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Population Dynamics of *Echinometra mathaei* (Echinoidea: Echinodermata) Found on Buleji, Pakistan, North Arabian Sea

Saima Siddique[1]* and Zarrien Ayub[2]

[1]*Marine Reference collection and Resource Centre, University of Karachi, Karachi-75270, Pakistan*

[2]*Centre of Excellence in Marine Biology, University of Karachi, Karachi-75270, Pakistan*

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ZA supervised this research and performed all statistical analysis and interpretation. SS collected samples, executed laboratory work and wrote the manuscript.

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ABSTRACT

The population structure of *Echinometra mathaei* was studied monthly from May 2011 to November 2012 at a rocky shore of Buleji, Pakistan, Northern Arabian Sea. The test diameter and total weight showed significant temporal variations. The test diameter/wet weight and test height/wet weight relationships followed negative allometry while test height/test diameter showed an isometric relationship. Length-frequency distribution analysis was bimodal in different seasons with the exception of three modes in summer'2012 and one mode in autumn'2012. Estimated parameters of the von Bertalanffy growth functions include growth coeffient $(K) = 0.48$ $year^{-1}$, theoretical asymptotic maximum size $(TD\infty) = 8.2$ cm and hypothetical age at length zero $(t_0) = -0.55$ year. The longevity was calculated to be 5.7 years. The natural mortality coefficient was found to be 1.584 $year^{-1}$. Further detailed studies on biological/ecological parameters of *E. mathaei* are needed for better understanding and management of this species in Northern Arabian Sea.

INTRODUCTION

Echinometra mathaei (Blainville, 1825) is one of the world's most abundant sea urchin distributed both in tropical and sub-tropical zones (Mortensen, 1943; Clark, 1976). This species is found abundantly on a rocky coasts of Pakistan (Tahera, 1993). *Echinometra mathaei* occupied several types of habitats like, intertidal and sometimes subtidal rocky shores (Nishihira *et al*., 1991; Hiratsuka and Uehara, 2007) and the coral reefs (Clark, 1976; McClanahan and Muthiga, 1989; Johansson *et al*., 2013).

The gonads called as "roe" represent the edible part of the sea urchins and are highly priced in the seafood market (Kennedy *et al*., 2007). The sea urchin fisheries with total global landings of 120,000 metric tonnes reached its peak in 1995, then started declining with global landing of 82,000 metric tonnes in 2012 (Carboni *et al*., 2012). The decline has been associated to overfishing, lack of proper management and pollution (Keesing and Hall, 1998; Andrew *et al*., 2002). The species of *Echinometra* has now been included in the landings of sea urchin, which was not the case earlier because of their smaller size (Rahman *et al*., 2000).

* Corresponding author: saima_siddiq@hotmail.com
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Growth studies based on size distributions (Kelso, 1971; Drummond, 1994; Muthiga, 1996), natural growth lines on test plates (Ebert, 1988), tagging experiments (Ebert, 1975) and observations in aquaria (Lawrence and Bazhin, 1998) have been reported in *E. mathaei*. In general, *Echinometra mathaei* has a moderate while variable growth as compare to other species of sea urchins (Ebert, 1975). The growth parameters, that is, asymptotic length $L\infty$ and growth coefficient K of *E. mathaei* have been reported from Hawaii (Ebert, 1975), Western Australia (Ebert, 1982) and Kenya (Muthiga, 1996). The growth was reported to be relatively fast during juvenile stages and became slower as the sea urchin approached the asymptotic size (Lawrence, 2013). The seasonal growth pattern in sea urchins was correlated with algal production and seawater temperatures (Walker, 1981; Tsuda *et al*., 2006).

The present study was initiated to understand the population structure and growth in sea urchin, *E. mathaei* found on Buleji, Pakistan. The study will provide baseline data for this species in the Arabian Sea, which can be utilized for its development and management purposes.

