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Morphology, morphometry and population dynamics of the mussel *Brachidontes pharaonis* from the western region of Gulf of Suez

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ABSTRACT

The morphology, morphometry and population dynamics of the mussel *Brachidontes pharaonis* from the rocky shore of the western region of Gulf of Suez at National Institution of Oceanography and Fisheries, Suez were studied. The study area was described as well as the species composition. The external and interior shell morphology of *B. pharaonis* was described. The estimated constants A and B for the morphometric relationships were computed. The shell length of *B. pharaonis* ranged between 4.5 to 32.5 mm with mean 17.9 mm and the corresponding total body weight (TBWt) was 0.015 to 2.195 g with mean 1.498g. The length-frequency distribution of monthly samples from July 2019 2019 to May 2020 has been studied. The age and growth of 674 specimens of this species were estimated by using length-frequency distribution method. The von-Bertalanffy growth parameters (VBGP) were $L\infty$=34.13 mm, K=1.0yr^{-1}, t_0= 0.0yr^{-1}, $W\infty$=3.11 g. The growth performance index (φ) was 3.66 for length and 3.0 for weight. The length-weight relationship indicated negative allometric growth (b=2.5391).

Keywords: Mussel, *Brachidontes pharaonis*, morphometry, population dynamics, Suez Gulf, Red Sea.

INTRODUCTION

The bivalve mussel *Brachidontes pharaonis* is widely distributed in the Western Pacific Ocean, Indian Ocean and the Red Sea (Morton, 1988). It is belonging to the family Mytilidae which is native to the Indian Ocean and Red Sea (Gilboa, 1976). It is also considered as invasive species which recently invaded more habitats, threatening indigenous bivalve species which may be, in the future, unable to compete with it in terms of reproductive effort and density (Sara *et al.*, 2008). It is migrated to the Mediterranean Sea through Suez Canal and from the Eastern African Coasts to Southern Africa (Barash and Danin, 1986).

Many studies had investigated the growth and shape of numerous species of mussels bivalves with respect to the impact of different environmental factors on them (Seed and Richardson, 1990; Kroeker *et al*., 2016; Bergstrom and Lindegarth, 2016). Morphometrics multivariate analysis of shell of bivalves was used to show their phenotypic responses (Caill-Milly *et al*., 2012). However, few studies were done on *B. pharaonis* morphological aspects (Arcidiacono and Di Geronimo 1976), ecological and physiological features (Safriel *et al*. 1980; Sara *et al*. 2000; Rilov *et al*. 2002) and hermaphroditism (Abdel Razek *et al*., 2017).

Few studies were done on the ecology, age structure, distribution, biometric relationships and hermaphroditism of *B. pharaonis* from the Red Sea, Gulf of Suez and Eastern Mediterranean Coast of Egypt (Mohamed, 1992, 1997; Radwan, 2014; El-Sayed *et al.*, 2016; Abdel Razek *et al*., 2017). Studying morphological variation can represent a powerful indicator for understanding the adaptation of organisms and help to predict their responses in their rapidly changing environment (Telesca *et al*., 2018).

This work aimed to study the morphology, morphometry and population dynamics of the common fouling mussel *Brachidontes pharaonis* on the western region of the Gulf of Suez at the National Institution of Oceanography & Fisheries (NIOF).

MATERIALS AND METHODS

I- Study Area:

Samples of the mussel *B. pharaonsis* were collected from the western region of the intertidal rocky shore of the National Institution of Oceanography & Fisheries at Suez is located on the western region of Suez Canal (Fig. 1).

Fig.1. Site of collection of samples of *B. pharaonis* at the NIOF at Suez.

II-Collection of mussel samples:

Collection of specimens of the mussel *B. pharaonsis* was performed at low tide by hand picking from an area of $1m^2$ during the period June 2019 to May 2020 from the rocky shore at from NIOF, Suez coast.

III-Morphological Study:

The external and internal morphology of samples of the mussel *B. pharaonis* were examined under stereoscopic dissecting binocular microscope. Camera lucida drawings were made for specimens. Also, photographic views were taken.

IV-Morphometeric Study:

In the laboratory, before processing the material, the surface of the mussel shells was cleaned of epibionts, sand and gravel. The number of individuals was counted and the length was measured to the nearest 0.1 mm with vernier calipers. The total body and shell weight of each individual were taken to the nearest 0.01 g. The monthly mean density (N, ind m^{-2}) was estimated for *Brachidontes pharaonis* populations.

The following shell measurements were taken for each specimen (Fig. 2):

1- Shell length (L) of the blue mussel was measured from the tip of anterior side of the shell to its posterior side.
2- Shell breadth (B) was measured from the dorsal side to the ventral side of the shell.
3- Shell width (W), the length between the right and left sides of the shell.
4- The total body weight (TBW) was measured using electronic scales with an accuracy of 0.01g.

Fig.2. Shell measurements of the mussel *B. pharaonis* from the western part of the shore of NIOF at Suez

The following morphometric relationships were studied:

1. Shell Length-Shell Breadth Relationship

2. Shell Length-Shell Width Relationship

3. Shell Width - Shell Breadth Relationship

The linear equation Y=A+BX was applied for these relationships. Where, A & B are constants whose values were estimated by the least square method.

4. **Shell measurements indices:** These include

Shell Width index= (Shell width/shell length)*100

Shell Height index= (Shell height/shell length)*100

Shell width-Shell breadth index = (Shell Breadth/shell width)*100

5. Shell Length-Total Body Weight Relationship:

The relationship between shell length and total body weight was computed using the formula of Le Cren (1951), TBWt = a ShL^b where TBWt is the total body weight in grams, L is the total length in mm, a & b are constants whose values were estimated by the least square method.

6. Shell Length-Shell Weight Relationship:

The relationship between shell length and shell weight was computed using the formula of Le Cren (1951), ShWt = a1 ShL^{b1} where ShWt is the shell weight in grams, ShL is shell length in mm, a1 & b1 are constants whose values were estimated by the least square method.

7. **Shell Length-Relative coefficient of condition (Kn) Relationship:**

Kn was calculated from the equation: Kn= Observed Weight /Calculated weight.

V. Age and Growth:

A-Determination of age

In the present study the length frequency data of samples was grouped in 4 mm shell length class interval for model progression analysis (MPA) in FiSAT II program. The age was determined indirectly using the analysis of length frequency data (Pauly, 1980, 1984a,b) method (smooth growth curve method) which allows the conversion of length frequency data into age groups.

B-Theoretical growth in length:

By fitting the von Bertalanffy growth model, using the Gulland and Holt (1959) method. Von Bertalanffy (1938) for theoretical growth in length can be written in the form:

$$\mathbf{L_t = L_\infty (1 - e^{-k(t-t_0)})}$$

Where: L_t = the length at age t , L_∞ = the asymptotic length at t_∞, K = growth coefficient and t_0 = age at which the length is theoretically nil).

Von Bertalanffy growth parameters ShL_∞ and K were estimated using the methods of Ford (1933) - Walford (1946), where the von Bertalanffy growth function (VBGF) was as follow:

$$\mathbf{ShL_{(t+1)}=ShL_\infty(1-e^{-K})+ShL_t(e^{-K})}$$

Where;

ShL_t : is the size of the mussel at age t.

$ShL_{(t+1)}$: are lengths at age $_{t+1}$ (1 = constant time interval and equal month).

e^{-K} : is the slope (b)

ShL∞ (1 – e –K): is the intercept (a).

The constants "a" and "b" of this linear relationship between ShLt and ShL_{t+1} were calculated by using the least square method and hence K and ShL∞ can be estimated as follows:

$b = e^{-K}$, where K = - Ln b

$a = ShL_\infty (1 - e^{-K})$

$ShL_\infty = a / 1-b$

The value of age at which shell length is nil (t_o) was estimated from the following rearranged formula of the von Bertalanffy equation:

$$\mathbf{t = t_o - 1/K \ Ln\ [(ShL_\infty - ShL_t)/ ShL_\infty]}$$

Where; "ShL_t": is the shell length at age t.

