth equation (Sparre and Venema, 1992) was used. Then, the non-linear squares estimation method was used in fitting VBGF to estimate the length-at-age curve (Pauly et al., 1992). The Von Bertalanffy growth function formula:

$$Lt = L\infty\left(1 - e^{-k(t-t0)}\right)$$

where L_{t}, L_{∞}, K, t, and t_0 are respectively represent the mean length at age t, the asymptotic length, the growth coefficient, the age of the specimens and the hypothetical age at which the length is zero (Newman, 2002).

Length converted catch curve was used to compute the total mortality (Z) whereas the empirical relationship was used to calculate the natural mortality (M) (Pauly, 1984, 1980):

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

Definitions of the above parameters remain the same with T representing mean annual habitat water temperature. After computing the Z and M values, which are the total mortality and natural mortality respectively, the fishing mortality (F) value was easily estimated using the linear relationship:

$$F = Z - M$$

However, the estimated values of the above expression make it possible to reckon the exploitation level (E) Gulland (1965) of *T. gratilla* using the equation:

$$E = \frac{F}{Z} = \frac{F}{F + M}$$

The retrograde projection of the set of available length-frequency data on the length axis as clarified in FiSAT II was used in discovering the recruitment pattern of the stock. The relative strength of pulse and number of pulses per year was determined by series of length-frequency data using the parameter L_∞, K and t_0 (t_0 = 0) described above. The NORMSEP procedure in FiSAT II was also used to determine the Normal distribution of the recruitment patterns (Pauly and Caddy, 1985).

3 Results

3. 1 Population Structure of *T. gratilla*

3.1.1 Size structure and length-weight relationship

The length-weight relationships of *T. gratilla* are drawn on a scattered plot of total converted length on the X-axis and weight on the Y-axis (Fig. 10). The parameters such as growth constant (a) and relative growth rate were estimated to be 0.9563 and 2.5634, respectively. The equation $TW = 0.9563TL^{2.5634}$ was obtained at the end of the result. The biometric relationship displayed a positive correlation between length and weight (R^2 = 0.847). The growth coefficient (b) was significantly different and also less than 3 (Student's t-test; $P < 0.05$), indicating a negative algometric growth pattern in *T. gratilla*.

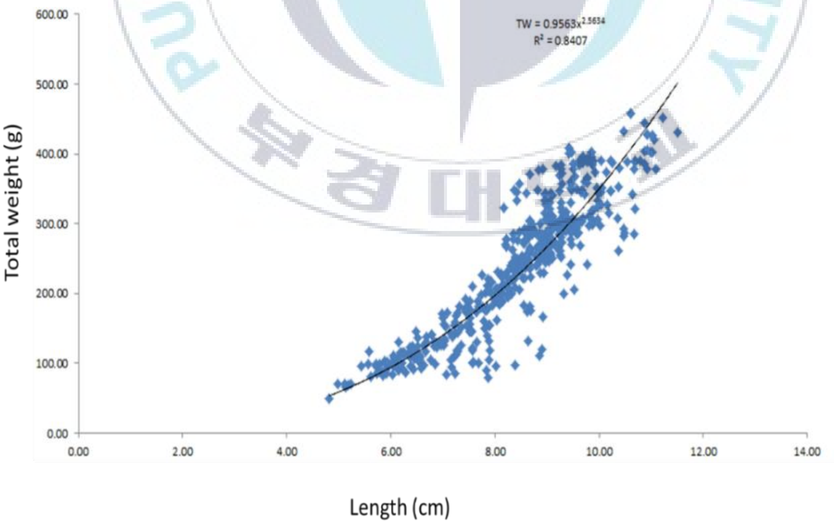

Figure 10. Length weight relationship of *T. gratilla* from the coastal waters of Sabah, Eastern Malaysia during the sampling periods between January and December 2016 (arithmetic scale)

3.2 Population parameters and stock status of *T. gratilla*

3.2.1 Growth parameters

The growth curve of a pooled length size distribution of *T. gratilla* is shown in Fig. 8. The growth parameters of Von Bertalanffy growth formula was estimated as asymptotic length ($L\infty$) = 12.38 cm and growth coefficient (K) = 1.7 yr^{-1} (Table 2). The values of $L\infty$ and K were used for the calculation of growth performance index ($\varphi' = Log_{10}K + 2Log_{10}L$), which was found to be 2.42. The potential longevity (t_{max} =3/K) was estimated as 1.765 years indicating that the *T. gratilla* can live for not more than 2 years in the habitat where the study was carried out. This value also showed the presence of a range of length-classes of *T. gratilla* that were captured is belongs to two cohorts season. The black and white bars in the restructured length-frequency distribution are positive and negative deviations from the weighted moving average of three-length classes (Fig. 11). However, the lifespan which defined the period needed for aquatic fish to attain 95% of its asymptotic length (King, 1995) showed a relatively short period for *T. gratilla* to reach K.