MATERIALS AND METHODS

Study area

The 1050 km long coast of Pakistan extends from the Indian border on the south–east to the Iranian border in the north-west (Fig. 1). The Buleji rocky ledge (24° 50'N;

66° 48’ E) on the shore of Karachi (Fig. 1) is a gradually sloping more or less triangular platform, which protrudes out in the Arabian Sea. The ledge is divisible into an exposed area which faces the open sea and is under high wave action and western protected side which is not under direct wave action and is totally submerged on high tides. The coast has elevated and depressed areas, big rocks and boulders in the high tidal zone and varying sizes of tide pools, small boulders, flat rocks and sandy patches in the mid and low tidal zones.

Fig. 1. Map showing the collection site. Scale bar 2 km. Inset shows the coastline of Pakistan.

Sampling and measurements

Preliminary surveys revealed that the sea urchin, *Echinometra mathaei* were found hiding in crevices and overhangs only in the low tidal zone of the exposed rocky shore of Buleji. For collection of sea urchins an area of 100 meter in length (parallel to sea) and 10 meter in width was selected in low tidal area and the sampling was done from the same area every month on low tides (-0.1 to -0.5 m tide). Sea urchins were distributed haphazardly far from each other in a sampling area so sampling was done randomly and tried to include every size of the sea urchin. Each month approximately 30 individuals of *E. mathaei* were handpicked and brought live in well aerated container to the laboratory. During the study period from April 2011 to November 2012, it was possible to do the sampling of sea urchins for 14 months only, as during June to August (monsoon season) due to roughness of sea, the access to the lowest tidal area was not possible and thus no specimen collected. The specimens were morphologically identified based on the descriptions of Tahera (1993). Various measurements, such as, test diameter (TD), test height (TH) to the nearest ±0.01 mm and wet weight (WW) to the nearest ± 0.01g was taken.

Data analysis

Morphometric relationships

Morphometric (TD, TH, WW) relationships were estimated using equation $Y = aX^b$. The values of a and b were estimated from the $\log_{10}$ transformed values of X and Y, that is, $\log_{10} Y = a + b \log_{10} X$ applying a linear regression analysis (Zar, 1996). The Student’s t-tests was used to confirm whether *b* values obtained in the linear regressions were significantly different from the isometric value (b= 1 or b= 3). Temporal variations in the morphometric characters was estimated by one-way ANOVA test (α= 0.05). Tukey test (multiple comparison test) was performed to see which months were different. Prior to the analysis the homogeneity of variance was tested by Cochran’s test and when needed the data was log-transformed.

Population structure

The population structure of *E. mathaei* was analysed monthly, using the Modal Progression Analysis (Gayanillo *et al*., 2005) where the individual cohorts were separated by using length frequency data based on Bhattacharya’s method (Bhattacharya, 1967) with the help of FiSAT II software (Sparre and Venema, 1998)

Growth parameters and longevity

The theoretical growth parameters, *K* and $TD\infty$ for *E. mathaei* was estimated from size frequency data using ELEFAN I by FiSAT II software (Sparre and Venema, 1998) and applied to Von Bertalanffy equation (Von Bertalanffy, 1938) to calculate length (test diameter) at different ages: $TDt = TD\infty\, [1 - e^{-K(t - to)}]$ where TDt is the diameter at age t, $TD\infty$ is the theoretical asymptotic maximum size, K is the growth coefficient, describing the rate at which the asymptotic size (test diameter) is attained, and t_0 the extrapolated time when size is equal to 0.

The hypothetical age at length zero (t_0) can be calculated using the K and $L\infty$ values by the formula (Lopez Veiga, 1979): $t_0 = 1/K * \ln [(TD\infty - TDc)/TD\infty]$ where K is the growth coefficient, $TD\infty$ is the asymptotic length, and TDc is the length at age t = 0 or length of recruits.

Longevity of the sea urchins was estimated using the approximation as Longevity = t_0 + 2.996/K (Pauly, 1983).

The instantaneous natural mortality coefficient (M) was calculated by equation described by Pauly (1980): $\text{Log } M = -0.0066 - 0.279 (\log L\infty) + 0.6543 (\log K) + 0.4634 (\log T)$ where K = growth coefficient (year^{-1}), $L\infty$ = length asymptotic (mm) and T = annual mean temperature in the habitat (ºC)

The data for seasonal variations were compared by considering the periods from November to February and May to September as winter and summer, respectively. The periods between March to April and October are referred to as spring and autumn, respectively.