By plotting $Ln[(ShL_\infty-ShL_t)/ShL_\infty]$ against (t), t_o was estimated from the value of the intercept of the curve on y-axis (Moses, 1988).

C-Theoretical growth in weight:

It can be written in the form:

$TBW_t = TBW_\infty (1 - e^{-k(t-t_0)})^n$,

Where:

TBW_t = the total body weight at age t ,

TW_∞ = the asymptotic total weight at t_∞,

K = growth coefficient

t_0=age at which the shell length is theoretically nil.,

n = the constant of length-weight equation.

D- Growth performance index (φ) :

It was estimated after Pauly and Munro (1984) as:

Ǿ = log10(K) + 2 log10(ShL∞)

(For length)

Ø = log10(K) + 2/3 log10(TBW∞)

(For weight)

Growth of *B. pharaonis* in the studied site was performed using overall growth performance index (OGP), proportional to the maximal rate of size increase during the lifetime. It was calculated as :

$OGP = \log (ShL_\infty * k)$ (Pauly 1979).

RESULTS

Taxonomy:

Brachidontes pharaonis (Fischer P., 1870) belongs to phylum Mollusca, Class Bivalvia, Order Ostracoda, Family Mytilidae, Subfamily Mytilinae, Genus *Branchiodontes;* Species *pharaonsis.*

Habitats: *B. pharaonis* lives in shallow water, at sea level or just below, attached by its byssus to rocks and stones, mostly in clusters.

Distribution

Worldwide: Indian Ocean, Red Sea and Mediterranean sea (like Port Said, Egypt by

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Fuchs, 1878, Lebanon by Gruvel and Moazzo, 1931, Syria by Kinzelbach, 1985 and southern Turkey by Kinzelbach, 1985).

I- Morphology:

1. Morphology: external and internal shell structure

Brachidontes pharaonis has an externally dark brown-black; internally tinged violet-black and its shell consist of two valves. The front end of shell is pointed, and the back considerably rounded. The dorsal side is slightly convex, while the ventral one is slightly concave. Generally the shell has an elongated form (Fig. 3).

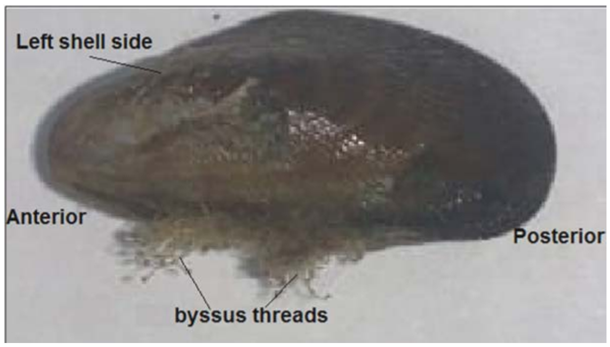

Fig.3. General view of the mussel *B. pharaonis* from (view from the exterior).

The size of the right and left shells are usually identical. The exoskeleton is dark and olive, dark brown, but more often black. On the back of the animal, shell valves are connected with a ligament. Shell consists of three layers: external (periostracum), internal (ostracum) and lower (gipostracum) - nacreous. The structure of the external skeleton is determined by environmental conditions in the living area. The streamline shape and durability of shell provide mussel a good fitness to dwelling in coastal zone and in waters with raised hydrodynamics. It is also promoted by unique ability of mussels to quickly and reliably attach to stones, seaweed, logs, to each other and other objects with a very strong byssus threads (Fig. 4a,b).

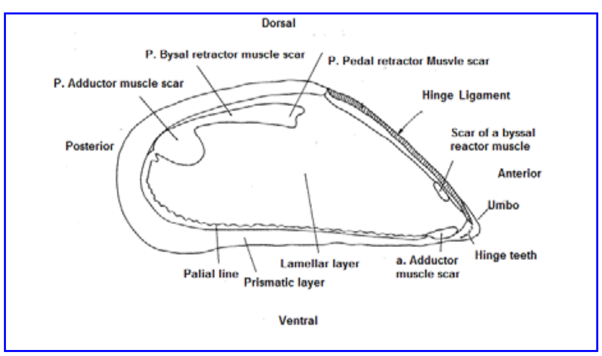

Fig. 4a. Camera Lucida drawing of the right shell valve of *B. pharaonis* showing its interior structures.

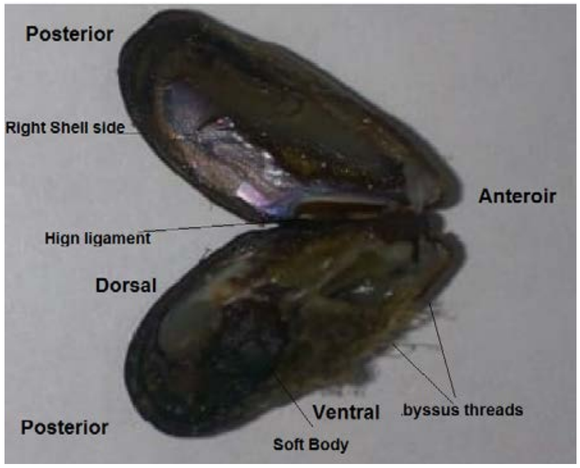

Fig. 4b. Photomicrograph of the two shell valves of *B. pharaonis* showing the interior structures.

III-Morphometry:

1- Shell Length - Shell Breadth Relationship:

It was obvious from Figure (5) that shell bradth of *B. pharaonis* increases with the increase in shell length. The mean shell breadth ranged from 3-12 mm for specimens with shell length ranged from 4.5-32.5mm. However the rate of increment percentage in the shell breadth decreases with increases of shell length (60% to 39%). This indicates that population of *B. pharaonis* in the investigated site has elongated shells, with a small breadth.

The linear equation that represents this relationship is as follow:

Shell Breadth (mm) = 1.138+ 0.354 Shell Length (mm) (R^2=0.991)

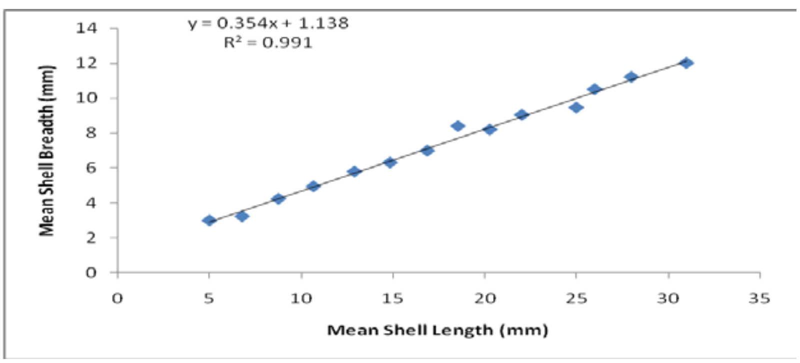

Fig. 5. Shell Length- Shell Breadth Relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

2- Shell Length - Shell Width Relationship:

It was indicated from Figure (6) that shell width of *B. pharaonis* increases with the increase in shell length. The mean shell height ranged from 2.7-11.8 mm for individuals with shell length ranged from 5-31mm. However the rate of increment percentage in the shell width decreases with increases of shell length (54% to 38%). This indicates that population of *B. pharaonis* in the investigated site has elongated shells, with a small height.

