



Effect of climate change on the reproduction pattern of sea urchin *Echinometra mathaei* at the Gulf of Suez, Red Sea, Egypt.

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ABSTRACT

The reproduction patterns of *E. mathaei*'s population at the Gulf of Suez were investigated during two periods, the first was 1992-1993 and the second was 2015-2016. The effects of elevating temperature during these periods on reproduction periodicities were studied. The surface water temperature showed an increase during the period 2015-2016 by 1.36 °C at summer and 1.24 °C at winter from that recorded during 1992-1993. In 1992-1993, individuals of *E. mathaei* had one definite lengthy spawning season, which were expressed by main spawning period from June to August with maximum gonadal activity in July. On contrary, there was an obvious shift at the spawning season during 2015-2016; individuals of *E. mathaei* exhibit more than one breeding season. However, they are resting only during December, January, February, May and September. They showed four spawning seasons, the first from October to November, 2015, the second from March to April, 2016; the third from June to August, 2016, and the fourth from October to November, 2016. The overall sex ratio (males to females) during the first period (1992-1993) of the current study was 1:2.5, while in 2015-2016, it recorded an average male to female of 1:2.4. Size at sexual maturity decreased from 1992-1993 (2.25 cm for females and 2.03 cm for males) to 2015-2016 (1.8 cm for females and 1.5 cm for males). The study recorded a positive relationship between fecundity and size. The oocyte/female was highest in 1992-1993 (23×10^5), decreased during 2015-2016 (11.2×10^5). Seasonal changes were observed in maturity stages related to spawning season at both periods of study. In the first period (1992-1993), most stages were represented with fluctuation in their percentage. The data collected showed that all stages showed one pattern of increasing and decreasing according to the stage until May, 1993 and subsequently, the pattern changed between the stages during the period from May to August. On the other hand, during the second period (2015-2016) all maturity stages were represented but in alternative states between the months of study.

INTRODUCTION

Most marine animals have seasonal reproductive cycles. However, environmental variables that synchronize reproduction of marine animals have been identified, and one of the most important environmental factors in this respect is temperature (Mercier and Hamel 2009). Temperature changes have been shown to synchronize reproduction in species that live in areas with seasonally changing sea temperature

(Giese and Pearse 1974). The seasonality changes in temperatures are mainly controlled by the characteristics of the geographical area.

The area concerned in this study is the Gulf of Suez, which is a long shallow and narrow body of water, 250 Km long, 32 Km wide and about 80-90 meter deep at its mouth, and averages only 20-30 meter depth along most of its length (Morcos, 1970 and Pearse, 1983). The prevailing north-westerly winds drive the surface waters south into the Red Sea (Morcos, 1970), and give the gulf a decidedly temperate character with seasonal temperature changes strongly influenced by the surrounding land. Due to of its northerly position and shallow depth, the Gulf of Suez is relatively temperate in character and large seasonal changes occur.

The increasing of surface water temperature at the gulf was evident during the successive years, it ranged from means of about 18 °c in winter to about 28 °c in the summer (Pearse, 1969), while in 2000 the range of sea surface temperatures varied from 17.7 °c in Winter to about 28.2 °c in summer (Fahmy, 2003, ElShenawy *et al*, 2006), Also the range of temperatures increased in 2015 varied from means of 17.96 °c in winter to about 29.25 °c in Summer (Abdelmongy and El-Mouselhy, 2015). As water temperature depends upon various factors, including radiation income, surface exchange with air temperature, beach radiation, latent heat and evaporation (Tailing, 1976), the increase in sun radiations and flux received from the sun during these years caused the surface water temperature to be increased. The increase in earth's temperature which called global warming refers to the recent and ongoing rise in global average temperature near Earth's surface. It is caused mostly by increasing concentrations of greenhouse gases in the atmosphere. The greenhouse effect is commonly a process of heat being let in and then being unable to escape.

The fauna of the Gulf of Suez consist almost entirely of members of the tropical Indo-Pacific assemblage, and many of species range across the Indian Ocean in the tropical central pacific (Por, 1978). Because of such genetic continuity, and the shallow temperate character of the Gulf of Suez, populations of tropical species with the Gulf may be near the extremes of their ecological and physiological capabilities (Pearse, 1983).

Echinometra mathaei is distributed widely on most coral reefs and are often the most prevalent sea urchin species on the reefs they inhabit (McCartney *et al*. 2000; McClanahan and Muthiga 2001). Sea temperatures seem to be important in regulating the reproduction periodicities also has a great effect on fertilization and early development stages of the sea urchin (Cohen-Rengifo *et al*, 2013). The reproductive cycle of *E. mathaei* has been examined over many areas of the world (Pearse 1968, 1969a; Pearse and Phillips 1968; Fujisawa and Shigei 1990; Drummond 1995; Alsaffar and Lone 2000; Muthiga and Jaccarini 2005). These studies showed different modes of reproduction, at some areas reproducing continuously throughout the year (Pearse and Phillips 1968; Kelso 1971), while others showed restricted spawning periodicities (Fujisawa and Shigei 1990; Arakaki and Uehara 1991; Muthiga and Jaccarini 2005).