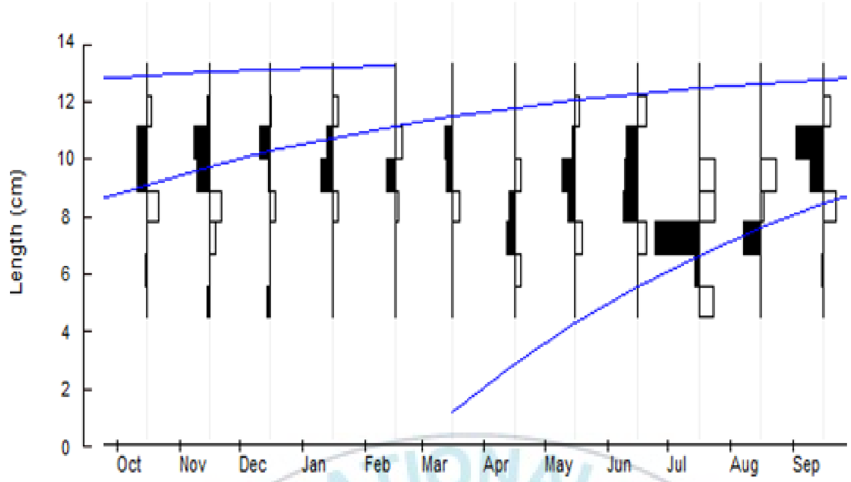

Figure 11. Growth curve of *T. gratilla* by ELEFAN 1 superimposed on the restructured length-frequency diagram (L∞ = 12.38 cm and K = 1.7/yr.)

3.2.2 Mortality and exploitation rate

Length converted catch curve analysis produce total mortality estimates value of Z = 4.94/yr for *T. gratilla* (Fig. 12). The natural mortality and fishing mortality were estimated at 3.24/yr and 1.71/yr, respectively at an ambient average temperature of 28℃. The above parameters were used for the determination of the exploitation level of *T. gratilla* in the Island.

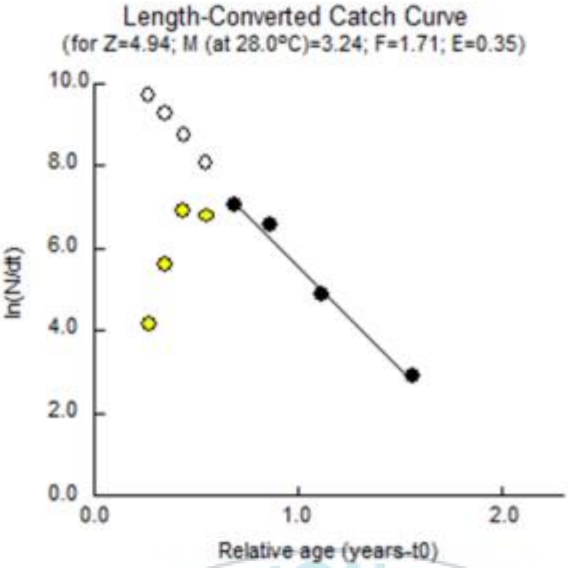

Figure 12. Length-converted catch curve of *T. gratilla* in the coastal waters of Bum Bum Island, Semporna, Sabah State, Malaysia

Table 2. Population parameters of sea urchin (*Tripneustes gratilla*) in the coastal waters of Bum Bum Island, Semporna, Sabah State, Malaysia

Parameters	***Tripneustes gratilla***
Asymptotic length value (L∞) (cm)	12.38
Growth coefficient or constant (K) per year	1.7
Natural mortality estimation(M)	3.23
Fishing mortality (F) per year	1.71
Total mortality (Z) per year	4.94
Exploitation (E)	0.35
Length range (cm)	4.5-11.5
Sample number	615

Average temperature (℃)	28
Growth performance (φ)	2.42
Potential longevity (t_{max} =3/K) years	1.76

The exploitation rate of *T. gratilla* was estimated E = 0. 35 /yr. The results revealed that the stock is underfished based on the assumption from Guland (1983) that an optimum exploitation of a stock become apparent when E = 0.5 or when fishing mortality equal to total mortality of the species. The empirical estimated result (E = 0.35 /yr.) could be associated with both intrinsic and extrinsic factors. Nevertheless, high demand, as well as continuous harvesting and unstrained exportation of the species show a likelihood of overexploitation and depletion of *T. gratilla* stocks in the future. Fig. 13 represents the relative yield per recruit and biomass per recruit of the species at ogive option of E_{50} = 0.35 yr^{-1}.

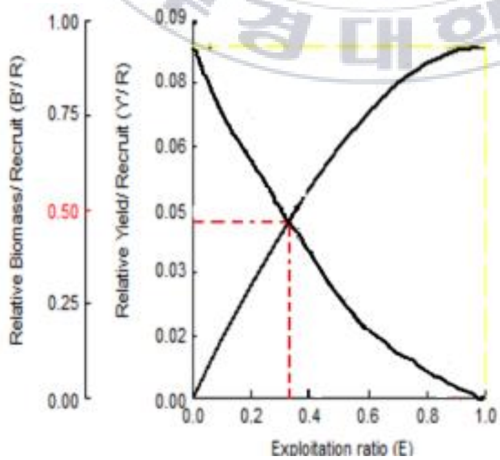

Figure 13. Relative yield per recruit and biomass per recruit curves for *T. gratilla* from Bum Bum Island, Sabah, Malaysia

3.2.3 Recruitment pattern of *T. gratilla*

The recruitment pattern of *T. gratilla* was observed to be continuous throughout the year with the maximum recruitment peak observed between the months of October and November (Fig. 11). The results revealed a single modal pattern of the species with a relative highest peak of recruitment at 18.0% during the month of November. However, there was a sharp decline in the pattern in the month of December and the lowest recruitment (<1%) was found in March (Fig. 14).