The linear equation that represents this relationship is as follow:

Shell Width (mm)= 0.779+ 0.359 Shell Length (mm) (R^2=0.986)

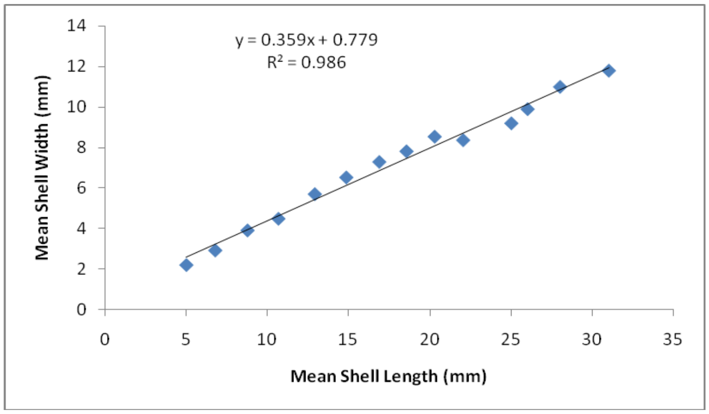

Fig. 6. Shell Length-Shell width Relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

3- Shell Width- Shell Breadth Relationship:

The graphical representation of the relationship between shell Width and shell breadth of *B. pharaonis* is shown in Figure (7). It was obvious that Shell height increases with the increase in shell width. The mean shell height ranged from 2.7-11.8 mm for individuals with shell length ranged from 5-31mm.The linear equation that represents this relationship is as follow:
Shell width (mm) = 0.341+ 1.011 Shell Breadth (mm) (R^2=0.985)

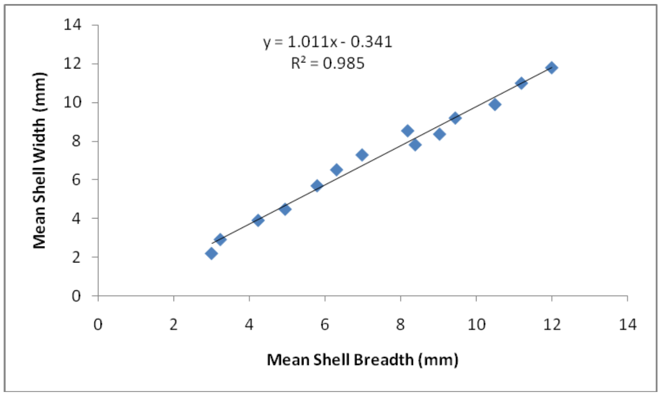

Fig. 7. Shell height-Shell width Relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

4- Shell measurements indices:
Shell Length – Shell Breadth Length Index:

The Mean shell breadth –shell length (ShB/Shl) index ranged from 38.7-60 with grand mean 43.9. This indicates that the grand total breadth represents about 43.9 % of the total shell length of *B. pharaonis* at the investigated area. Also, Figure (8) indicates that the growth of shell length is highly faster than that of breadth.

The linear equation that represents the relationship between shell breadth-shell length index and shell length can be represented as:

Shell breadth-shell length index= 51.13-0.466 Shell Length (mm) (R^2=0.895)

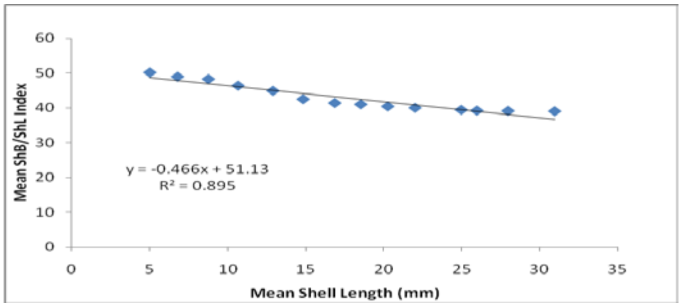

Fig. 8. Shell Width-Shell Length index –shell length relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

Shell Length – Shell Width Length Index (ShB/ShL):

The Mean ShB/ShL index ranged from 39.0-44.9 with grand mean 39.2. This indicates that the grand total height represents about 39.2 % of the total shell length of *B. pharaonis* at the study area. On the other hand, the growth of shell height is much slower than that of shell length as shown in Figure (9).

The linear equation that represents the relationship between shell height-shell length index and shell length is as follows:

Shell width-shell length index= 46.28-0.230 Shell Length (mm) (R^2=0.893)

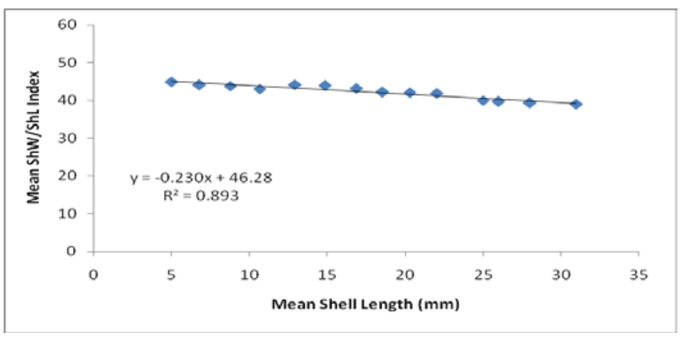

Fig. 9. Shell width-Shell Length index –shell length relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

Shell width-Shell breadth index:

The Mean shell width –shell breadth index ranged from 90-98.3 with grand mean 93.5. This indicates that the grand total width represents about 93.5 % of the total shell breadth of *B. pharaonis* at the investigated area. Also, Figure (10) shows that there is a positive relationship between shell width-shell breadth index and growth of shell breadth i.e. the values of this index increase with the increase of shell breadth growth. The linear equation that represents the relationship between shell width-shell breadth (ShW/ShB) index and shell breadth is as follows:

Shell width-shell breadth index= 87.20-0.864 Shell breadth (mm) (R^2=0.757)

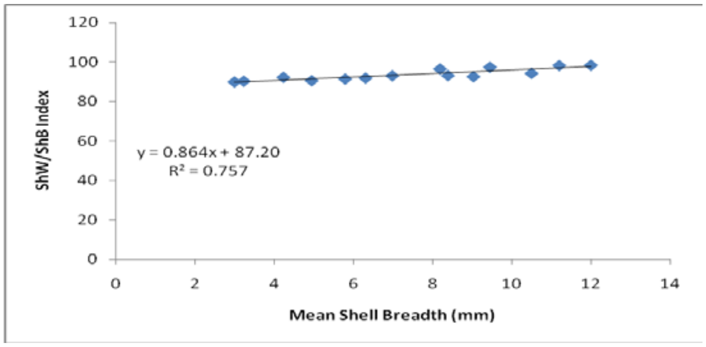

Fig. 10. Variation of Shell with-Shell breadth index with increase of shell breadth of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

With the growth of *B. pharaonis*, shell become more elongated and narrow, with more parallel dorso-ventral margins. These variations could be explained by shapes being driven by the maintenance principle of a physiologically favorable surface-area to volume ratio, which increases in elongated shells. The observed shapes, along with physiological acclimatization, could represent an important component of mussel adaptation to environmental stressors.

5- The length – total body weight relationship

Figure (11a) showed the shell length-Total body weight relationship of 491 individuals of *B. pharaonis* in the Gulf of Suez. In the present study, the value of (b) was about 2.998 which represented by the equation: $TBWt = 0.1379ShL^{2.5391}$ (R=0.973). This indicated that the growth in weight is negative allometric. The asymptotic weight of *B. pharaonis* was 3.23g.

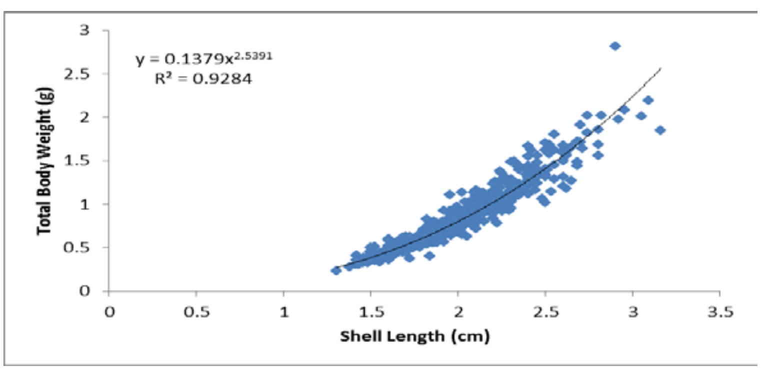

Fig. 11a. Average Shell Length-Total body weight relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

The monthly variation in the total body weight of *B. pharaonis* with increase of shell length is shown in Figure (11b) and the values of regression constants of this relationship (a and b) and coefficient of determination (R^2) are shown in Table (1).