Yonge (1940) believed that the spawning periods of many of the species at the Low Isles, Great Barrier Reef, were influenced by the temperature fluctuations. The same author divided the spawning periods of tropical species into four groups in relation to inferred temperature requirements: those spawning (1) at about 30°C, (2) between 23°C and 28°C and having semiannual spawning period in some areas, (3) at anything above about 24°C, and (4) at anything above 18°C. A lower "critical temperature around 18-20°C, corresponding to Yonge's fourth category, may be involved with the reproduction of *Echinometra mathaei*. Murintsev (1963) further

shows that surface sea temperatures in the West-central Pacific generally don't fall below 18-20 °C except in Japan, and Japan is the only area in this region where *Echinometra mathaei* seems to have a distinct summer spawning period.

The breeding patterns of tropical sea urchins have studied by many investigators. Although a number of species seem to reproduce throughout the year, many species have periodic seasonal breeding pattern. These patterns include both semi-annual breeding rhythms, as well as monthly rhythms. Pearse and Barksdale (1986) reported that most species of invertebrates in the northern subtropical parts of the region (e.g. Red Sea) tend to spawn in boreal summer, while those in southern subtropical parts (e.g. Southern Great Barrier Reef) tend to spawn in austral summer.

Pearse (1969) mentioned that the sea urchin *Echinometra mathaei* spawns in summer in the Gulf of Suez and Japan, but continuously spawns throughout the year elsewhere in its distribution including off Southern Australia, where sea temperatures more than 30 °C.

The Indo-Pacific echinoid *Echinometra mathaei* reproduce continuously throughout the year in the northern Red Sea and most other areas, (Pearse, 1968; Pearse 1969; Pearse and Phillips, 1968). However, in Gulf of Suez and off Japan, gametogenesis is fully synchronous among individuals of this species, and spawning is restricted to summer months.

Therefore, during the current work we investigate the reproduction pattern in *E. mathaei* with the aim of assessing the reproductive periodicity and evaluating the relationship between its reproductive cycle and sea water temperature at Gulf of Suez, Red Sea.

MATERIALS AND METHODS

Study site:

The Gulf of Suez is a part from the Red Sea, the gulf has temperate characters since the extensive sandy bottom, and relatively shallow depths compared to the adjacent Red sea and Gulf of Aqaba. The length of the gulf is 314 Km and it varies in width from 19 to 32 Km and average depth 40 m with a max. depth of 70 m.

Ain Sukhna area in the western Gulf of Suez 60 Km south Suez city (Fig., 1). The Site is well protected and has weak water currents and low wave action. The area of study is shown in Figure 1. The area of study is characterized by scattered coral patches and rocky and sandy substrate.



Fig. 1: The study area at the north-western Gulf of Suez

Field Observations and Specimen collection:

A survey was made at the study area during two periods, the first from October, 1992 to November, 1993 and the second from October 2015 to November 2016. During each visit, water and air temperatures were recorded using a graduated thermometer. Twenty five specimens were collected monthly from both intertidal and subtidal areas. Intertidal specimens were collected by hand, and SCUBA diving was used to collect the subtidal specimens. The individuals were selected from among the largest ones found to avoid any bias arising from the relation between size and the gonad index value. Small and medium size specimens were also sampled to determine the population's size at first sexual maturity.

Reproduction studies:

Specimens were dissected upon arrival at the laboratory after 1 h journey (during this journey the animals were kept in aerated water tanks). Coelomic fluid was drained from all tissues and sediments were removed from the gut. Drained weight was measured to the nearest 10^{-2} g, then the gonads were weighted to the nearest 10^{-3} g. The gonad index (GSI) was calculated as follows:

$$GSI = \frac{\text{Wet weight of gonad}}{\text{Wet weight of urchin}} \times 100$$

The gonads were examined microscopically to determine the sex of each individual, then the percentage of males and females were calculated each month for sex ratio determination.

The size at first maturity was determined by examining the gonad of each individual urchin.

An estimate of absolute fecundity (FA) was made from a small sample of the ovary (weighted to the nearest 10^{-4} g, GW). Oocytes used for this calculation were collected from large ovary tubules. Eggs were carefully removed from the ovary, placed in filtered seawater and shaken to suspend them evenly in 5 ml saline solution (0.9 NaCl). This suspension was then poured into a petri dish marked with a 25-cm grid. The mean number of eggs per grid was calculated from a six randomly selected grids and was multiplied by the number of grids within the petri dish. The absolute fecundity was determined by dividing the gonad weight by the sample weight and multiplying this by the mean number of oocytes in the sample.

For each urchin the average number of oocytes in the entire gonad was calculated by applying the following formula

$$\text{Total oocyte number} = \frac{\text{Egg number of sample} \times \text{total gonad weight}}{\text{weight of sample}}$$

The gonads were examined externally and microscopically to define the maturity stages. In total, five maturity stages were defined in both males and females based on morphology size and appearance of the gonads.

RESULTS

Temperature

The temperature measured at 2015-2016 recorded a mean value of 29.56 °C during summer season and 18.76 °C during winter season. These values showed an increase in temperature by 1.36 °C at summer and 1.24°C at winter from the values

recorded at 1992-1993 that was 28.20 °C during summer season and 17.5 °C during winter season (Table, 1).

Table 1: Mean water temperature recorded at different years at the study site.