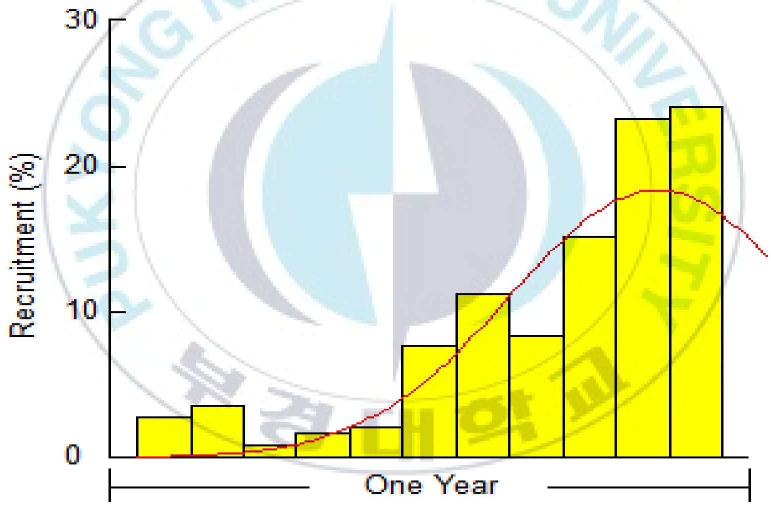

Figure 14. Recruitment pattern of *T. gratilla* in Bum Bum Island, Sabah, Malaysia during January-December 2016

3.2.4 Cumulative probability of capture

The predicted highest length of *T. gratilla* value and 95% confidence interval are generated from the intersection of overall highest converted length at the various intersection lines is shown in Fig. 15. The figure estimates the probability of capture at the first size extreme length 8.00 cm, and this value is less than the average converted length 8.44 cm.

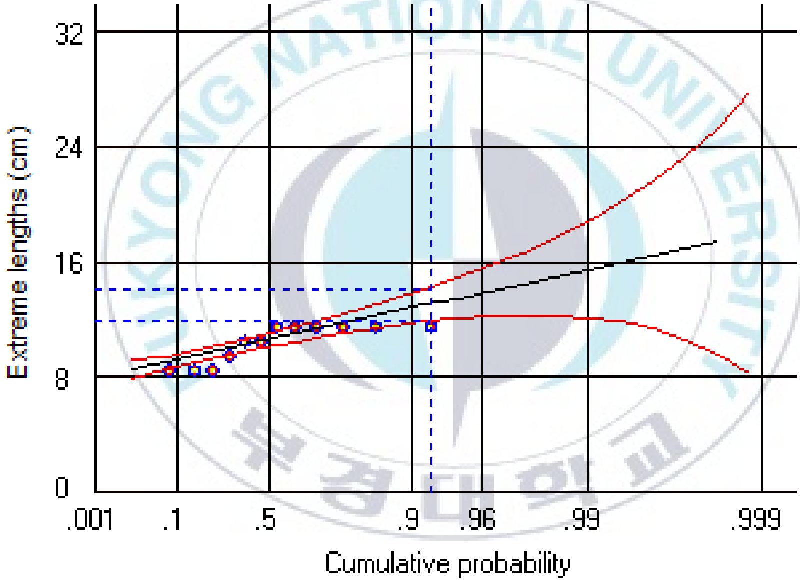

Figure 15. Cumulative probability of *T. gratilla.* The predicted maximum length value and the 95% confidence interval are obtained from the intersection of the overall maximum length with the line y and x, z, respectively

3.2.5 Virtual population analysis (VAP)

The fallouts of the length-structured VPA of *T. gratilla* together with the length-weight relationship is depicted in Fig.16. The result indicates that the fishing mortality was at a very minimal rate at 4.5 cm mid-length group and the highest mortality rate of 4.08 was at 9.0 cm mid-length group. The survival rate was high at minimum length and a sharp decline as the length increases. However, the fishing mortality was comparatively low over mid lengths from 5.8 mm to 6.5 cm and the values were higher from 7.5 cm to 9.0 cm mid-length.

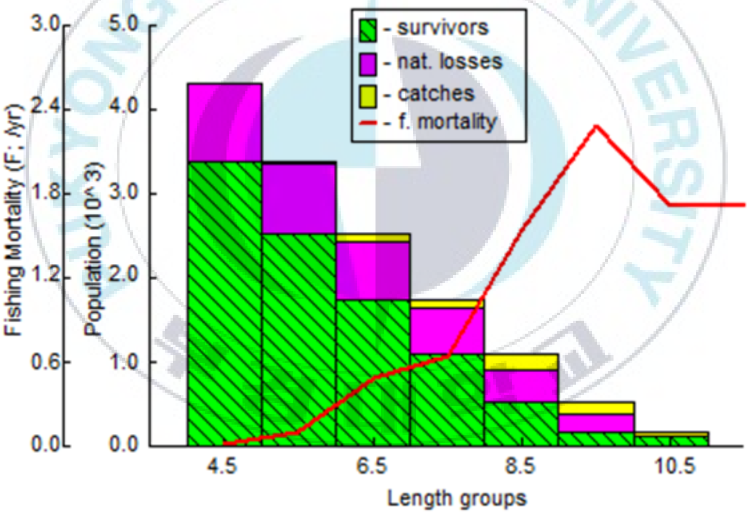

Figure 16. Length structured virtual population analysis (VPA) of *T. gratilla* in Bum Bum Island, Sabah, Malaysia

