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RESEARCH PAPER

Population Dynamics of the Cockle *Cerastoderma glaucum*: A comparison between Lake Qarun and Lake Timsah, Egypt

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Abstract

The cockle *Cerastoderma glaucum* represents one of the most common marine mollusc species present in Egyptian waters. This study aims to investigate the population structure, growth, mortality, and exploitation status of this cockle along Lake Qarun and Lake Timsah in order to make a comparison study. Cockles were collected from Lake Qarun at monthly intervals between February 2008 and May 2009 and collected from Lake Timsah at four seasons only. Length frequency data were analyzed using FiSAT software for estimation of population parameters to evaluate the stock. Asymptotic length ($L\infty$) was smaller in Lake Qarun (28.35 mm) compared to that in Lake Timsah (33.60 mm).Growth coefficient (K) was higher in Lake Qarun (0.450 yr^{-1}) than in Lake Timsah (0.280 yr^{-1}).Growth performance index (Φ) values were similar (2.56) in both cockle stocks. The theoretical maximum age (T_{max}) was higher in Lake Timsah (12.6 yr^{-1}) than in Lake Qarun (7.4 yr^{-1}). Total mortality (Z) was estimated by length-converted catch curve at 1.02 and 0.24 yr^{-1}, fishing mortality (F) at -0.04 and 0.47 yr^{-1} and natural mortality (M) at 1.06 and 0.71 yr^{-1} for Lake Qarun and Lake Timsah, respectively. Recruitment was continuous and showed two major pulses in the two lakes.

Keywords: Growth, mortality, recruitment, FiSAT II, Lake Qarun, Lake Timsah, Egypt.

Introduction

The cockle, *Cerastoderma glaucum* (poiret, 1789), a bivalve mollusk which is very common in the Mediterranean Sea and southern Europe, preferentially dwells on muddy bottoms of lagoons and estuaries. It has been recorded from the coasts of Egypt, Tunisia, Turkey, Sardinia, Italy, Greece, Portugal, Spain, France (Atlantic and Mediterranean coasts), The Netherlands, the British Isles, Denmark, Finland, Norway and in the Wadden Sea, Adriatic Sea, Red Sea, Aegean Sea and Caspian Sea (Brock and Wolowicz, 1994; Malham *et al*, 2012).

C. glaucum may play an important ecological role in reducing the particulate organic load with a wide range type of salinity and thermal characteristics. This makes *C. glaucum* an interesting subject for cultivation and/or reducing the environmental impact of organic loading in estuaries' systems (Trotta and Cordisco, 1998). *C. glaucum* plays also an important direct and indirect role in nutrients cycles. It is eaten by human and considered as a very cheap food resource due to their occurrence in high densities. The indirect role is by sharing in food chain as some marine animals' prey upon them. Therefore, *C. glaucum* is an important macrobenthos that share in regulating the benthic fauna ecosystem in its habitat (El-Shabrawy, 2001; Fishar, 2000).

The cockle represented one of the most dominant species of the macrozoobenthos living in Lake Qarun, Fayoum, Egypt (Abdel-Malek and Ishak,1980; El-Shabrawy, 2001; Fishar, 2000). The standing crop and biomass of the cockle ranged from 11 to 93 ind.m^{-2} and from 6.9 to 70.7 g fresh weight.m^{-2}, respectively (El-Shabrawy, 2001). Several records of *C. glaucum* were also undertaken from other Egyptian waters, e.g. Lake Bardawil (Fishar, 2005), Suez Canal Lakes (Barash and Danin, 1972) and Lake Timsah (Mohammad, 2002; Mohammed *et al*, 1992; 2006). Nevertheless, available information on *C. glaucum* is scarce in Egypt (Kandeel *et al*, 2013; Mohammad, 2002; Mohammad *et al*, 2006).

For planning and sustainable management of bivalve resources, knowledge of various population parameters and exploitation level (E) of that population is essential. The present study is the first attempt to estimate the population structure, growth, mortality, and exploitation rates and recruitment pattern of *C. glaucum* so as to assess the stock position of the species in Lake Qarun, Egypt, using FiSAT. Also, height, breadth, and total weight were measured for allometry study.