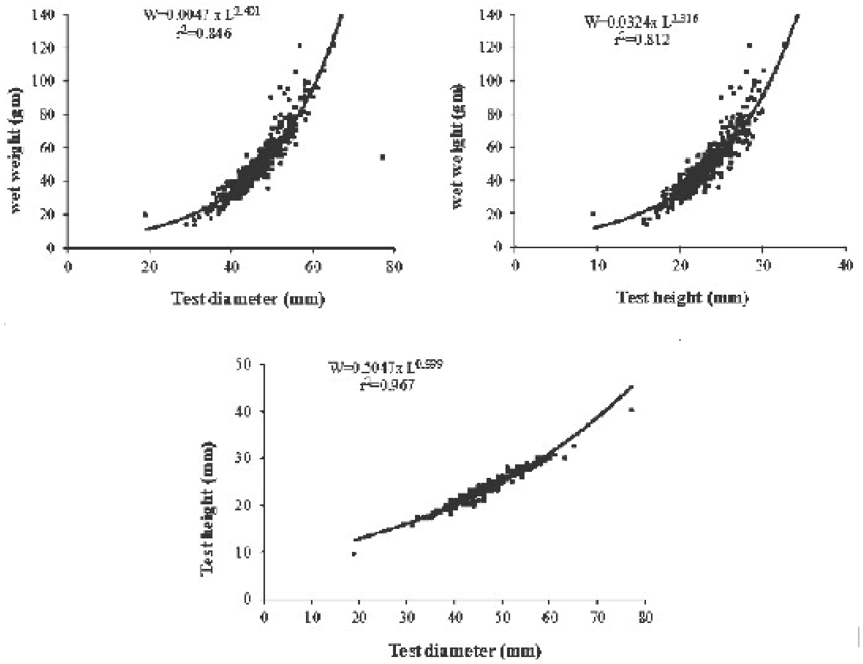

Fig. 2. Relationships between total wet weight -test diameter; total wet weight-test height and test height and test diameter for sea urchin *Echinometra mathaei* during study period (April 2011-November 2012) at Buleji.

RESULTS

Morphometric relationships

The regression equations between test diameter/wet weight and between test height/wet weight showed negative allometry and in these relationships the coefficients of determination (r^2) were 0.846 and 0.812, respectively. The test height/test diameter showed an isometric relationship with b value equal to 0.999 (Fig. 2 and Table I).

Table I. Morphometric relationships between total wet weight (WW), test diameter (TD), test height (TH) of the *Echinometra mathaei* population at Buleji (N = 391).

Relation	Model	a	S.E. (a)	b	S.E. (b)	r^2	t-test
WW/TD	WW= TD^b	0.005	0.086	2.401	0.052	0.846	-11.547*
WW/TH	WW= aTH^b	0.032	0.077	2.316	0.056	0.812	-12.123*
TH/TD	TH= aTD^b	0.505	0.016	0.999	0.009	0.967	- 0.140*

a, intercept; b, slope; S.E, standard error; r^2, coefficient of determination; * statistically significant values, P< 0.001.

Population structure

A total of 391 individuals of sea urchins were measured during the study period. All the morphometric characters showed significant temporal variations. Temporal variations in test diameter *of E. mathaei* varied significantly (one-way ANOVA, F = 4.12, P < 0.01) in