4 Discussion

The length-weight relationship is vital in the studies of gonad development, metamorphosis, the rate of feeding, maturity, and well-being of the fish population (Le Cren, 1951). Characteristics of the length-weight relationship in fishes and invertebrates like this Echinoderm sea urchin (*T. gratilla*) revealed that the (b) value of the exponent is 3 when the growth in weight is isometric and allometric when the value is less lesser and higher than 3. This implies that when b<3, the body of species changes with a shape as it grows larger, and when b>3, no changes in body shapes as the species grow larger. However, this study showed a negative allometric growth coefficient of 2.56 for *T. gratilla* in Sabah, where the study was carried out. There has been a similar study in different species by Rahman et al. (2012) where b value recorded for *Diadema setosum i*n Pangkor Island, Malaysia was negative allometric with the estimated b value of 1.83, which was much less than the present study for *T. gratilla*. Further studies concerning distributions patterns, environmental factors, and feeding biology, are urgently needed to understand the actual reasons for negative

allometric growth in *T. gratilla* around the study area of Eastern Malaysia.

The Asymptotic length (L∞) of *T. gratilla* was found to be 12.38 cm with the growth coefficient (K) value of 1.7 yr^{-1}. A study was also conducted in Southern Guimaras where Regalado et al. (2011) found different values of L∞ and K than those obtained by Bacolod and Dy (1986) and Juinio-Menez et al. (2008) in *T. gratilla* (Table 3). Differences in the estimates of growth parameters revealed that conditions of a particular site and food availability might affect the growth rates and size of *T. gratilla* including the areas where the present research was conducted.

Table 3. Comparisons of asymptotic length (L∞) and growth coefficient (K) values of *T. gratilla* in different study areas

Location	Species	L∞ (cm)	K /yr.	References
Malaysia	*T. gratilla*	12.38	1.7	Present study
Southern Guimaras	*T. gratilla*	11.40	1.08	Regalad-o et al. (2011)
Danahon Bank, Bohol	*T. gratilla*	10.80	1.80	Bocolod and Dy (1986)
Quezon Island, Bolinao	*T. gratilla*	11.30	1.30	Menez et al. (2008)

In this study natural mortality (M) and fishing mortality (F) were found to be 3.24 yr^{-1} and 1.71/yr., respectively for *T. gratilla* with an exploitation level (E) of 0.35. In the absence of unexploited natural resources, it is often tedious to estimate natural mortality (M) empirically, therefore based on the knowledge of the life history characteristics (Joseph, 2014) of *T. gratilla*, a qualified guess of M was estimated. Even though, research suggests that once the juveniles of *T. gratilla* are beyond the parental care, natural mortality initially is relatively high. However, the resulted in higher natural mortality (N); than the fishing mortality (F) showed a clear indication that the stock is under-fished, which means the lower the F value, the lower the exploitation rate. Moreover, yield is optimized when fishing mortality equals to natural mortality and exploitation rate at 0.5 is considered optimum level, and so when the exploitation rate is more than 0.5, the stock is said to be over-fished (Gulland, 1965).

The total instantaneous mortality, Z = 4.94 /yr. of *T. gratilla* in our study was more than the F value, which could be attributed to factors such as predations as some urchins have been observed attacking and preying on each other (Tsuchiya et al., 2009), disease, overpopulation of the stock and other exogenous sources that lead to death of urchins before attaining their expected lifespan. According to Vaitlingon (2005), sea urchins are most often killed by bad weather and heavy rainfall. However, mortality in urchins could be attributed to the fact that the juveniles are not targeted in the fishery or caught as bycatch since the larger the size of urchin caught, the larger the size of gonad and the price at market. It means there is a pragmatic approach to modeling age-specific mortality, which makes the mature urchins an explicit interest in the fishery (Djiman et al., 2016). In simple terms, M could be dichotomized into intrinsic and extrinsic effects in the fishery. The reliability of M determined by M/K ratio is in the range of 1.22- 2.50 for most fish species (Djiman et al., 2016). However, the M/K ratio (3.23/1.7) of 1.9 obtained was within the above range, indicating that the natural mortality estimates were reliable for *T. gratilla* in the present study site. Again, according to Barry and Tegner (1989), ratio Z/K denotes predominance of growth on the mortality of the population if is <1 and >1 shows predominant of mortality on growth. Conversely, ratio Z/K = 1 means mortality is at a state of equilibrium on the population with the growth. The result (Z/K = 4.94/1.7 = 2.9) obtained from the present study showed that the mortality of *T. gratilla* was predominant on growth.

Again, from the probability curve of capture, the values estimated for the size at first capture was slightly less than the average converted length which showed that smaller size is also caught in the fishery. This also means that smaller sizes are not giving the opportunity to mature into full adult size before harvesting. Moreover, it could be attributed to small size net and illegal fishing gears used in the harvesting of the species. It is therefore recommended that large mesh sized nets of above 8.5 cm can be used for sustainability of the fishery.

The growth performance index (φ) obtained is the basis for comparison of growth indicators with the von assumption of Bertalanffy model. The index is the accurate and genuine procedure of computing the average growth parameters of a particular species according to Spare and Venema (1997). Henceforth, it should not differ significantly from compared values of different groups of data for the same kinds. However, the result obtained for φ (2.42) in *T. gratilla* seemed to be in the acceptable range. For the reason that a comparable study conducted by Djiman et al. (2015) obtained the value of φ = 2.43. According to Baijot and Moreau (1997), the classified growth performance index between the range of 2.65 to 3.32 is considered as a slow growth rate. The slow growth performance of *T. gartilla* obtained in the present study could be attributed to natality as it have a paramount influence to cause a population to increase or decrease. Therefore natality in the study site should be discouraged.