Years	Temperature (°C)	
	Summer	winter
1992-1993	28.20	17.5
2015-2016	29.56	18.74

Sex ratio

The sex ratio of *Echinometra mathaei* recorded differences between the two periods of study. In 1992-1993, it recorded an average male to female of 1:2.5 with a percentage of 20% males and 80% females. The highest percentage recorded at that period was 11.7% males to 88.3% females at March, 1993 and the lowest sex ratio was recorded at November, 1993 with a percentage of 30% males and 70% females (Fig. 2). While in 2015-2016, it recorded an average male to female of 1:2.4 with percentage 35.2% males and 64.8% females. The highest percentage recorded 29.1% males and 70.9% females at October, 2015 and the lowest percentage recorded 40.3% males and 59.7% females at January 2016 (Fig. 3). The sex ratio was significantly deviated from the expected ratio 1:1 at the two periods, but the deviation was more in 1992-1993 than in 2015-2016. However, the ratio is not constant throughout the period of study particularly during the spawning season.

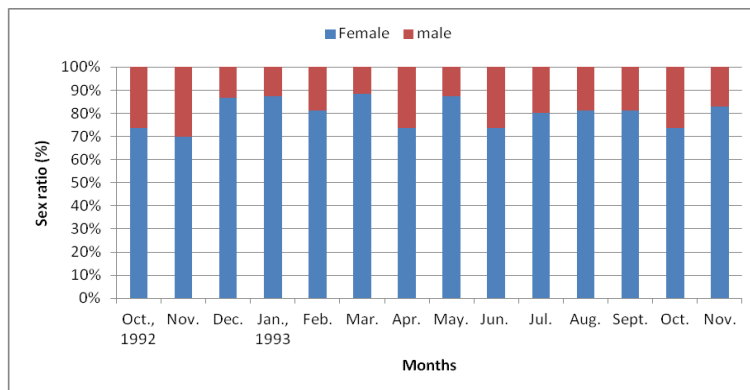


Fig. 2: Monthly variations in sex ratio of *E. mathaei* during the period from Oct., 1992 to Nov., 1993.

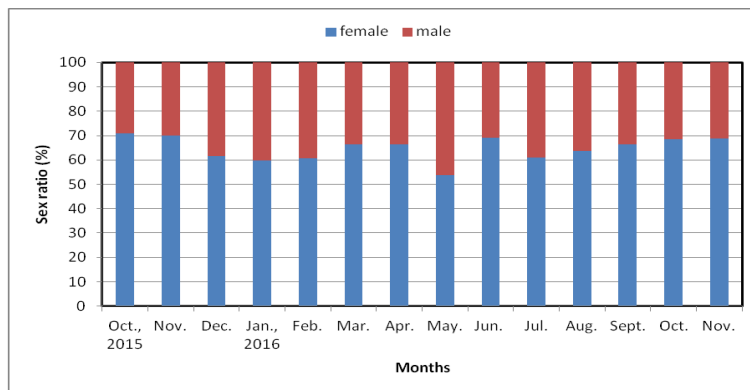


Fig. 3: Monthly variations in sex ratio of *E. mathaei* during the period from Oct., 2015 to Nov., 2016.

Generally, females markedly outnumbered males all the year around particularly during summer and autumn months at the first period (1992-1993), while at the second period (2015-2016), the number of females still outnumbered males throughout the year but with less deviation from the 1:1 ratio. On the other hand, during the breeding season, the number of females exceeds the number of males.

Size at sexual maturity

During the period from October, 1992 till November, 1993, the males of *E. mathaei* reached their sexual maturity at 2.03 cm test diameter, while females reached its sexual maturity at 2.25 cm test diameter. Whereas, *E. mathaei* individuals reached their sexual maturity at smaller sized during the period from October, 2015 to November, 2016, the males reached their sexual maturity at 1.5 cm, while females reached the sexual maturity at 1.8 cm (Table, 2).

Table 2. Size at first sexual maturity of *E. mathaei* recorded at the two periods of study.

Months	1992-1993		2015-2016	
	female	male	female	male
Oct.	2.25	2.05	1.83	1.5
Nov.	2.19	2.06	1.8	1.52
Dec.	2.15	2.03	1.79	1.53
Jan.	2.36	2.03	1.8	1.5
Feb.	2.3	2.04	1.78	1.52
Mar.	2.3	2.01	1.8	1.52
Apr.	2.25	2.03	1.8	1.49
May.	2.2	2.06	1.86	1.48
Jun.	2.2	2.06	1.86	1.46
Jul.	2.15	2.07	1.81	1.45
Aug.	2.1	2.1	1.77	1.46
Sept.	2.25	2.11	1.79	1.5
Oct.	2.25	2.05	1.81	1.51
Nov.	2.2	2.07	1.81	1.52

Reproductive seasonally and Gonad Index

The reproductive cycle of *E. mathaei* at Gulf of Suez was investigated for the same two periods (1992-1993 and 2015-2016). Gonad index values showed high variation during the two periods. In the period 1992-1993, individuals of *E. mathaei* had one definite lengthy spawning season, which were expressed by main spawning period from June to August with maximum gonadal activity in July. For females the average G.S.I. decreased from October, 1992 to March, 1993. Then it began to increase from April to May. In June the average G.S.I. sharply increased to reach its peak (12.5) at July and then decreased from September to November, 1993. Males exhibited a similar pattern as in females, however, maximum G.S.I. value was recorded at July (5.2).