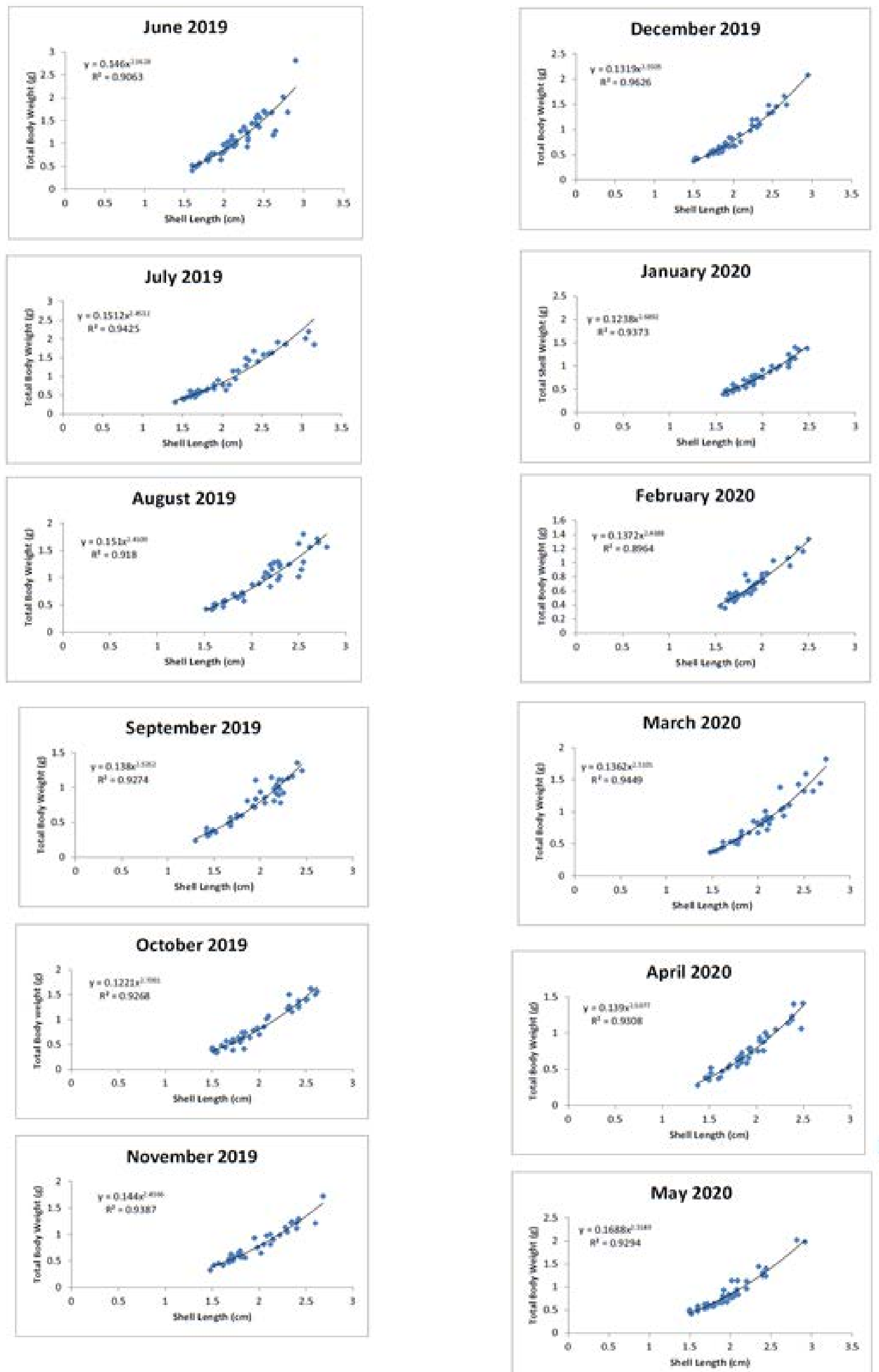

Fig. 11b. Monthly Shell Length-Total body weight relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

Table (1). The values of regression constants of the shell length-Total body weight relationship (a and b) and coefficient of determination (R^2) of *B. pharaonis* from niof at Suez Gulf during the period June 2019 to May 2020.

Month/Year	**a**	**b**	**R^2**
June 2010	0.1460	2.5628	0.9063
July 2019	0.1512	2.4532	0.9425
August 2019	0.1510	2.4109	0.918
September 2019	0.1380	2.5352	0.9274
October 2019	0.1221	2.7091	0.9268
November 2019	0.1440	2.4366	0.9387
December 2019	0.1319	2.5505	0.9626
January 2020	0.1238	2.6892	0.9373
February 2020	0.1372	2.4688	0.8964
March 2020	0.1362	2.5101	0.9449
April 2020	0.139	2.5077	0.9308
May 2020	0.1688	2.3149	0.9294

Analysis of the monthly variations in values of the regression constant of the Shell Length-Total body weight relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez indicated that October and January are the most favorable months for growth in weight of this species and the lowest values were recorded at August and May (Fig. 11c).

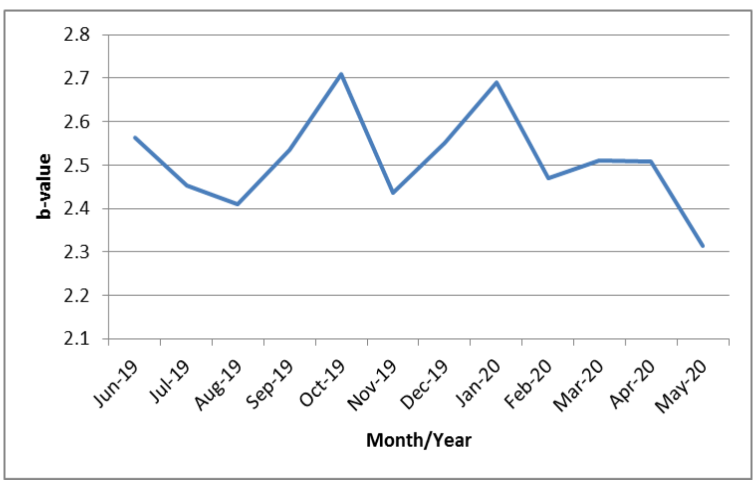

Fig. 11c. Monthly variations in values of the regression constant of the Shell Length-Total body weight relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

6-Shell Length - Shell Weight Relationship:

Figure (11b) showed the shell length-Total body weight relationship of 491individuals of *B. pharaonis* in the Gulf of Suez. In the present study, the value of (b) was about 2.998 which represented by the equation: ShWt = $0.0903ShL^{2.4723}$ (R=0.7347). This indicated that the growth in weight is negative allometric.

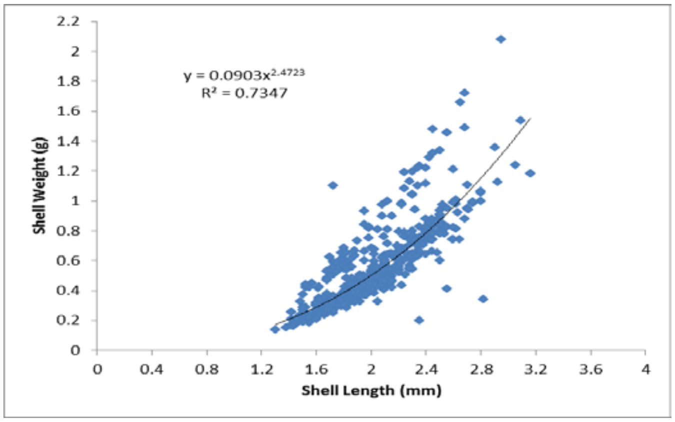

Fig. 11b. Shell Length-Shell weight relationship of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

7-Relative coefficient of Condition (Kn):

In the present study, the values of Kn of *B. pharaonis* were recorded according to different Shell lengths (Fig. 12). It was obvious that most of the investigated samples of *B. pharaonis* have Kn values more than 0ne which indicates the suitability of the environment for their growth.