In our study, the recruitment pattern of *T. gartilla* was found to be continuous throughout the year. The lowest and the highest percentage of recruitments were observed in November (18%) and March (<1%), respectively. Until now, there has been no published report on the recruitment of *T. gratilla* in Malaysia. However, the previous study of recruitment pattern of *T.gratilla* in Southern Guimaras waters by Regalado et al., (2011) revealed that the recruitment occurred almost throughout the year with two peaks separated by four to five months.

The present study demonstrates that *T. gratilla* attained a maximum size of 115 mm (11.5 cm) within the 2 years of age. Previous study demonstrated that an individual with 40 mm on the Atlantic coast of Europe can be 2.5 years old, while a similarly sized individual in the western Mediterranean can be as old as 4 years (Sellem et al., 2000). While working in the Marseille (France), Regis (1979) reported an individual of 42 mm diameter which was 11 years old, however, Turon et al. (1995) observed in Spain an individual of 40 mm was over 5 years of age. The varry results comparisms can be said that lifespand is dependent on the location of the species natural harbitat and other factors.

5 Conclusion

We estimated that *T. gratilla* is a relatively fast-growing species compared to the other Echinoids (Echinodermata: Echinoidea). The population has high natural mortality and the pressure from fishing activities to the wild stocks are still minimal and the stocks can be said to be underexploited. Our study also represents the first attempt to delineate the basic information on the population’s structures, stock status and growth performances of the *T. gratilla* population. As there have been continuous demand and harvesting of this endemic high valued *T. gratilla* throughout the world, proactive measures have to be taking to avoid a future threat of overexploitation. Since this research is the first of its kind in the study area, we strongly hope that the outcome of this research would be of great help for Malaysian as well as global sea urchin fisheries industry.

6 References

Abdul, Hamid, A.T., Sumitro, S.B., Widodo, N.B., Hakim, L. (2015). Color diversity and distribution of sea urchin *Tripneustes gratilla* in Cenderawasih Bay eco region of Papua, Indonesia. *The Egyptian Journal of Aquatic Research* 41(3), 273-278.

Abdul, Hamid, A.T., Binur, R., Lutfi, S., Hakim, L., Widodo, B.N., Sumitro, S.B. (2014). Genetic aspects of the commercially used sea urchin *Tripneustes gratilla*. *Journal of Biological Researches*, 20(2), 12-17.

Amirali, M., Daliri, M., Raeisi, H., Haghparast, S., Yousefi, J.A., Bahmani, M., Roudbaraki A.F., Vahabnejhad, A. (2016). Population dynamic of *Acipenser persicus* (Borodin, 1897) in the southern Caspian Sea (Guilan province) using Monte Carlo and Bootstrap methods. *International Conference on the Future of Sturgeon Aquaculture*, 142-144.

Andrew, N.L., Agatsuma, Y., Ballesteros, E., Bazhin, A.G., Creaser, E.P. (2002). Status and management of world sea urchin fisheries. *Oceanography and Marine Biology Annual Review*, 40, 343-425.

Bacolod, P.T., Dy, D.T. (1986). Growth, recruitment pattern and mortality rate of sea urchin, *Tripneustes gratilla* Linnaeus, in a seaweed farm at Danahon Reef, Central Philippines. *Philippines Science*, 23, 1-14.

Baijot, E., Moreau, J. (1997). Biology and demographic status of the main fish species in the reservoirs of Burkina Faso. In Baijot E, Moreau J, Bouda S, Ed: Hydrological Aspects of Fisheries in Small Reservoirs in the Sahel Region, Wageningen, Netherlands: *Technical Centre for Agricultural and Rural Cooperation*, 79-109.

Barry, J.P., Tagner, M.J. (1989). Ecological Heterogeneity. *Springer Science & Business Media*, 299 pp.

Beverton, R.J.H., Holt, S.J. (1957). On the dynamics of exploited fish populations. *Fishery Investigation Series*, 19, 533 pp.

Chang-Po, C., Kun-Hsiung, C. (2012). Reproductive periodicity of the sea urchin, *Tripneustes gratilla* (l) in Taiwan: compared with other regions, *International Journal of Invertebrate Reproduction*, 3(6), 309-319.

Conklin, E.J., Smith, J.E. (2005). Abundance and Spread of the Invasive Red Algae, *Kappaphycus* spp., in Kane'ohe Bay, Hawai'i and an Experimental Assessment of Management Options. *Journal of Biological Invasion* 7(6), 1029–1039.

Dafni, J. (1992). Growth Rate of the Sea Urchin *Tripneustes gratilla elatensis*, Israel Journal of Zoology, 38(1), 25-33.

Digby, M.C. (2013). The use of ulva as a feed supplement in the development of an artificial diet and feeding regimes to produce export quality roe from the sea urchin *Tripneustes gratilla* (linnaeus). Prof. John J. Bolton, University of Cape

Town Dr. Brett M. Macey, Department of Agriculture, Fisheries and Forestry, South Africa.

Dincer, T., Cakli, S. (2007). Chemical composition and biometrical measurements of the Turkish Sea urchin (*Paracentrotus lividus*, Lamarck, 1816). *Critical Reviews in Food Science and Nutrition*, 47, 21-26.