On contrary, there was an obvious shift at the spawning season during 2015-2016, from that recorded in 1992-1993. At the period 2015-2016, individuals of *Echinometra mathaei* didn't exhibit a specific breeding season. It seems that they are not synchronized in their reproductive activities and they have more than one spawning season. However, they are resting only during December, January, February, May and September. Reproductive efforts of females and males are maximal in summer and moderate in winter and spring. Individuals exhibit a wide range in their G.S.I. with maximal values recorded in July and August. They showed four spawning seasons, the first from October to November, 2015, the second from March to April, 2016 the third from June to August, 2016, and the fourth from October to November, 2016. For females the average G.S.I. recorded high value

during October and November, 2015 being 5.98 and 5.12, respectively. Then the G.S.I. value decreased from December (3.01) to February (2.96). Afterwards, it increased again at March (5.21) and April (5.88), before it drops during May (2.16) and increased once more from June (5.98) to August (5.66), with a peak at July (6.18). In September, 2016 the average G.S.I. sharply decreased to reach 3.34 then increased again at October and November, 2016, being 5.29 and 4.89, respectively. The male gonads exhibited exactly the same pattern as observed for females (Figs. 4 & 5).

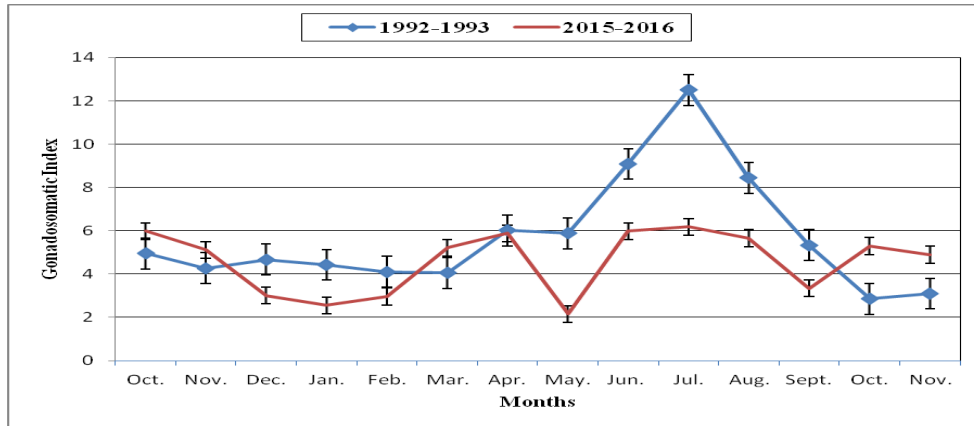


Fig. 4: Monthly fluctuation in gonadosomatic index for females *Echinometra mathaei* with standard deviation (SD) during the two periods 1992-1993 and 2015-2016.

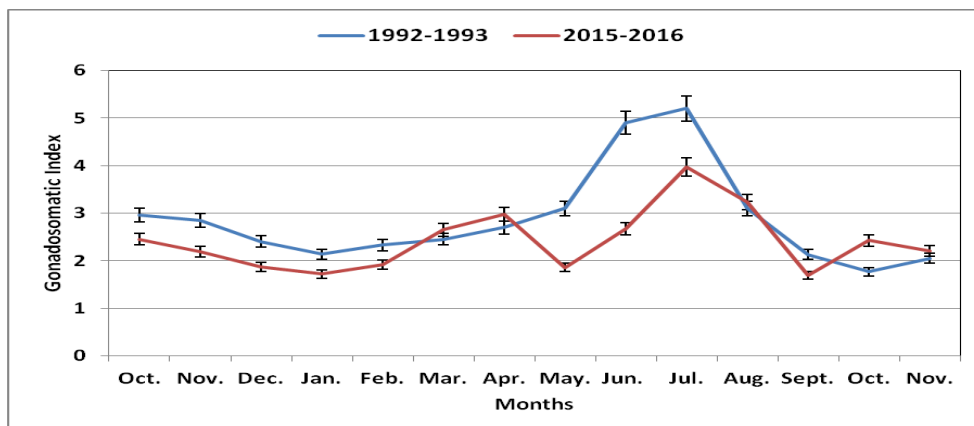


Fig. 5: Monthly fluctuation in gonadosomatic index for males *Echinometra mathaei* with standard deviation (SD) during the two periods 1992-1993 and 2015-2016.

Fecundity

Fecundity (number of mature oocyte/female) of *E. mathaei* showed high variation during the two periods of study. The data obtained showed that fecundity was highest in 1992-1993 period ranged between 0.9×10^5 and 61×10^5 oocyte/female, while it decreased during the period 2015-2016 ranged from 0.4×10^5 and 41.7×10^5 oocyte/female.

The relationship between *E. mathaei*'s size and fecundity was investigated during this study. At the first period (1992-1993), the largest female recorded was 7.5 cm test diameter and its fecundity was 23×10^5 oocyte, while the smallest female recorded was 2.5 cm test diameter and its maximum fecundity was 0.9×10^5 oocyte. There was a highly significant difference between the size of *E. mathaei* and fecundity ($p = 0.006$). Whereas during the second period (2015-2016) the largest female recorded was 7.5 cm test diameter and its fecundity was 11.2×10^5 oocyte,

while the smallest female recorded was 2.0 cm test diameter and its maximum fecundity recorded 0.4×10^5 oocyte. Also there was a high significant difference between fecundity and different years investigated ($p = 0.002$) (Fig. 6).