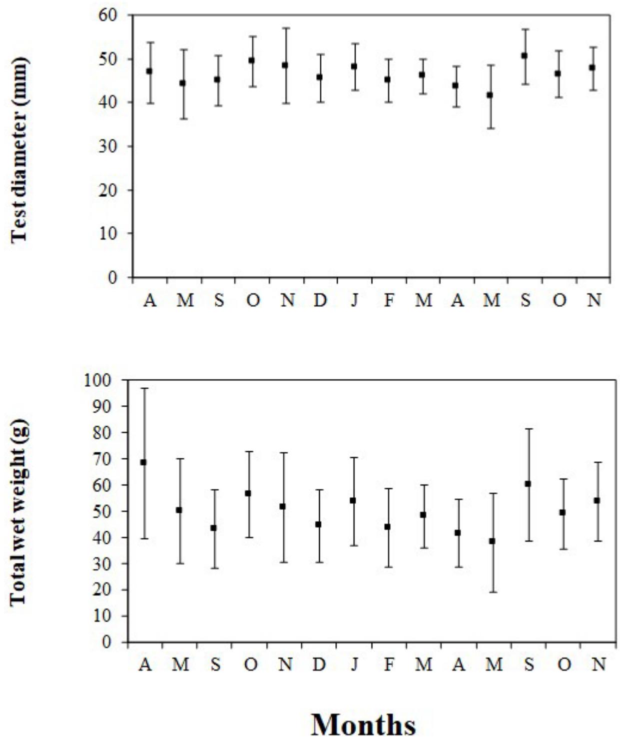

Fig. 3. Temporal variability of the morphometric characters of *Echinometra mathaei* population from April 2011 to November 2012 at Buleji.