Djiman, L., Chikou, A., Vreven, E., Snoeks, J., Moreau, J., Vandewalle, Laleye, P. (2015). Population parameters and exploitation rate of *Sarotherodon melanotheron melanotheron rüppell*, 1852 (Cichlidae) in: Lake Toho, Benin. *Journal of Biodiversity and Environmental Sciences (JBES) ISSN*, 6(2), 259-271.

Djiman, L., Vandewalle P.A., Brahim, A., Moreau, J., Laleye, P. (2016). Population parameters and exploitation rate of *Sarotherodon galilaeus galilaeus* (Cichlidae) in Lakes Doukon and Togbadji, Benin. *African Journal of Aquatic Science* 41(2), 151-160.

FAO, (2009). Fishery and Aquaculture Statistics. FAO yearbook 2009. *FAO Fisheries Department*, Rome, Italy, 1 – 80.

FAO, (2012). State of World Fisheries and Aquaculture 2006. *FAO Fisheries Department*, Rome, Italy, 1 – 209.

Gulland, J.A. (1983). Fish Stock Assessment. A Manual of Basic Method. *FAO/Wiley Series on Food and Agriculture, Rome*, 241.

Gulland, J. A. (1965). Estimation of mortality rates. In: Annex to Arctic Fisheries Working Group Report *ICES C*. pp.231–241.

Hamid Abdul A.T., Sutiman B.S., Luchman H., Nashi W., Robi, B., Suhaemi, Aji, W.A. (2017). Biology of the commercially used sea urchin *Tripneustes gratilla* (Linnaeus, 1758) (Echinoidea: Echinodermata). *Ocean Life. 1(1), 1-10.*

Joseph, E.P. (2014). Age-specific natural mortality rates in stock assessments: size-based vs. density-dependent. *ICES Journal of Marine Science*, 71(7), 1629–1637.

Juinio-Meñes, M., Bangi, H.A., Malay, M.G., C., D. (2008). Effect of type of feed, stocking density and grow-out site on gonad index, growth and survivorship of cultured sea urchin (*Tripneustes gratilla*). *Philippines Agriculture Science*, 91 (4), 439-449.

Kay, E.A. (1994). Marine ecosystems in the Hawaiian Islands. In: Kay EA, editor. A natural history of the Hawaiian Islands: selected reading II. Honolulu: *University of Hawaii Press*; 1994, 187–195.

Klumpp, D.W., Salita-Espinosa J.T., Fortes, M.D. (1993). Feeding ecology and trophic role of sea urchins in a tropical seagrass community. *Aquatic Botany*, 45(2-3), 205-229.

King, W.R., Sabherwal, R. (1995). An Empirical Taxonomy of the Decision-Making Processes Concerning Strategic Applications of Information Systems. *Journal of Management Information Systems*, 11(4), 177-214.

Koike, I., Mukai, H., Nojima, S. (1987). The role of the sea urchin, *Tripneustes gratilla* (Linnaeus), in decomposition and nutrient cycling in a tropical seagrass bed. *Jounal of Springer link* 2(1), 19-22.

Lessios, H.A., Kane, J., Robertson, D.R. (2003). Phylogeography of the pantropical sea urchin *Tripneustes*: contrasting patterns of population structure between oceans. *BioOne Complete Journal* 57(9) 2026-36.

Lesser, M.P., Carleton, K.L., Böttger, S.A., Barry, T.M., Walker, C.W. (2011). Sea urchin tube feet are photosensory organs that express a rhabdomeric-like opsin and PAX6. Proceedings of the Royal Society B: *Biological Sciences*, 278(1723), 3371–3379.

Lawrence, J.M., Lawrence, A.L., McBride, S.C., George, S.B., Watts S.A., Plank, L.R. (2001). Developments in the use of prepared feeds in sea-urchin aquaculture. *Journal of World Aquaculture society*, 32(3), 34-39.

Lawrence, J.M., Otaiza, S.O.R., Lawrence A.L., Bustos, E. (1997). Enhancement of gonad production in the sea urchin *Loxechinus albus* in Chile fed extruded feeds. *Journal of World Aquaculture* Society, 28(1), 91-96.

Le Cren, E.D. (1951). The length weight relationship and seasonal cycle in gonadal weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology* 20, 271-279.

Linnaeus, C. (1758). System through the three kingdoms of nature, classes, orders, the genera, the species, with the characters, the differences, synonyms, places. Edition; reformed. Lawrence Salviua, *Stockholm. II*, 824 pp.

Matsuoka, N. (1993). Biochemical systematics of echinoderms. *Zoological Society of Japan* 20(8), 985-988.

Md. Shamim, Parvez, M., Aminur, Rahman, Fatimah, Md., Yusoff, A., Arshad, Sang-Go Lee, (2017). Studies on the ontogenic development of a high-valued tropical sea urchin, *Tripneustes gratilla* (Linnaeus, 1758) for seed production and commercial aquaculture. *International Journal of Advances in Chemical Engineering and Biological Sciences (IJACEBS)*, 5(1), 6-14.

Miskelly, A. (2002). Sea Urchins of Australia and the Indo-Pacific. *Capricornica Publications*, Sydney, Australia, ISBN: 9780957745568, 180p.

Moreau, J., Bambino, C., Pauly, D. (1986). A comparison of four indices of overall growth performance based on 100 tilapia populations (Fam. Cichlidae). In: Maclean J, Dizon LB, Hosillo LV, Ed. The first Asian fisheries forum, *Asian Fisheries Society, Manila*, 201-206.

Munro, J.L., Pauly, D. (1983) A Simple Method for Comparing Growth of Fishes and Invertebrates. *ICLARM Fishbyte*, 1, 5-6.