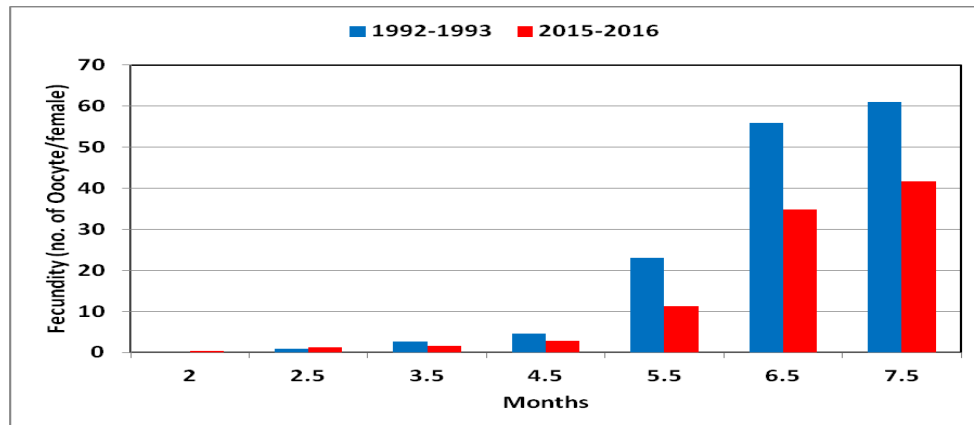


Fig. 6: Variation in fecundity (no. $\times 10^5$) of *Echinometra mathaei* with length during the two periods of study (1992-1993 and 2015-2016).

Gonad morphology and maturity stages

The gonads of both sexes of *E. mathaei* are five broad ribbons, located just beneath the test and extended along the five interambulacral columns. They are pointed interiorly, slightly rounded posteriorly and the broadest part at the middle of the ribbon. On the outer side of the ribbon there is a groove which runs along the ribbon from the posterior part to the interior one. The groove is terminated by a small gonoduct, which open in the genital pore at the apical system. Mature oocytes are stored in the lumen of acini till the spawning period. The large oocytes are found at the center of the lumen, whereas the small ones are found near the periphery of the acini.

In total, five maturity stages were defined based on morphology size and appearance of the gonads. In immature stage (Stage I), gonad growth involved the formation of new ribbon arising from the gonad base, with a subsequent increase in ribbon length and diameter, the gonads are very small, thread like in shape with whitish color and extended from apical system to about half of the interambulacral columns. At stage II (growing stage), both females and males could be identified by the presence of developing oocytes and spermatocytes. At maturity stage (Stage III), and as the gonads approached maturity the gonads are large and consist of large number of acini which can't be distinguished by the naked eye. Microscopic examination revealed that acini are thread like and elongated in males but short and thick in females. The color of the gonads varied from pale yellowish to dark orange in ripe females and varied from creamy color to dark brown in mature males. These colors were related at least partly to the sex and state of maturity of the animals. At partially spawned stage, which occur throughout the spawning season, the simultaneous presence of both spawned and unspawned tubules indicated that partial spawning was occurring (stage IV), which could be a characteristic of this species. Spent gonad tubules (stage V) were wrinkled and greatly reduced in size, with white translucent color for both species.

In this respect, seasonal changes were observed in maturity stages related to spawning season at both periods of study. In the first period (1992-1993), most stages were represented with fluctuation in their percentage. The partial spawned stage fluctuated between 5 to 12 % from October to April, it rises to 47% to 80%

during May to August (the spawning season), then decreased again to 25% to only 4% from September to November. Growing stage increased from 53% at October, 1992 to reach its maximum percentage being 38% at March, 1993, before it decrease beginning from April (28%) to August (2%). The mature stage exhibited the same pattern, increased from 10% at October, 1992 to 56% at April, 1993, then decreased from May, 1993 (25%) to August, 1993 (8%), indicate a definite spawning season from May to August. It is obvious that there was a reverse relationship between partially spawning stage and both growing and mature stages at which the former increased when the latter two stages decreased. The data collected showed that all stages had one pattern of increasing and decreasing according to the stage until May, 1993 and subsequently, the pattern changed between the stages during the period from May to August (Fig. 7).