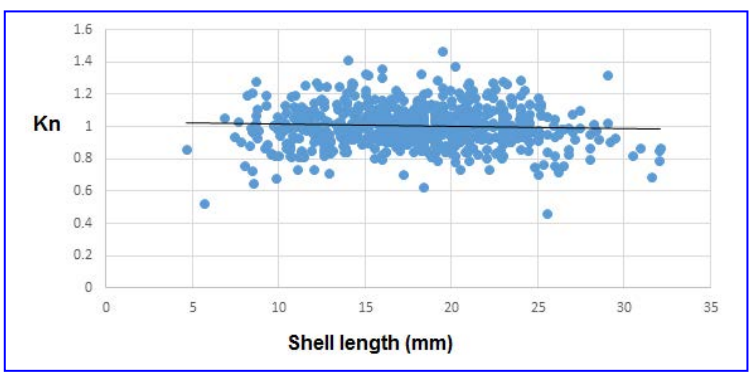

Fig. 12. Relationship between relative coefficient of condition (Kn) values and shell length of *B. pharaonis* from the western shore of Suez Gulf at NIOF Suez.

II-Population dynamics:

1. **Species composition and population density:**

The study area of the intertidal zone of the shore of NIOF is formed of sand, gravels and large concrete blocks which are covered by marine green filamentous algae. Blue mussels (*B. pharaonis*) and skeleton of tubeworms are found with this algal bloom (Fig. 13).

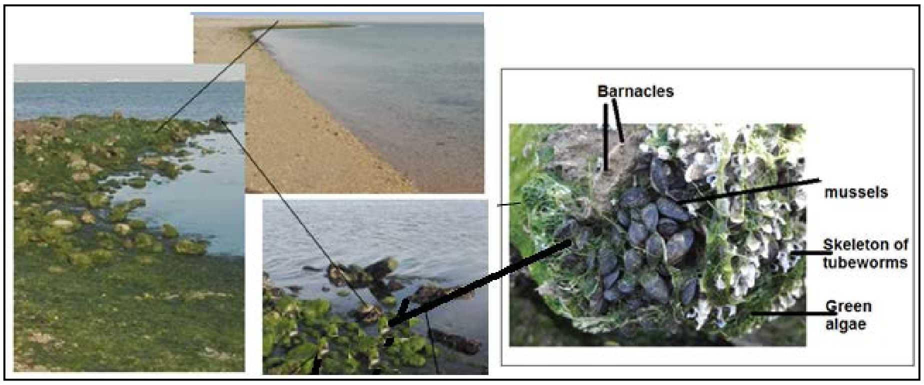

Fig. 13. The study site at the intertidal zone of the shore of NIOF at Suez during low tide, With species found at this investigated site.

The average monthly population density of *B pharaonis* in the investigated site at NIOF at Suez Gulf ranged from 6.19% (205 individuals/m^2) during January 2020 to 9.97% (330 individuals/m^2) in October 2019, with a mean value of 275 ± 10 individuals/m^2. The overall size-frequency distribution was asymmetric, shifted toward the predominated size (12.5-20.5 mm) (Fig. 14) which representing more than 75% of the total number of mussels sampled (Fig. 15).

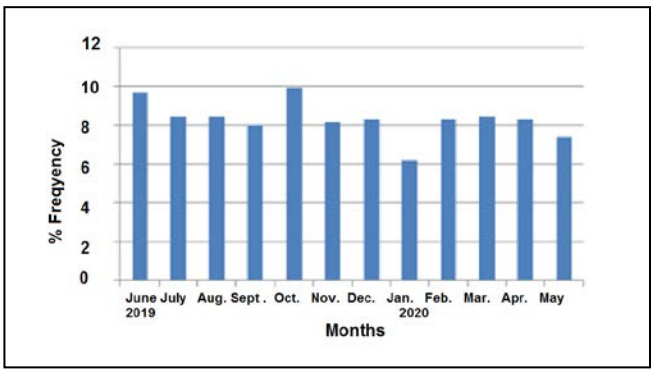

Fig. 14 Monthly frequency % of populations of *B. pharaonis* from NIOF, Suez.

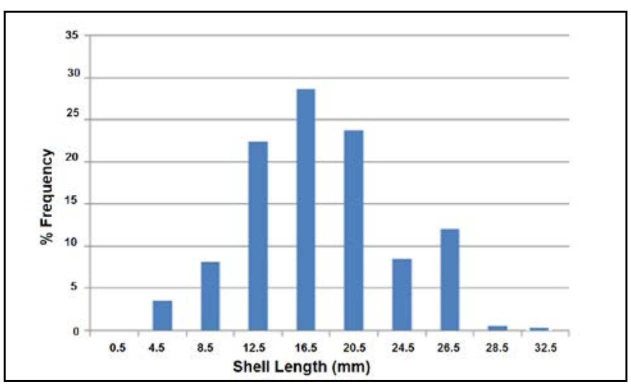

Fig. 15 Frequency % of different sizes of *B. pharaonis* from NIOF, Suez.

1-Age and growth

The monthly length frequencies for all individuals from the investigated site during the period June 2019 to May 2020 of *B. pharaonis* are presented in Figures (16 & 17).

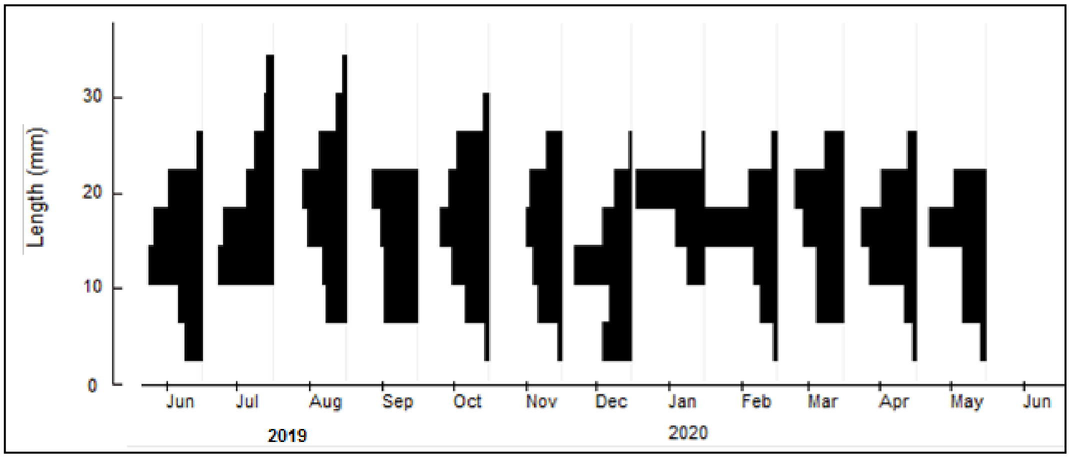

Fig. 16. Monthly shell length-frequency distribution of *B. pharaonis* from the western shore of Suez Gulf at NIOF.