Materials and Methods

Study Areas

Lake Qarun

Lake Qarun is one of the largest lakes of Egypt. It is a closed saline lake in the northern part of El-Fayoum Depression, 85 km to the southwest of Cairo). The lake lies between 30° 34` and 30° 49` E longitude and 29° 25` and 29° 34` N latitude (Figure 1) at 44 m below the sea level and covers, as a whole, an area of about 226 km^2. Lake Qarun receives annually about 470 million cubic meters of drainage water through 12 drains of which "Bats" and "Wadi" drains carry most of the water brought to the lake (Fathi and Flower, 2005). Salinity of water in lake has increased gradually since the 20th century and caused a profound effect on the faunal composition of the lake and reduced their standing crop (El-Shabrawy, 2001).

Lake Timsah

The Suez Canal connects the northern end of the Red Sea, at the top of the Gulf of Suez, to the Mediterranean Sea at Port Said. It has a total length of about 162 km and includes several shallow lakes (Figure 2). Lake Timsah lies at the middle of the Suez Canal between 30° 33` and 30° 35` N and 32° 16` and 32° 19` E. It has a surface area of about 15 km^2 and a depth ranging from 6 to 13 m.

The bottom of the southern region of The lake around El-Taawen area consists of mixed muddy sand and gravel with some shell fragments. The percentage of organic matter ranged between 1.1 and 2.3%.Water salinity ranged between 35.4 ‰ and 43.2‰. Water temperature varied from 15.9°C in winter to 30°C in

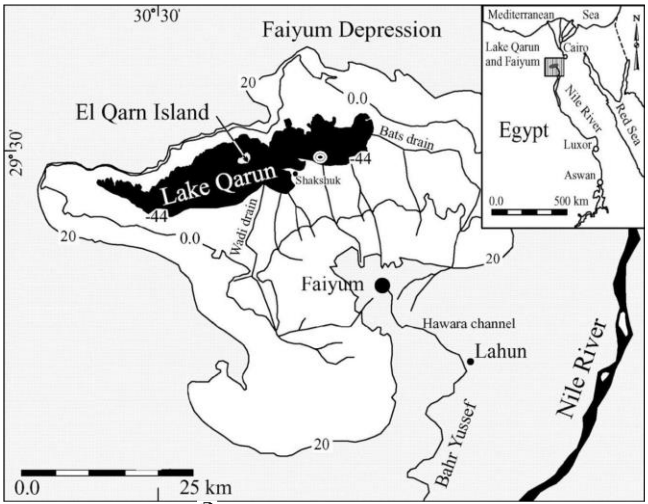

Figure 1. Map of Lake Qarun showing sampling site (⦿).

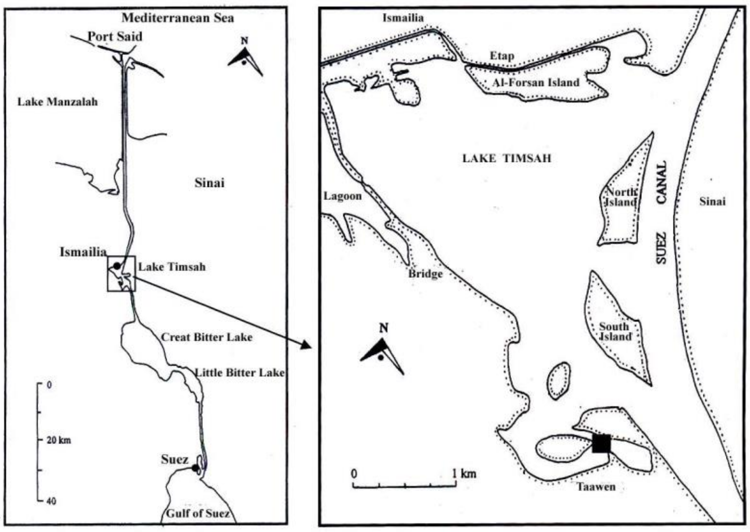

Figure 2. Map of the Suez Canal showing sampling site (■) in Lake Timsah.

summer (Kandeel, 2008).