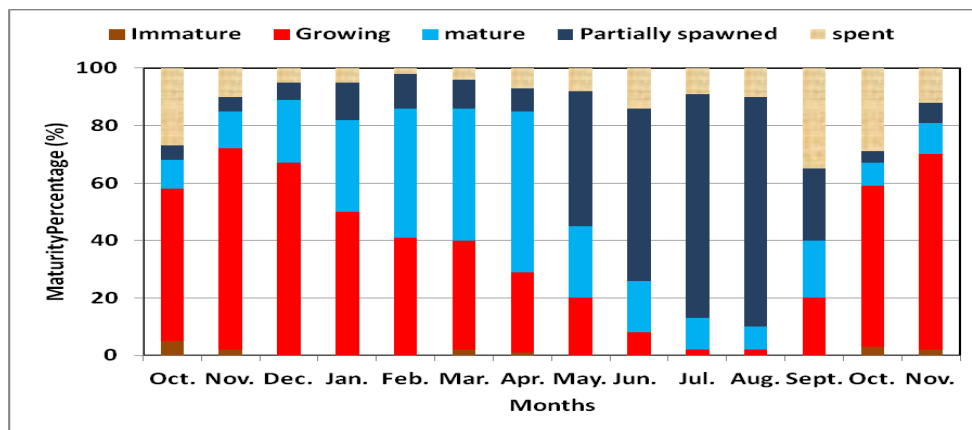


Fig. 7: Frequency of gonadal development of female *Echinometra mathaei* from October, 1992 to November, 1993 (no.= 280).

On the other hand, during the second period (2015-2016) all maturity stages were represented but in alternative state. The growing stage increased from 20% at October, 2015 to 69% at December, 2015, then decreased to only 8% at April, 2016, increased again to 37% at May, 2016, followed by a reduction to 12%, 4% and 8% during June, July and August, 2016, respectively. An increase was recorded during September, 2016 before it decreased again during October and November, 2016. Whereas mature and partially spent individuals showed an opposite patterns, they showed high percentages during October, 2015 followed by a decrease during November, 2015, with the appearance of high percentage of spent individuals (45%). While mature individuals increased during January and February, 2016, recorded 48% and 58%, respectively, the partially spent individuals recorded low percentages fluctuated between 1% and 6% during the same months. Beginning from May, 2016 the mature individuals decreased (37%), while the partially spawned individuals increased (22%). This situation continued during March and April, 2016, then at May, 2016 the situation reversed again as the percentage of mature individuals recorded 48% and the percentage of partially spawned and spent individuals recorded 6 and 4%, respectively. Again during June, July and August, 2016, the mature individuals decreased recorded 40, 39 and 29%, respectively, while the partially spawned individuals increased, recorded 30, and 35%, before it decreased again during August and September, 2016 recording only 8%. The spent individuals showed increasing percentages from June to August, 2016, recorded 16, 21 and 54%, while there was no record of spent individuals during September, 2016. At October

and November, 2016, the mature individuals decreased to 34 and 22%, respectively, while both partially spawned and spent individuals increased (Fig. 8).

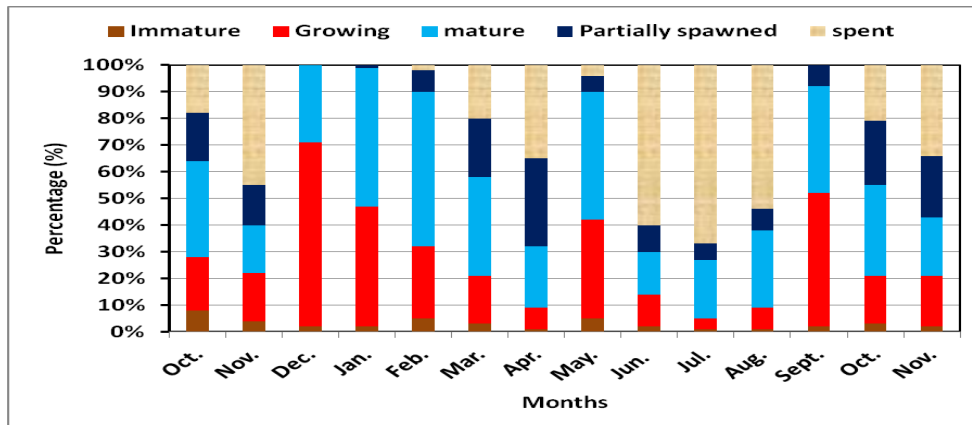


Fig. 8: Frequency of gonadal development of female *Echinometra mathaei* from October, 2015 to November, 2016 (no.= 280).

DISCUSSION

Most marine invertebrates undergo an annual reproductive cycle. Many show variations of timing in the events of the cycle from place to place and from year to year (Hasan, 1995; Abou zied, 1991).

The general seasonal nature of these cycles as well as sequential changes associated with a well-defined cycle clearly indicates that there must be mechanisms of synchronization not only within population but also with other activities in the organisms (Pearse and Barksdale, 1986). Operation of the reproduction involve a cyclic demand for energy and material. This fueling of reproduction show a temporal pattern in amplitude, frequency and direction, with the overall reproductive strategy (Fauda, 1990). The energy demand is due to the food reserve and the quantity of energy and materials devoted to reproduction compared to other metabolic needs, this is one of the factors controlling the reproduction events, in addition to developmental phasing which include the time of onset and size at sexual maturation, while the external factors include lunar rhythm, salinity and the most important of all temperature. Not only an external factor, temperature affect all the internal process, beginning from gamete maturation, sexual maturity, reproductive efforts..etc. Water temperature depends upon various factors, including radiation income, surface exchange with air temperature, beach radiation, latent heat and evaporation (Tailing, 1976).