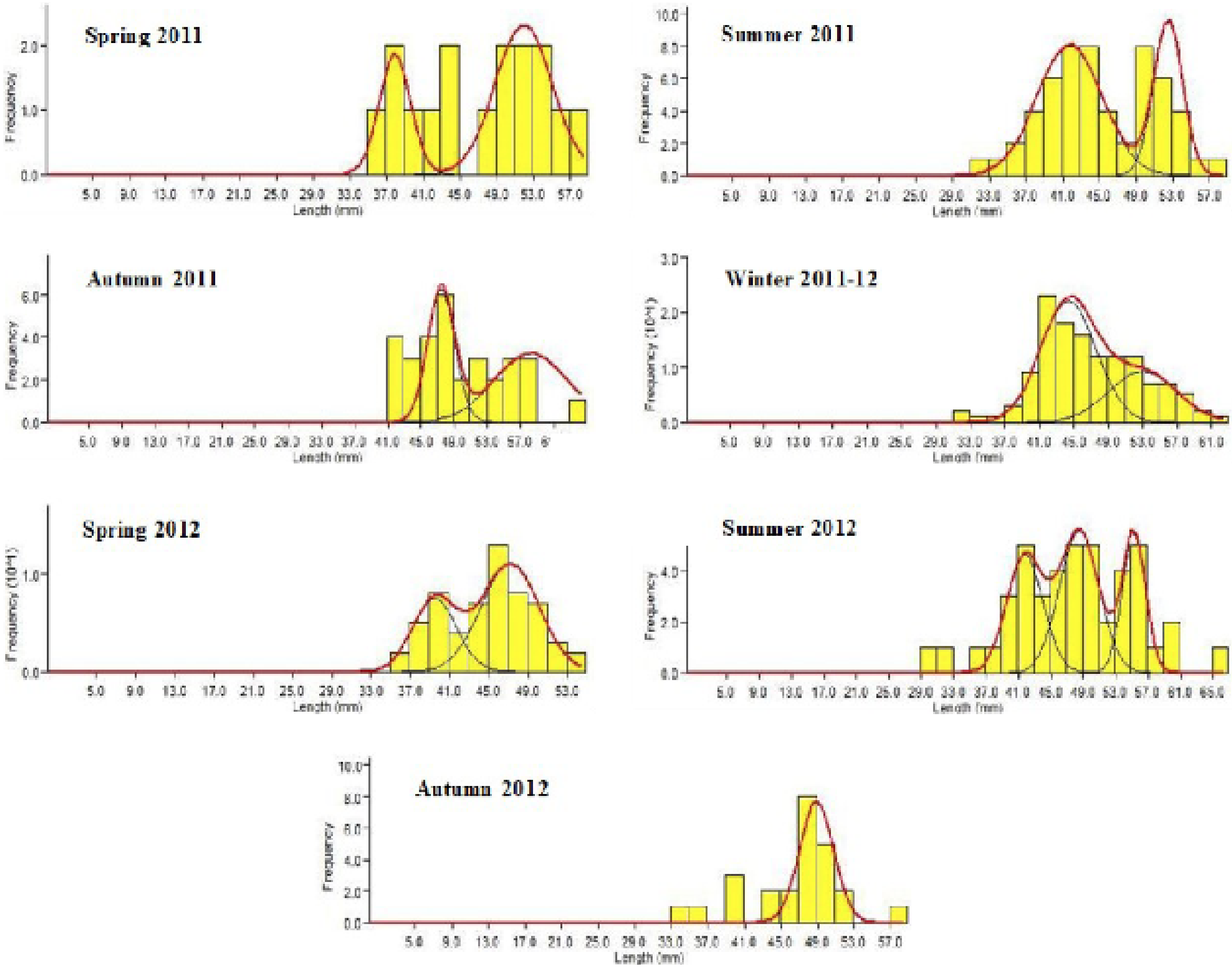

Fig. 4. Modal progression analysis of *Echinometra mathaei* size-frequency data (thick line) based on Battacharya's method at Buleji.

May'12 and September'12 while wet weight varied significantly (one-way ANOVA, F = 4.66, P < 0.01) in April'11 and May'12 from rest of the months (Fig. 3).

Length-frequency distribution analysis of *E. mathaei* was bimodal in different seasons while three modes were found in summer 2012 and one mode in autumn 2012 (Fig. 4). The small-sized individuals of less than 40 mm were represented by 16.9% of the population. The medium-sized individuals (41-50 mm) were 51.1% and larger-sized individuals (51-60 mm) were 23.2% of the population. The larger individuals of greater than 60 mm were represented by few individuals (0.8%) (Fig. 4).

Growth parameters and longevity

The theoretical growth parameters, *K* and TD∞ for *E. mathaei* estimated from size frequency data using ELEFAN I by FiSAT software were 0.48 yr^{-1} and 8.2 cm, respectively (Fig. 5). These two parameters were substituted into the equation: $t_0 = 1/K * \ln [(TD\infty - TDc)/TD\infty]$ with *TDc* = 1.9 cm (based on the diameter of the smallest sea urchin acquired by free collection during the period of study) to estimate the t_0 = - 0.55 year.

Therefore, growth in sea urchin can be described by the following von Bertalanffy equation:

$$TD_t = 8.2[1 - e^{-0.48(t - (-0.55))}]$$

The longevity was calculated to be 5.7 years. The natural mortality coefficient was found to be M= 1.584 $year^{-1}$.

Age and growth

The growth in *E. mathaei* calculated by using von Bertalanffy equation showed that this species attained the sizes of 3.2, 4.3, 5.1, 5.8, 6.3, 6.7, 7.0, 7.3, 7.5, 7.6, 7.8, 7.8, 7.9, 8.0, 8.0 and 8.1 cm at the age of 1, 2, 3, 4, 5, 6, 7 and 8 years, respectively at Buleji (Fig. 6).

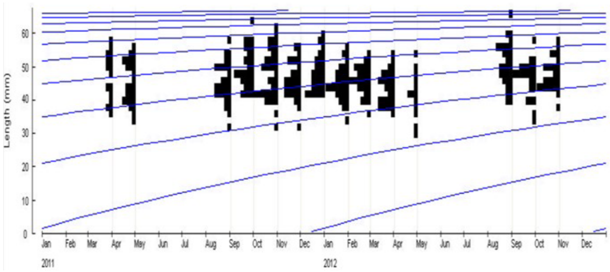

Fig. 5. Length-frequency distribution output from FiSAT with superimposed growth curve for *Echinometra mathaei* at Buleji. D∞ = 8.2 cm (test diameter), K = 0.48 year^{-1}.