Sampling Procedure

Samples of *C. glaucum* were collected from Lake Qarun at monthly intervals between February 2008 and May 2009 by dragging from a depth of nearly 2 meters. But samples of Lake Timsah were collected in four seasons only; spring (April), summer (July), autumn (October) 2008 and winter (February) 2009. The sediments were washed out carefully in situ through one mm mesh size sieve. The materials retained by the sieve were kept in labeled containers filled with 5% formaldehyde-seawater solution.

Laboratory Procedure

In the laboratory, shell length (maximum distance on the anterior-posterior axis) of each cockle was measured to the nearest 0.1 mm using a Vernier caliper. Length measurements were used to produce length-frequency distribution for each sample collected from the two lakes using class intervals of 1 mm size. Other size parameters, such as shell height (maximum dorso-ventral axis), shell width (maximum lateral axis) and total weight (precision of 0.0001 g) were measured. Weight measurements were done using top-loading digital balance and were restricted to adult cockles.

Data Analysis

Von Bertalanffy Growth Parameters

Length-frequency data were analyzed using the FiSAT II software as explained in detail by Gayanilo *et al* (2005). The growth parameters; asymptotic shell length ($L\infty$ in mm) and growth co-efficient (K, yr^{-1}) of the Von Bertalanffy Growth Formula (VBGF) were estimated by means of ELEFAN-I (Pauly and David, 1981; Pauly and Morgan 1987). Additional estimates of $L\infty$ and Z/K values were obtained by plotting $\bar{L}$ minus L' on $\bar{L}$ (Wetherall, 1986 as modified by Pauly, 1986), i.e.

$$\bar{L} - L' = a + b\,\bar{L}$$

Where, $L\infty = -a/b$ and $Z/K = -(1+b)/b$

Where $\bar{L}$ is defined as the mean length computed from L' upward in a given length-frequency sample, while L' is the limit of the first length class used in computing a value of $\bar{L}$.

The estimates of $L\infty$ and K were used to calculate the growth performance index Φ (Pauly and Munro. 1984) using the equation:

$$\Phi' = \log(K) + 2\log(L\infty)$$

Growth performance index is a topic related closely to population dynamics of benthic macro-invertebrates (Brey, 1999). This index enables comparisons of the growth performances of specimens at different sampling sites and also with other closely-related species e.g, *Cerastoderma edule*.

The inverse von Bertalanffy growth equation (Sparre and Venema 1992) was used to find the lengths of *C. glaucum* at various ages. Then VBGF was fitted to estimates of length-at-age curve using non-linear squares estimation procedures (Gayanilo *et al*, 2005). The VBGF is defined by the equation:

$$L_t = L_\infty [1 - e^{-K(t - t_0)}]$$

where L_t = mean length at age t, L_∞ = asymptotic length, K = growth co-efficient, t = age of the *C. glaucum*, and t_0 = 0; the hypothetical age at which the length is zero (Pauly and David, 1981).

The theoretical maximum age (T_{max}) was calculated for each population using the following equation constructed by Michaelson and Neves (1995),

$$T_{max} = \frac{\ln L_\infty + Kt_o}{K}$$

Mortality and Exploitation Rate

Total mortality (Z, yr^{-1}) was estimated by length-converted catch curve method (Pauly, 1983; 1990). FiSAT outputs Z yr^{-1} as well as the 95% confidence intervals surrounding Z based on the goodness of fit of the regression.

Natural mortality rate (M) was estimated using the empirical relationship of Pauly (1980):

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

Where $L\infty$ is expressed in mm and T, the mean annual habitat temperature which were

27°C and 25°Cover the study period at Lake Qarun and Lake Timsah, respectively.

Once Z and M were obtained, then fishing mortality (F, yr^{-1}) was estimated using the relationship: F = Z-M, where Z is the total mortality, F, is fishing mortality and M is natural mortality.

The exploitation rate (E) was obtained by the relationship of Gulland (1971):

$$E = F/Z = F/(M+F)$$

Recruitment Pattern

The routine in FiSAT reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse, using the VBGF parameters (Moreau and Cuende 1991; Pauly, 1983;). Normal distribution of the recruitment pattern(%) was determined by NORMSEP (Pauly and

Caddy, 1985) in FiSAT.