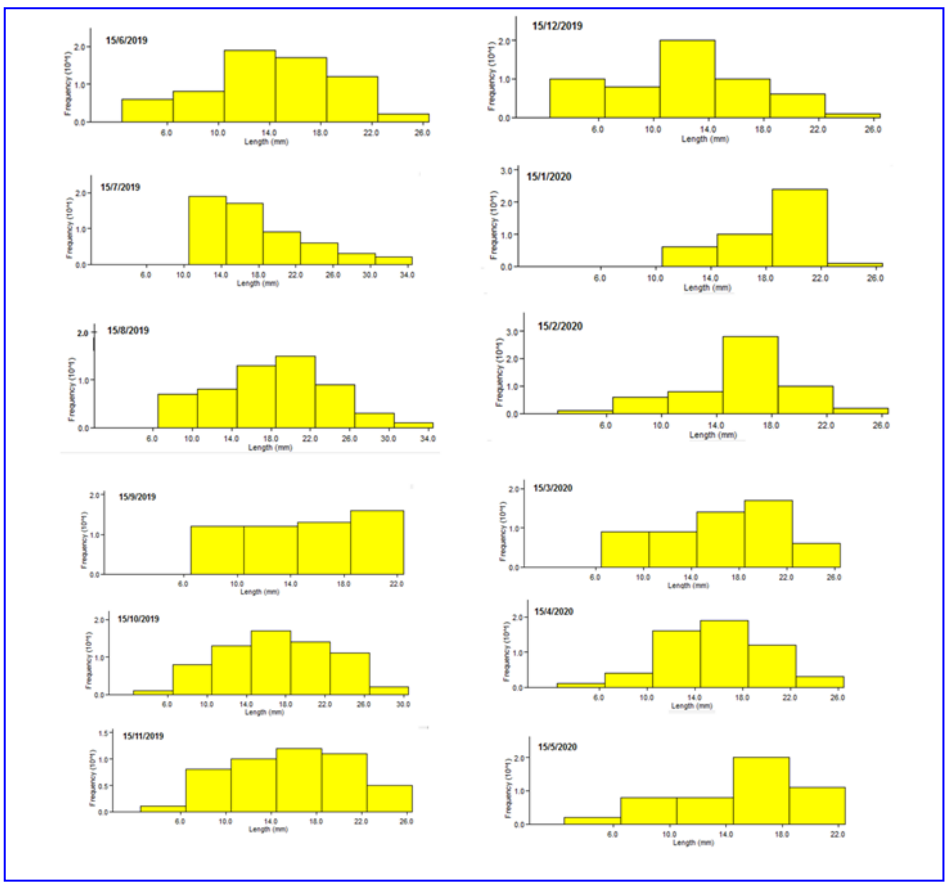

Fig. 17. Shell length-frequency distribution of each month for *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

The smooth growth curve was drawn using FiSAT II program for the monthly shell length frequency distribution of *B. pharaonis* from the investigate site as shown in Figure (18). The result indicated that the longevity of 650 specimens ranged from 4.5 to 32.5. The mean shell length at different age groups for each month throughout the investigated period is shown in Table (2).

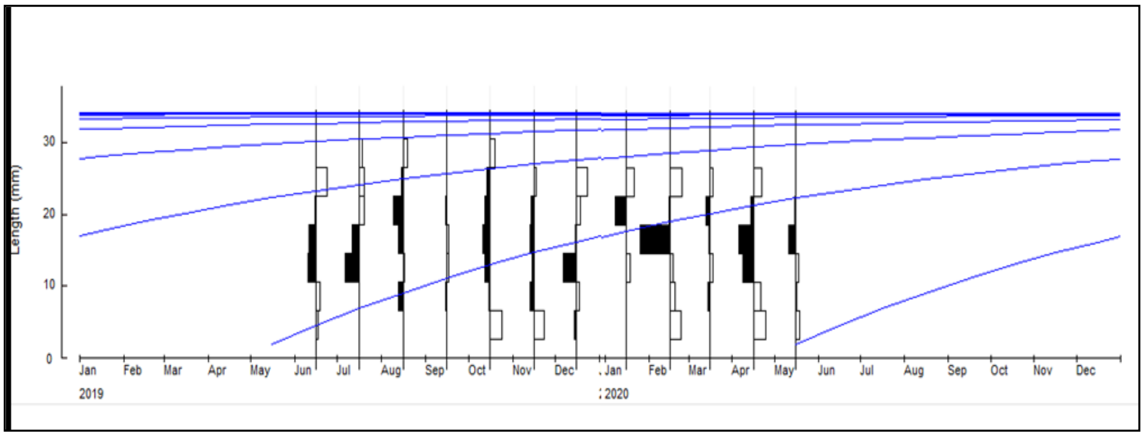

Fig. 18. Smooth growth curve passing through the maximum number of peaks of the repeated length frequency distribution of *B. pharaonis* from the western shore of Suez Gulf at NIOF, Suez.

Table (2). Estimated mean shell length for each age group at different months for *B. pharaonsis* from the western shore of Suez Gulf at NIOF, Suez.

	Age group / Date	0	1	2	3
Mean shell length (mm) ±sd	June 2019	21.20±3.433 (n=10)	25.85±4.649 (n=17)	30.20±4.743 (n=23)	0.0
	July 2019	19.63±6.010 (n=15)	26.37±.642 (n=15)	30.30±4.102 (n=15)	32.21±2.501 n=5)
	August 2019	14.70±3.899 (n=5)	24.22±5.256 (n=18)	29.97±4.168 (n=19)	30.63±6.128(n=8)
	September 2019	8.25±2.062 (n=4)	25.02±4.535 (n=21)	27.27±3.408 (n=22)	32.83±5.294(n=3)
	October 2019	10.50±2.582 (n=13)	24.79±4.268 (n=24)	27.96±3.971 (n=13)	0.0
	November 2019	11.61±5.754 (n=9)	26.39±3.594 (n=28)	30.12±4.464 (n=13)	0.0
	December 2019	14.39±3.341 (n=18)	25.97±3.482 (n=15)	27.85±4.107 (n=17)	0.0
	January 2020	7.12±7.532 (n=30)	15.40±12.700 (n=37)	16.87±13.515 (n=33)	0.0
	February 2020	17.33±3.073 (n=18)	27.05±3.379 (n=20)	29.25±4.434 (n=12)	0.0
	March 2020	17.38±3.294 (n=16)	28.06±3.669 (n=16)	29.89±4.804 (n=18)	0.0
	April 2020	19.55±3.407 (n=19)	29.38±4.224 (n=8)	30.89±4.261 (n=23)	0.0
	May 2020	21.71±47.202 (n=19)	26.77±4.264 (n=19)	31.24±4.495 (n=19)	33.50±4.202 (n=19)

n= number of specimens

The average monthly population density of *B pharaonis* in the investigated site at NIOF at Suez Gulf ranged from 205 to 330 individual/m^2 during June 2019 and October 2019, respectively, with a mean value of 275±10 individual/m^2. The overall size-frequency distribution was asymmetric, shifted toward the predominated size (12.5-

20.5 mm) (Fig. 19) which representing more than 75% of the total number of mussels sampled (Fig. 20).

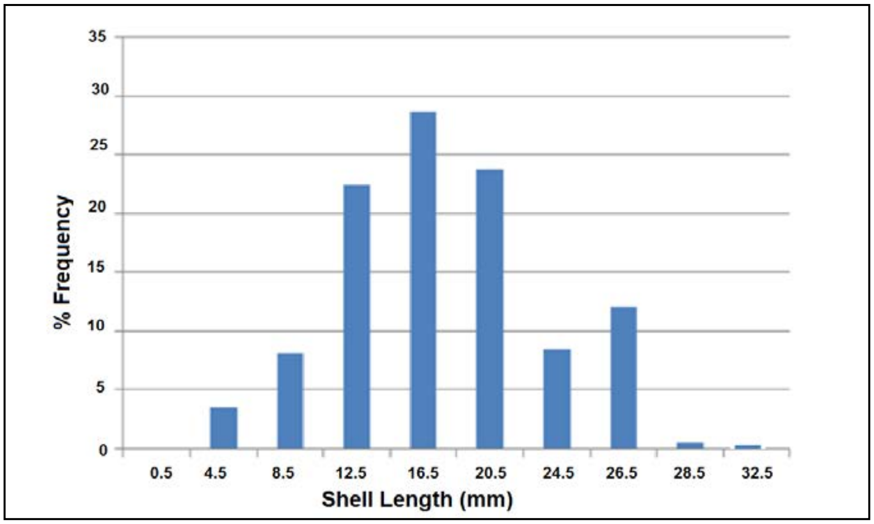

Fig. 19 Distribution of size-frequency % of populations of *B. pharaonis* from NIOF, Suez.

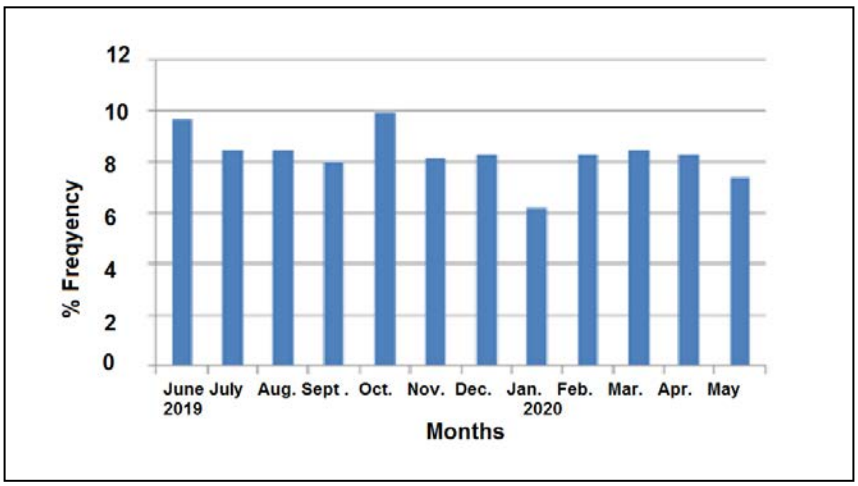

Fig. 20. Distribution of monthly size-frequency % of populations of *B. pharaonis* from NIOF, Suez.