Since the mid-20th century the human activity gradually increased and became the dominant cause of observed warming in earth's climate, which increased during the last three decades than any preceding decade since 1850 (IPCC, 2013). Due to the last 15-year periods there was a trend of continuous elevating temperature starting in 1995, 1996, and 1997 being 0.13 °C, 0.14 °C and, 0.07 [−0.02 to 0.18] °C, respectively (Stocker *et al.* 2013). Many literatures recorded an increase in earth's temperature of most regions since the early 1980s, observed warming ranged between 3°C and 2°C during the period from 1971 to 2010 (Held *et al.*, 2010; Xie and Vallis, 2012; Koven *et al.*, 2013). In this warming trend, the Northern Hemisphere, showed its warmest 30-years period from 1983 to 2012 of the last 1400 years. The increase in water temperature due to warming is different according to depth, where the upper ocean layer (0-700 m depth) warmed more than deeper

depths because more than 60% of the net energy increase in the climate system is stored in the upper ocean (0–700 m) and only about 30% is stored in the ocean below 700 m (Knutti *et al.*, 2008). On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. While during the period from 2003 to 2010 the temperature increased more slowly than the period from 1993 to 2002 (Knutti, and Hegerl, 2008, IPCC, 2013).

Temperature change is not regionally uniform, the strongest ocean warming is projected for the surface in tropical and Northern Hemisphere subtropical regions, which ranged between 0.6°C to 2.0°C per decade (Knutti and Tomassini 2008). The temperature data acquired from the current study is compatible with the conclusion that the tropical and subtropical area recorded strongest ocean warming, it recorded an increase in water temperature at the Gulf of Suez of 1.63 °C during summer and 1.24 °C per 23 years period from 1992-1993 to 2015-2016.

Temperatures recorded during the current study for the second period (2015-2016) were in agreement with results of previous records at the Red Sea as Abdelmongy and El-Moselhy (2015), who recorded a summer temperature of 29.25 °C and a winter temperature of 17.96 °C, 28.2 °C at summer and 20.17 at winter (Madkour, 2013) and 30.5 °C at summer and 22.8 °C at winter (Dorgham *et al.*, 2012).

Sea temperatures seem to be important in regulating the reproduction periodicities also has a great effect on fertilization and early development stages of the sea urchin, (Cohen-Rengifo *et al.*, 2013).

Maria Byrne, *et al.* (2009) mentioned that global warming is causing ocean warming and acidification. The interactive effects of warming and acidification on fertilization and development of this echinoid were determined. Experimental treatments (20–26°C, pH 7.6–8.2) were tested in all combinations for the ‘business-as-usual’ scenario, with 20°C/pH 8.2 being ambient. Percentage of fertilization was high (>89%) across all treatments. There was no difference in percentage of normal development in any pH treatment. In elevated temperature conditions, +4°C reduced cleavage by 40 per cent and +6°C by a further 20 per cent. Normal gastrulation fell below 4 per cent at +6°C. At 26°C, development was impaired. Providing that temperature, but not pH, compromises sea urchin fertilization and early development under near-future climate change scenarios.

The current study showed that the increased water temperature at the study site seems to affect the reproduction rhythm which recorded a great difference between the two periods of study (1992-1993 and 2015-2016). The reproductive cycle showed positive correlation with the rise of surface water temperature. The important role of temperature variations in the reproduction of *E. mathaei* was shown by many other workers from other parts of the world (e.g., Pearse 1969a; Sakairi *et al.* 1989; Byrne 1990; Pecorino *et al.* 2014; Wangenstein *et al.* 2013). Variation in temperature suggested being the key exogenous signal for spawning in *E. mathaei* (Bronstein and Loya, 2014).

According to many authors temperature play the major role governing the reproduction of echinoids. Du to this concept Pearse (1974) suggested that *E. mathaei* might have a restricted spawning period in the higher latitudes (above 27° N), which its spawning is expected to be restricted to the summer months, and continuous spawning throughout the year closer to the equator where the environmental factors, especially temperature, are presumed more stable. This proposal was consonant with many studies from many parts of the world as the

continuous reproduction recorded from Honsu, Japan (Kobayashi, 1969), Minatogawa, Japan (Fujisawa and Shigei, 1990), Hawaii (Kelso, 1971). On the other hand, many reports from higher latitudes recorded restricted spawning period related to the seasons with higher temperature with an annual peak during August–September and was followed by a drop in the GSI value in October, indicating a single annual spawning event as recorded from Kenya (Muthiga and Jaccarini, 2005), Persian Gulf (Keshavarz, 2017), Tanzania (Bronstein and Loya, 2014), Eastern coast of South Africa (Drummond, 1995). While previous studies at the Gulf of Suez reported a single summer spawning period from June to September (Pearse 1969; Hasan, 1995).