Nancy, B., Ogden, C.J., Isabella, A.A. (1989). Distribution, abundance and food of sea urchins on a leeward hawaiian reef. *Bulletin of marine science*, 45(2), 539-549.

Newman, S.J. (2002). Growth, age estimation and preliminary estimates of longevity and mortality in the moses perch, Lutjanus russeli (Indian ocean form), from continental shelf waters off north-western Australia. *Asian Fish Science*, 15, 283-294.

Parvez, M.S., Rahman, M.A., Yusoff, F.M. (2016). Sea urchin fisheries in Malaysia: status, potentials and benefits. In: Rahman, M.A. and Monticolo D. (eds.), Proceedings of the 5th International Conference on Chemical Engineering and Biological Sciences. *International Scientific Academy of Engineering and Technology*, Kuala Lumpur, Malaysia, 14–16.

Philip, J., Siikavuopio, S. (2012). A Guide to the Sea Urchin Reproductive Cycle and Staging Sea Urchin Gonad Samples. Philip James (philip.james@nofima.no) Sten Siikavuopio (sten.siikavuopio@nofima.no) Nofima AS Muninbakken 9-13, Breivika P.O.Box 6122 NO-9291 Tromsø Tel. +47 77 62 90 00 Fax +47 77 62 91 00 E-mail: nofima@nofima.no. *Nofima*, 9-13.

Pauly, D., Munro, J.L. (1984). Once More on the Comparison of Growth in Fish and Invertebrates. *ICLARM Fishbyte*, 2, 21.

Pauly, D., David, W. (1981). ELEFAN 1, BASIC Program for the Objective Extraction of Growth Parameters from Length-Frequency Data. *Journal of Meeresforch*, 28, 205-211.

Pauly, D. (1980). On the Interrelations between Natural Mortality, Growth Parameters and Mean Environmental Temperature in 175 Fish Stocks. *ICES Journal of Marine Science*, 39, 175-192.

Pauly, D., Soriano, M.L. (1985). Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In: First Asian

Fisheries Forum, *Asian Fisheries Society* (eds. J. L. Maclean, L. B. Dizon and L. V. Hosillos), 149–495.

Pulz, O., Gross, W. (2004). Valuable products from biotechnology of microalgae. Applied Microbiol. Biotechnol, 65: 635-648.

Quinn, T. J. II, Deriso, R.B. (1999). Quantitative fish dynamics. Oxford University Press, Oxford. *Agricultural Sciences*, 4, 8.

Rahim, S.A.K.Ab, Nurhasan, R. (2016). Status of Sea Urchin Resources in the East Coast of Borneo. *Journal of Marine Biology*, 2016, 8.

Rahman, M.A., Amin, S.M.N., Yusoff, F.Md, Arshad, A., Kuppan P., Shamsudin, M.N. (2012). Length weight relationships and fecundity estimates of long-spined Sea Urchin, Diadema setosum, from the Pulau Pangkor, Peninsular Malaysia. *Aquatic Ecosystem Health & Management*, 15(3), 311-315.

Rahman, M.D.A., Fatimah, Md., Yusoff, A., Arshad, S.M.N., Amin, M., Shamsudin, N. (2013). Population Characteristics and Fecundity Estimates of Short-spined White Sea Urchin, Salmacis sphaeroides (Linnaeus, 1758) from the Coastal Waters of Johor, Malaysia. Asian Journal of Animal and Veterinary Advances, 8, 301-308.

Rahman, M.A., Yusoff, F.M. Arshad, A. (2014). Potential and prospect for sea urchin resource development in Malaysia. *Fishmail*, 21, 16–18.

Rahman, M.A., Uehara, T., Lawrence, J.M. (2005). Growth and heterosis of hybrids of two closely related species of Pacific sea urchins (genus Echinometra) in: Okinawa.Aquaculture, *Journal of aquaculture*, 245, 121–133.

Rahman, M.A., Yusoff, F.M., Arshad, A., Amin, S.M.N, Shamsudin, M. N. (2013). Population Characteristics and Fecundity Estimates of Short-spined White Sea Urchin, *Salmacis sphaeroides* (Linnaeus, 1758) from the Coastal Waters of Johor, Malaysia. *Asian Journal of Animal and Veterinary Advances*, 8(2), 301-308.

Rahman, M.A., Yusoff, F.M. (2010). Sea urchins in Malaysian coastal waters. *The Oceanographer*, 4, 20–21.

Rahman, Md., Yusoff, F.M., Marimuthu, K. (2017). Sea Urchin - A New Potential Marine Bio-resource for Human Health. In: S. Bhore, K. Marimuthu and M. Ravichandran (eds.), Biotechnology for Sustainability: Achievements, Challenges and Perspectives. *AIMST University*, Kedah, Malaysia, 418-444.

Rahman, M.A., Yusoff, F.M., Arshad, A. (2014). Potential and prospect for sea urchin resource development in Malaysia. *Fishmail*, 21, 16–18.

Rahman, S., Tsuchiya, M., Uehara, T. (2009). Effects of temperature on hatching rate, embryonic development and early larval survival of the edible sea urchin, *Tripneustes gratilla. Biologia*, 64 (4), 768-775.

Regalado, J.M., Campos, W.L., Santillan, A. S. (2010). Population biology of *Tripneustes gratilla* (Linnaeus) (Echinodermata) in seagrass beds of Southern Guimaras, Philippines. *Science Diliman*, 22(2), 41 – 49.