Biometric Studies

The biometric relationships between the different shell dimensions (allometric growth) were described by the general equation,

$$Y = a + b X$$

where:Y and X are paired shell dimensions and represent a dependent and an independent variables, respectively.

The relationship between shell length (L, mm) and total weight (W, g) was investigated by applying the linear least squares method for log-transformed data of parameters:

$$\text{Log } W = a + b \log L \text{ or } W = aL^b$$ (Ricker, 1975; Quinn and Deriso, 1999)

where W= a dependent variable; a = intercept (initial growth coefficient); b = slope (relative growth rate of size parameters). The association degree between size parameters was calculated by the determination coefficient (r^2). Additionally, data were submitted to an analysis of variance (ANOVA) to estimate variance ratio (F) and the significance level of r^2.

The deviation of the b value of the regression function from the isometric value (i.e. length-weight relation: b = 3; length-height-breadth relation: b = 1) was analyzed by means of a t-test, as expressed by the following equation (Monti *et al*., 1991):

$$t_s = (b - \beta)/s_b$$

where t_s = t-test value; b = slope; β = isometric value of the slope; s_b = standard deviation of the slope (b). A comparison between the obtained values of t-test and the correspondent tabled critical values allowed for determination of the statistical significance of the b values. A significance deviation indicates a negative ($b < 3$ or $b < 1$) or positive ($b > 3$ or $b > 1$) allometric relationship.

The estimation of the weight-length relationships was carried out in four occasions; spring 2008, summer, autumn, and winter 2009. The slopes (b) and intercepts (a) of these relationships were compared between Lake Qarun and Lake Timsah by applying one-way analysis of variance (ANOVA). Statistical analysis was carried out using MINITAB software (version 13, 2000). Significance levels of statistical tests were set at P = 0.05.

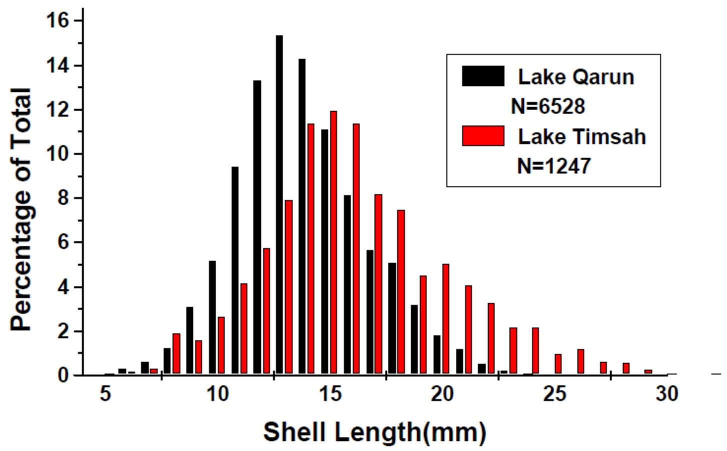

Figure 3. Variations in the percentage occurrence of the different size classes of *C. glaucum* collected from Lake Qarun and Lake Timsah through the study periods. N=number of individuals examined.

Table 1. Population parameters of C. glaucum collected from Lake Qarun and Lake Timsah

Population parameters	Lake Qarun	Lake Timsah
Asymptotic length (L∞) in mm	28.35	33.60
Growth co-efficient (K) yr-1	0.450	0.280
Growth performance index (Φ)	2.56	2.56
The theoretical maximum age (T_{max}) yr-1	7.4	12.6
Natural mortality (M) yr	1.06	0.71
Fishing mortality (F) yr-1	-0.04	-0.47
Total mortality (Z) yr-1	1.02	0.24
Exploitation rate (E)	-0.04	-1.98
Length range (mm)	4.0-27.0	5.0-32.0
Sample number (N)	6528	1247

Results

Population Structure and Growth

Population Structure

Overall, 6528 and 1247 individuals of *C. glaucum* were measured and their population structure studied for Lake Qarun and Lake Timsah, respectively (Figure 3).The broad length range varied between 4.0 - 27.0 and 5.0 - 32.0 mm shell length (Table 1) for the two lakes, respectively. The majority of cockle populations were attributed to size classes 12 - 15 and 14 - 17 mm which represented 54.03 and 43.53% of total samples collected from the two lakes, respectively. Large-size individuals (> 21 mm) represent only 2.09 and 15.48% for total samples collected from Lake Qarun and Lake Timsah, respectively.