The current study indicated the presence of three periods of recruitments of populations of *B. pharaonis* from NIOF, Suez during the investigated period from June 2019 to May 2020. These were at July, August and December as shown in Figure (21). Their Relative % recruitment values are shown in Table (2).

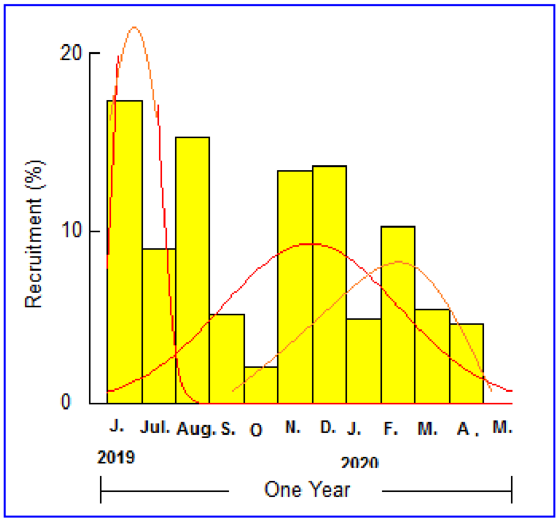

Fig. (21). % of relative recruitment of population of *B. pharaonis* from NIOF, Suez, during the investigated period from June 2019 to May 2020.

Table 2. The Relative % recruitment values of population of *B. pharaonis* from NIOF, Suez, during the investigated period from June 2019 to May 2020.

Relative Time	% Recruitment
June 2019	17.33
July	8.80
August	15.13
September	4.95
October	2.15
November	13.23
December	13.69
January 2020	4.80
February	10.03
March	5.26
April	4.61
May	0.00

2- Von Bertalanffy growth parameters:

The estimated von-Bertalanffy growth parameters (VBGP) were $L\infty$=34.13 mm, K=1.0yr^{-1}, t_0= 0.0yr^{-1}. The growth performance index (φ) was 3.66 (for length in mm) and 3.336 (for weight in g.).

The estimated overall growth performance (OGP) For *B. pharaonis* from Suez Gulf is equal to 1.533.

DISCUSSION

1- Morpology and Morphometry:

Branchiodontes pharaonsis (Fisher P. 1870) is one of the marine invertebrates that can exhibit a wide range of morphological variations in its natural environment as a result of its plastic response to environmental conditions such as wave exposure and tidal height (Seed, 1973), exposure to predators (Reimer and Tedengren, 1996) and density of conspecifics (Seed, 1968; Seed and Richardson , 1990). In the midlittoral rocky habitats of the Mediterranean sea it reached its maximum length at 40mm (Sirna *et al.*, 2006), while in the present study it reached 32.5mm in the Suez Gulf.

Studying shape variability and its relation with environmental causes is important to understand the diversity of life, and to know the great heterogeneity of forms that found in nature (Schmidt-Nielsen, 1984; Thompson, 1917; Adams *et al*., 2004). Telesca *et al*., (2018) described general relationships between shell shape variations in the Atlantic *Mytilus* species and environmental drivers that are independent of developmental (age) and genetic (species) contributions to mussel shape. They found that morphological variation in *Mytilus* can represent a powerful indicator for understanding the adaptation of organisms and help to predict their responses in a rapidly changing environment. In the present study the shell shape of *B. pharaonis* is slightly varied with the increase in shell length or age. It is elongated and wide, with relatively large height in small mussels and became elongated with relatively small width and height. The posterior end is rounded, the anterior end is elongated, the dorsal side is slightly convex and the ventral side is slightly concave. Telesca *et al*. (2018) indicated that less favourable conditions affected the shell shape of the blue mussels *Mytilus edulis* and *M. trossulus* in the North Atlantic and Arctic and lead to the formation of elongated and narrow shells, with more parallel dorsoventral margins. These variations could be explained by shapes being driven by the maintenance principle of a physiologically favourable surface-area to volume ratio (Seed and Richardson, 1990) which increases in elongated shells. The observed shapes, along with physiological acclimatization could represent an important component of mussel adaptation to environmental stressors (Tomsen *et al*., 2013).

Although *B. pharaonis* is greatly resembles the populations of *B. variablis* yet, it was considered a monophyletic clades of *B. viriabilis* by examining the mitochondrial DNA sequences of 16S-rDNA and cytochrome oxidase (COI) genes and its distribution is mainly in the Red and Mediterranean seas,while distribution of *B. variablis* is in Indian and Pacific Oceans (Terranova *et al*., 2007). Safriel and Ritte (1983) detected unique alleles of a few populations from the Red Sea and western Mediterranean Sea using Allozyme analyses. Therefore, the current values of regression constant of different body measurements can be used for inter and intera-specific variation in population of *B. pharaonis* in the Suez gulf.

The maximum shell length and total body weight of specimens of *B. pharaonis* from Adabia were 33.2mm and 3.25 g, respectively, while those from Ain Sokhna were 37.3 mm and 4.75g (El-Sayed *et al*., 2016). In the current study the maximum shell length and total body weight of the same species from NIOF on Suez Gulf were 32.5mm and 1.815g. Mohammed (1992) recorded large mussels of *B. variabilis* up to 36 mm shell length in the Great Bitter Lake, Suez Canal. These results indicated that the habitats at Ain Sokhna on Suez Gulf are most favorable for the growth of these blue mussels.

The condition indices portrayed by morphometric measurements represent a basis for developing an explanatory hypothesis about biological responses or different ecological scenarios for populations. In the present investigation the values of the regression constant of different morphometric linear relationships for populations of *B. pharaonis* can be used to differentiate this species in its locality at Suez Gulf. Also, this may indicate that shell shape plasticity can represent a powerful indicator to understand the alterations of these blue mussel communities in its environment. In the present results the relations between shell length and both shell width and breadth were allometric with values of regression coefficients (b) greatly less than one (0.359 and 0.354, respectively). Although similar allometric relationship was recorded for the two populations of the same species from Adabia and Ain Sokhna on the Suez Gulf (0.746 and 0.853 and 0.663 and 0.740, respectively. These results may indicate that the habitats and environmental conditions are favorable at Adabia and Ain Sokhna rather than at the present investigated site at NIOF, Suez Gulf.

In spite of the variations in shell features of the mussels *B. pharaonis* that are difficult to quantify (like umbo orientation, convexity of the ventral margin) yet the fine-scale shape patterns can be characterized without alterations of linear shell dimensions. Moreover, the development of geometric morphometrics can also provide another tool to investigate mussels shape variation (Crampton, 1995; Gardner and Thompson, 2009; Valladares *et al*., 2010) .

In the present investigation the growth of total body weight with shell length of *B. pharaonis* was allometric. Similar results were given by El-Sayed *et al*. (2016) for the two populations of the same species from Adabia and Ain Sokhna on Suez Gulf with b values of the regression coefficients of this relationship were 2.112 and 2.376, respectively. In the current study the value of (b) was estimated to be 2.630. Sara *et al*. (2008) for the same species from Mediterranean Sea recoded that b value of the allometric relationship of Shell Length and Total body weight reached 2.7 during summer and autumn. Also, Radwan (2014) reported that b value for specimens *of B. pharaonis* was 2.38 from Lake Timash (Suez Canal), 2.76 from Gulf of Suez, 2.78 from Marsa Alam (Red Sea), 2.97 from Bardawil Lagoon and 2.71 from Port Said (Mediterranean Sea)

On the other hand, in the present study the relative coefficient of condition (kn) values of *B. pharaonis* in the investigated habitats on the Suez Gulf were more than 0ne indicating the suitability of the environment for their growth. This agreed with the results of El-Sayed *et al*. (2016) for two populations of the same species from Adabia and Ain Sokhna on Suez Gulf.