Regis, M.B. (1979). Analysis of fluctuations in physiological indices in two echinoids (*Paracentrotus lividus* and *Arbacia lixula L*.) in the Gulf of Marseille in the Bay of Marseille. *Tethys*, 9, 167-181.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, Bulletin 191, Ottawa. *Agricultural Sciences*, 5, 2.

Robinson, S.M. (2004). The Evolving Role of Aquaculture in the Global Production of Sea Urchins. In: Sea Urchins Fisheries and Ecology, Lawrence, J.M. and O. Guzman (Eds.). *Fishmail*, 21, 16–18.

Rodolf, T.P. (2012). The growth and survival of the sea urchin *Tripneustes gratilla*, a possible biocontrol agent for invasive macroalgae. University of Hawaii.

https//scholarspace.manoa.hawaii.edu/bitstre-Am/10125/101316/1/Pan_Rodolf_r.pdf.

Saifur, R., Tsuchiya M., Uehara, T. (2009). Effects of temperature on hatching rate, embryonic development and early larval survival of the edible sea urchin, *Tripneustes gratilla*. *Journal of Biologia* 64(4), 768-775.

Sea Urchin Harvesters Association California, (2000). "SUHAC Home-page" (On-line). Accessed 11/10/2018, GMT: 6:30. http://www.seaurchin.org.

Sellem, A., Langar, H., Pesando, D. (2000). Age and growth of the sea urchin *Paracentrotus lividus* Lamarck, 1816 (Echinodermata-Echinoidea) from the gulf of Tunis (Mediterrannean). *Oceanologica Acta*., 23 (5), 607-613.

Scherrer, B. (1984). Biostatistics. *Gaëtan Morin Publisher*, 1999. Systat version 15.

Sparre, P., Venema, S.C. (1992). Introduction to Tropical Fish Stock Assessment. Part 1. Manual, FAO Fisheries Technical Paper, 306. No. 1, Review 1, *FAO*, Rome, 376.

Scholtz, R., Bolton, J.J., Macey, B.M. (2013). Effects of different microalgal feeds and their influence on larval development in the white-spined sea urchin *Tripneustes gratilla*. *African Journal of Marine Science* 35(1), 25-34.

Sheppard, B.H., Soars, N., Dworjanyn, S.A., Davis, A.R., Byrne, M. (2010). Impact of Ocean Warming and Ocean Acidification on Larval Development and Calcification in the Sea Urchin *Tripneustes gratilla*. *PLoS One* 5(6), 11372.

Siti, A.K.Ab.R., Nurhasan, R. (2016). Status of Sea Urchin Resources in the East Coast of Borneo, *Journal of Marine Biology*, 2016, 8.

Tan, L.W.H., Ng, P.K.L. (1988). A guide to seashore life. *Singapore Science Centre*, Singapore, 159.

Toha, A.H.A., Sumitro, S.B., Hakim, L., Widodo N., Binur, R., Suhaemi, Anggoro, A.W. (2012). Review: Biology of the commercially used sea urchin *Tripneustes gratilla* (Linnaeus, 1758) (Echinoidea: Echinodermata). *Journal of Ocean Life* 1, 1-10.

Tsuchiya, M., Nishihira, M., Poung-In S., Choohabandit, S. (2009). Feeding behavior of the urchin-eating urchin *Salmacis sphaeroides*. Galaxea, *Journal of Coral Reef Studies*, 11, 149–153.

Turon, X., Giribet,G., Lopez, S., Palacin, C. (1995). Growth and population structure of *Paracentrotus lividus* (Echinodermata: Echinoidea) in two contrasting habitats. *Marine Ecology Progress Series*, 122: 193–204.

Vaïtilingon, D., Rasolofonirina, R., Jangoux, M. (2005). Reproductive cycle of edible echinoderms from the Southwestern Indian Ocean. I. *Tripneustes gratilla* L. (Echinoidea, Echinodermata). *Western Indian Ocean Marine Science* 4 (1), 47-60.

Venema, P.S., Siebren, C. (1997). Introduction to the evaluation of tropical fish resources Part 1: Manual. *FAO Fisheries Technical Document*, 306(2), 420.

Whalen, K. (2008). Sea Urchin Dissection Protocol. Copy right 1997 *Carolina Biological Supply company* 2700 York road.

Westbrook, C.E., Ringang, R.R., Cantero, S.M., HDAR, TNC Urchin Team, Toonen, R.J. (2015). Survivorship and feeding preferences among size classes of outplanted sea urchins, *Tripneustes gratilla*, and possible use as biocontrol for invasive alien algae. *Peer Journal*, 3, 1235-7717.

Worley, A. (2001). Strongylocentrotus purpuratus. (Online), Animal Diversity web. Accessed October 31, 2018, GMT: 6:45PM.

http:// animaldiversity.org/accounts/strongylocentus_purpuratus/

Ziegenhorn, M.A. (2016). Best Dressed Test: A Study of the Covering Behavior of the Collector Urchin *Tripneustes gratilla*. *PloS one*, 11(4), 0153581.

Internet source:

https://www.amazingborneo.com/sabah/diving/sites, assessed: 4/08/2018, GMT: 6:48 pm.

http://www.pulaumabul.com/pulau-bum-bum, assessed: 9/08/2018, GMT: 8:21 pm.

https://e360.yale.edu/features/as-oceans-warm-the-worlds-giant-kelp-forests-begin-to disappear, Accessed: 12/10/2018 GMT: 4:59.