Growth Parameters

The observed extreme lengths were 27.0 and 32.0 mm for Lake Qarun and Lake Timsah,

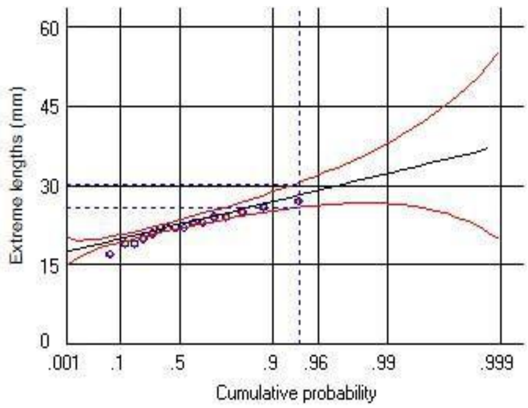

Figure 4. Predicted extreme length of *C. glaucum* (28.07 mm) collected from Lake Qarun.

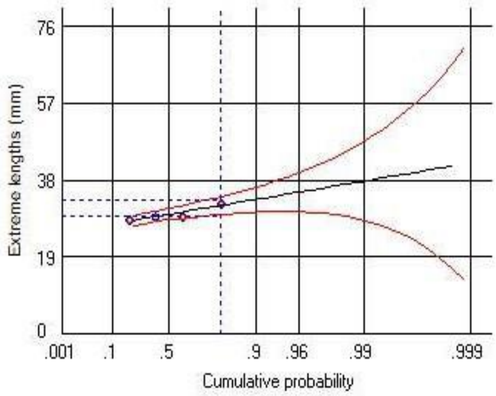

Figure 5. Predicted extreme length of *C. glaucum* (31.20 mm) collected from Lake Timsah.

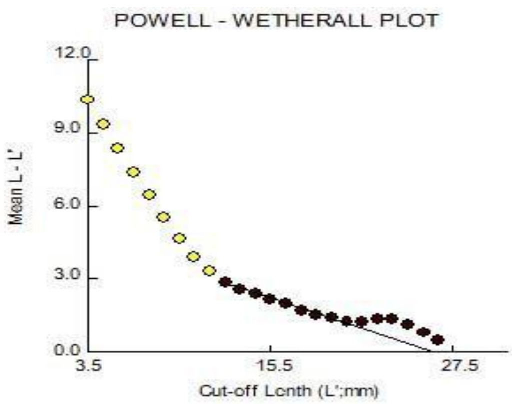

Figure 6. Powell-Wetherall plot of the estimation of L∞ (28.35 mm) and Z/K (3.809) for *C. glaucum* in Lake Qarum.

respectively. Also, the computer predicted extreme length was smaller in Lake Qarun (28.07 mm) than in Lake Timsah (31.20 mm) (Figure 4 and Figure 5). At 95% confidence interval, the extreme length ranged between 25.80 - 30.35and 29.24 - 33.15mm for Lake Qarun and Lake Timsah, respectively.

The Powell-Wetherall plot is shown in Figure 6 for Lake Qarun population. The corresponding estimates of L∞ and Z/K were 28.35 and 3.809, respectively and the correlation coefficient for the regression line was -0.990 (a = 5.44 and b = -0.208). For Lake Timsah population (Figure 7), the estimates of L∞ and Z/K were 35.00 and 4.129, respectively and the correlation coefficient for the regression line was -0.993 (a = 6.82 and b = -0.195).