On the other hand, b-value of the regression constant of the Shell Length-Total body weight relationship of *B. pharaonis* being slightly higher in summer at Adabia and reached the highest value during winter at Ain Sokhna on Suez Gulf (El-Sayed *et al*. (2016) which are similar to the current results for the same species where the highest values were recorded at October and January, while the lowest ones were at May and August.

2- Age and growth

Different methods were used to estimate age and growth of bivalves. Surface shell rings were often indistinct and therefore unreliable indicators of age, while annual growth lines in the nacreous layer of the shell, can provide an alternative method for determining the age and growth rate of *Mytilus edulis* (Bayne, 1976; Bayne and Worrall, 1980; Lutz and Castagna, 1980). Seed and Richardson (1990) studied sections of individual *Mytilus edulis* shells grown in plastic mesh cages in the North Sea and sampled throughout the year. The results indicated the presence of tidal microgrowth patterns in the outer prismatic layer which also revealed clearly marked annual patterns of deposition. The identification of these patterns, which result from the narrowing of the tidal growth bands during the colder winter months, has permitted the past growth history of individual mussels to be determined. The authors estimated the age of *M. edulis* to reach to 11 years old. In the current mussel *B. pharaonis* the tidally induced banding pattern is not apparent, however patterns of weak growth bands resulting from an endogenous rhythm of shell deposition with no apparent environmental periodicity have been observed in its prismatic layer.

Size frequency distributions for some species of bivalves are distinctly polymodal with each mode representing an individual year class. By estimating the mean size of these modes population growth rate can be assessed. Analyses of size frequency distributions have previously been used to estimate growth rates of *M. edulis* (Theisen 1968, Bayne and Worrall 1980, Rodhouse *et al*. 1984). In the present study the length frequency distribution of *B. pharaonis* had been applied to estimate its age to be 3 years. However, Elsayed *et al*. (2016) using the length frequency distribution for two populations of *B. pharaonis* from Adabia and Ain Sokhna at Suez Gulf recorded 5 size classes.

In the study of Seed and Richardson (1990) some individuals of *M. edulis* attained shell lengths of 70 mm in their first few years of growth, others within the same population attained shell lengths of 25 to 30 mm during the same period. Such reductions in growth rate may reflect intense intraspecific competition. In the current study there were monthly variations in the shell length of *B. pharaonis* where the maximum shell length varied between 20.5mm to 32.5 mm. In populations containing several age classes like that recorded in the current study (3 age classes) large numbers of small mussels may become ensnared amongst the abyssal threads of larger individuals and are consequently at a severe disadvantage in their competition for food (Seed 1968, Kautsky, 1982). The maximum shell length for the same species varied in different localities. It was 36 mm at Sicily (Mediterranean Sea) (Sara *et al*. (2008), 40 mm at Indo-Pacific regions (Zenetos, *et al*., 2005), 40 mm, 30 mm at Suez Gulf, Suez Canal, Bardwil, and Marsa Alam (Radwan, 2014), 20 mm at Hong Kong (Morton, 1988), 22 mm at India (Rajagopal *et al*., 2003), 18 mm at Gulf of Aqaba and Suez Gulf at Suez (Mohammed, 1992, 1997).

Also, growth of *B. pharaonis* can be modulated by several interacting factors including water temperature and depth, food availability and the degree of aerial exposure (Seed & Richardson, 1990). In the current investigation *B. pharaonis* was found to have a great ability to live in its habitat in the Gulf of Suez, Red Sea with high salinity, abundant of food and wave exposure and sedimentation are optimal. This agreed with the results of Safriel *et al*. (1980); Sara` *et al*. (2000); Terranova *et al*. (2006). On the other hand, shell changes in *B. pharaonis* can reflect its responses to environmental conditions at Suez Gulf and the level of its shape variation can be used as an indicator of habitat change selecting for specific traits. Similar conclusion was given for by Fitzer *et al*. (2015) where they found that ocean acidification and temperature increase impact mussel shell shape and thickness. Therefore, multi-population studies across broad geographical areas on the Red Sea are essential to investigate responses of *B. pharaonis* populations to different environmental driver forces. Similar conclusion was given by Kroeker *et al*. (2016, 2017) for populations of *Mytilus*.

Sukhotin *et al.* (2007) studied the growth of mussel *Mytilus edulis* in 24 wild populations and one cultured population located in the White Sea and the southeast part of the Barents Sea. They found that the maximal longevity and the size of this mussel varied between 7 and 18 years and

25.5 and 77.7 mm, respectively. Its von Bertalanffy growth parameters, L_∞, and k were 119.9mm, $0.044y^{-1}$, and 27.7mm and $0.263y^{-1}$, respectively. However, in the current work the maximum age and size for *B. pharaonis* from Suez Gulf was 3 years and 32,5mm, respectively. The values of L_∞, k were 34.13mm and 1.0 y^{-1}. The growth performance was 3.66 for shell length and 3.33 for total body weight, while its overall growth performance index (OGP) was 1.533. The difference in longevity and maximum shell length can be related to the type of species and the geographical location of the population within the studied region. Sukhotin *et al.* (2007) concluded that the growth of *M. edulis* was mostly determined by local environmental factors, including those related to vertical zonation, rather than by latitude/longitude and related temperature effects.

In the present work the average monthly population density of *B pharaonis* in the investigated site at NIOF at Suez Gulf varied from 205 to 330 individual/m^2 during June 2019 and October 2019, respectively, with a mean value of 275±10 individual/m^2. The overall size-frequency distribution was asymmetric, shifted toward the predominated size (12.5-20.5 mm) which representing more than 75% of the total number of mussels sampled. Mohammed (1992) counted population density of *B. variabilis* within the bed in the Great Bitter Lake was (1182.1±75.2/m') and it varied according to the type of substrate where it reached 900 on the hard substrate and about 2200 on the soft one.

The results of the current study will help in differentiation between inter and intra-specific variation of similar and different population species of *B. pharaonis* in the Red Sea as well as in other worldwide localities.

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Morphology, morphometry and population dynamics of the mussel *Brachidontes pharaonis* from the the western region of Gulf of Suez

الشكل والقياس وديناميكية العشائر لبلح البحر *Brachidontes pharaonis* من المنطقة الغربية لخليج السويس

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المستخلص

تمت دراسة الشكل والقياس وديناميكية العشائر لبلح البحر *Brachidontes pharaonis* من الشاطئ الصخري للمنطقة الغربية لخليج السويس بالمعهد القومي لعلوم المحيطات والمصايد بالسويس. تم وصف منطقة الدراسة وكذلك تكوين الأنواع. تم وصف شكل القشرة الخارجية والداخلية لـلحيوان كما تم حساب الثوابت المقدرة A و B للعلاقات المورفومترية. تراوح طول الصدفة لـهذا الحيوان بين ٤.٥ إلى ٣٢.٥ ملم بمتوسط ١٧.٩ ملم ووزن الجسم الإجمالي المقابل ٠.٠١٥ إلى ٢.١٩٥ جرام بمتوسط ١.٤٩٨ جرام. تمت دراسة التوزيع الطولي التكراري للعينات الشهرية من يوليو ٢٠١٩ إلى مايو ٢٠٢٠. تم تقدير عمر ونمو ٦٧٤ عينة من هذا النوع باستخدام طريقة توزيع الطول والتكرار. كانت معلمات نمو (von-Bertalanffy) هي $L\infty = 34.13$ مم، $K = 1.0yr^{-1}$، $t_0 = 0.0yr^{-1}$، $W\infty = 3.11$. وكان مؤشر أداء النمو (φ) 3.66 للطول ، 3.0. للوزن. أشارت العلاقة بين الطول والوزن إلى نمو سلبي في القياس ($b = 2.5391$).