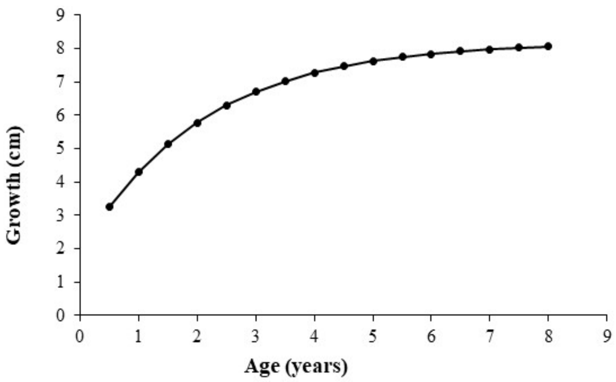

Fig. 6. Von Bertalanffy population model estimates of size-at-age for *Echinometra mathaei* at Buleji.

DISCUSSION

Juveniles less than 20 mm test diameter of *E. mathaei* were not found in the present study, probably they were hidden in crevices or get settled usually at shallower depths and when grow larger migrate from these area to join the adult population on the rocky shores. Previous studies for *Diadema antillarum* in the Caribbean (Bak, 1985) and for *S. droebachiensis* in Northern Norway (Sivertsen and Hopkins, 1995) gave the similar reason about the juveniles. There is another suggestion that the large sized individuals of *E. mathaei* occupied the most favourable locations forcing the smaller individuals to occupy suboptimal locations (McClanahan and Kurtis, 1991) or smaller individuals are more susceptible to predators and thus avoid comparatively open places, a strategy which is also common in other echinoids in the presence of predators (McClanahan and Kurtis, 1991).

In the present study the longevity in *E. mathaei* was estimated to be 5.7 years with the maximum size of 7.7 cm, which showed that sea urchins in Pakistan grows more rapidly to a larger size than *E. mathaei* from Western Australia which attained maximum size of 4.987 cm in 7 years (Ebert, 1982) and to a size of 8.5 cm at an age of around 7 years on reefs in Kenya (Muthiga, 1996).

In the present study the *K* (growth rate) and *TD*∞ (asymptotic size) for *E. mathaei* were estimated to be 0.48 yr^{-1} and 8.2 cm whereas in the same species the *K* and *TD*∞ value were 0.292 yr^{-1} and 4.095 cm from Hawaii (Ebert, 1982). The *TD*∞ for *E. mathaei* from different parts of the world was found to range between 4.095 to 5.499 cm and common growth rate $K = 0.322$ yr^{-1} (Ebert, 1982). From this it can be concluded that in the present study the estimates of asymptotic size and growth rate were greater than those estimated by Ebert (1982) for the same species in the Indo-Pacific including Hawaii, Western Australia, Seychelles, Kenya, Israel and Enewetal Atoll. The difference in growth rates and asymptotic size of *E. mathaei* from different parts of the world including Pakistan may be related to factors, such as, food and hydro dynamism which are said to be the main factors determining the growth rate in echinoids (Ebert, 1968; Himmelman, 1986; Muthiga, 1996). The growth in echinoid is also dependent on density (Levitan, 1988). The differences in growth estimates between different studies can also be expected because of the broad geographic range and differences in habitats (Ebert, 1982; Pederson and Johnson, 2007).

The present study provides information on the population structure and growth of sea urchin, *E. mathaei* on a Buleji rocky shore of Pakistan. These animals in a rocky shores and shallow waters, controls the abundance and distribution of algae and can have profound influence on the structure of benthic communities (Andrew, 1989; Vadas and Elner, 1992; Valentine *et al*., 1997) rather they play an important role in the dynamics of the entire habitat (Barrett *et al*., 2009). Therefore, there is a need to monitor the role of sea urchin play on the algal cover of our coast, which can be characterize the pattern of urchin fluctuations in Arabian Sea.

CONCLUSIONS

Based on the above discussion, we conclude that the present study deliver baseline information on the growth and population structure of sea urchin, *Echinometra mathaei* on rocky shore of Karachi, Pakistan. The growth rates, asymptotic length and longevity in of *E. mathaei* was estimated to be greater than reported from the same species in other parts of the world. Therefore, it is concluded that Pakistani sea urchin species has possible potential that could be exploited commercially according to scientific outlines. But for further understanding and management of this species advance comprehensive studies on biological/ecological scale of *E. mathaei* are required.

Statement of conflict of interest

The authors declare there is no conflict of interest.

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