Whether we agreed or disagreed with Pearse's assumption, it is certain that temperature has the prime effect on the spawning period as showed at the current study where during the first period (1992-1993), *E. mathaei* showed a definite annual reproductive cycle during summer season starts at June and ends at August with maximum gonadal activity at July. On the other hand, an obvious shift at the spawning season was recorded during the second period (2015-2016), they don't exhibit a specific breeding season and showed four spawning periods, the first from October to November, 2015, the second from March to April, 2016 the third from June to August, 2016, and the fourth from October to November, 2016. The shift recorded during the present work may be attributed to the rise in water temperature during the 23 years apart between the two periods of study; this is attributed to the global warming phenomena. The environmental parameters have been suggested to play an important role in regulating the reproduction of *E. mathaei*. These parameters include temperature (Byrne 1990; Guillou and Michel 1993; King *et al.* 1994; Vairitingon *et al.* 2005; James *et al.* 2007), photoperiod (Kelso 1971; Pearse *et al.* 1986; McClintock and Watts 1990; Walker and Lesser 1998; Shpigel *et al.* 2004), salinity (Harrington *et al.* 2007), food availability (Lawrence and Lane 1982; Poorbagher *et al.* 2010), population density (Bay-Schmith and Pearse, 1987), wave swept area (Muthiga and Jaccarini, 2005) and pH (Pearse and Cameron 1991), from these parameters temperature have the major role in governing *E. mathaei* reproduction. This was recorded from the current study as well as from other studies (Byrne, 1990; Siikavuopio *et al.*, 2006, 2008)

Gonadal indices and their changes over time have been used as indicators of reproductive cycle for many species of marine animals. They are often called "reproductive efforts" which measure the energy expenditure by individuals on reproduction. The increase in GSI during the period of gonad maturation is mainly due to deposition of large amount of protein and lipids in the developing eggs and spermatozoa. It is therefore reasonable to expect that the weight of the gonad would reflect the accumulation and utilization of these energy reserves (Fauda, 1990; El-Sayed, 1992; Hasan, 1995).

The actual manner in which sex ratio is controlled be of little relevance to the phenology of reproduction although more power forces most favor the existence of primary sex ratio close to one. The link with adaptedness may be more apparent in other aspects of reproduction which include sexual characteristics, age and maturity, season of spawning and feature of egg size and fecundity. However, overall sex ratio (males to females) during the first period (1992-1993) of the current study was 1:2.5 in 1992-1993, with a percentage of 20% males and 80% females. While in 2015-2016, it recorded an average male to female of 1:2.4 with percentage 35.2% males and 64.8% females. The sex ratio was significantly deviated from the expected ratio 1:1 at the two periods, but the deviation was more in 1992-1993 than in 2015-

2016. However, the ratio is not constant throughout the period of study particularly during the spawning season. Generally, females markedly outnumbered males all the year around particularly during summer and autumn months at the first period (1992-1993), while at the second period (2015-2016), the number of females still outnumbers males throughout the year but with less deviation from the 1:1 ratio. This ratio was not consistent throughout the year particularly at the end of spawning season which number of females was relatively exceeds the number of males. Generalization about sex ratios at the species level should be made with caution because local variation from ratio of 1:1 may be caused by differential mortality, migration or habitat selection, and restricted nutrition (Warner, 1977; Cobb and Caddy, 1989).

Based on the agreement between gonad indices and gametogenesis *E. mathaei* have a definite annual reproductive cycle at summer during the period 1992-1993. On the other hand, the same species showed unusual spawning pattern at the period 2015-2016 and it recorded a lengthy spawning season with repeating spawning throughout the year. The differences in the mean gonadal index between the two periods may reflect either difference in individual growth of the gonads or in the degree of synchronization of gonadal development in the population (Byrne 1990). If the individuals in the population are synchronized, that if they all grow and ripen together, changes in the mean gonadal index will reflect individual gonadal growth and not all the maturity stages will be represented at all seasons as the case in the first period of study (1992-1993). If the gonads grow and mature at different times, all maturity stages will be represented in the population as the case recorded during the second period (2015-2016) of the current study. The present study indicates that individuals of *E. mathaei* were asynchronized in their reproductive cycle during the period from 2015 to 2016 since individuals were in different stages of gametogenic development. Hence the population appeared spawn at all seasons. Characteristics of gametogenesis in *E. mathaei* are similar to most echinoids (Walker *et al.* 2007). In the first stage, there is nutrient accumulation with gonad increase in size. Following nutritive build up, gametogenic cells began to grow and mature along the ovarian wall as the nutritive cells decrease. The mature oocytes and sperms occupying the entire lumen of the gonads with little nutritive materials remaining. At this time the remaining gametes are either reabsorbed or do not grow until the start of the next reproductive period, nutritive materials again begins to accumulate. Hellal (1986) noticed that medium sized oocytes were not seen in the gonads after spawning. In the present study, this phenomena was observed only during the period from 1992 to 1993, while during the period from 2015 to 2016 such a phenomenon was not observed, where all stages of gametogenesis were found in the gonads throughout the year. This indicated that the ripe individuals occur throughout the year and rarely are all the individuals ripe at any one time, but at least some ripe individuals should almost always be present. The presence of small oocyte with very low proportions in the gonads of *E. mathaei* during spawning season shows maturing of all oocytes. The relationship between spawning and the length of time eggs held in the gonads is rather complicated. If egg production is continuous and extended over several months, an animal could release egg cautiously with little storage, release eggs in short bursts or release eggs all at once. In the present study, during the period 2015-2016, individuals of populations of *E. mathaei* reach ripeness at different times and spawning involving different individuals, must be continuous during the year

As concluded in the current study elevation of temperature due to global warming phenomena affected the reproductive status of *Echinometra mathaei* at the

Gulf of Suez as a part of ocean life, this life in the sea as whole was affected. The change of the normal pattern of life will greatly affect the entire ecosystems and environmental stability.

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