The ELEFAN-I (Electronic Length Frequency)

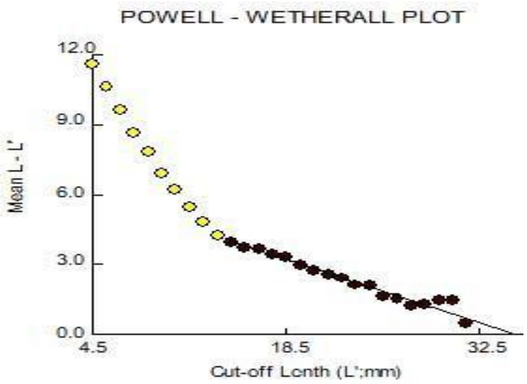

Figure 7. Powell-Wetherall plot of the estimation of L∞ (35.00 mm) and Z/K (4.129) for *C. glaucum* in Lake Timsah.

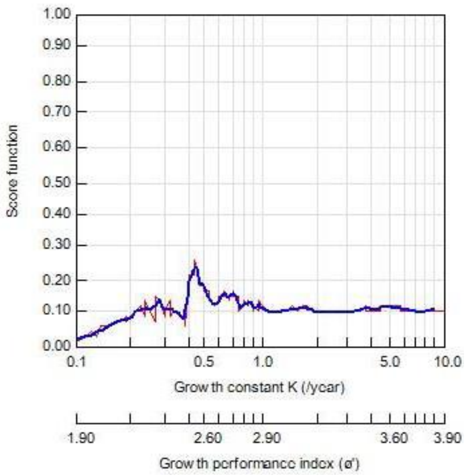

Figure 8. Scan of "K" value for *C. glaucum* collected from Lake Qarun.

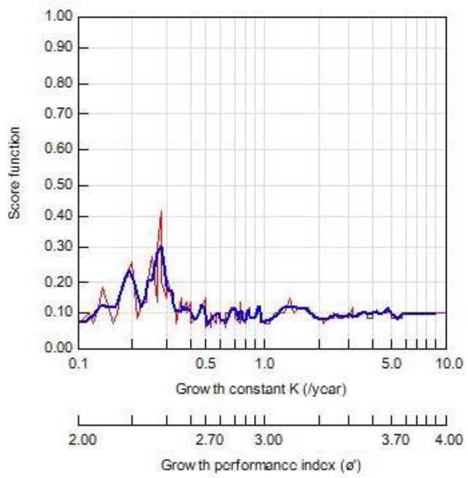

Figure 9: Scan of "K" value for *C. glaucum* collected from Lake Timsah.

Analysis program estimated asymptotic length (L∞) and growth co-efficient (K) of the Von Berttalenfy Growth Formula (VBGF) were 28.35 mm and 0.450 yr^{-1} and 33.60 mm and 0.280 yr^{-1} for cockles collected from Lake Qarun and Lake Timsah, respectively. For these estimates through ELEFAN-I, the response surface (Rn) used for the curves were 0.254 (Figure 8) and 0.414 (Figure 9) for the two lakes, respectively. Figure 10 and Figure 11 show length frequency distribution and the superimposed growth curves estimated by ELEFAN-I for *C. glaucum* collected from Lake Qarun and Lake Timsah, respectively. Growth performance index (Φ′) of Pauly and Munro (1984) was similar (2.56) in both lakes (Table 1).

Age and Growth

The sizes attained by *C. glaucum* in Lake Qarun were 10.3, 16.8 and 21.0 mm at the end of 1st, 2nd and 3rd years of age, respectively. The absolute increases

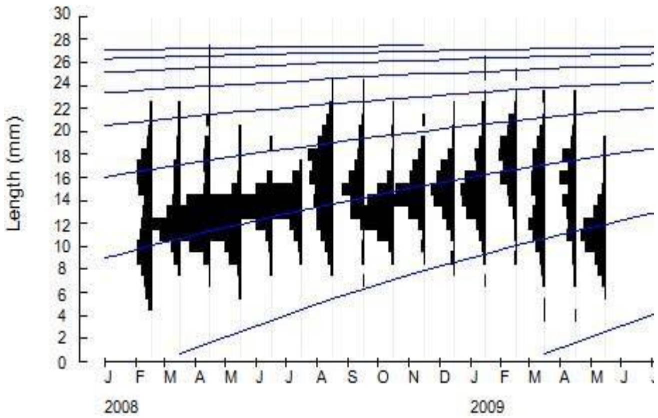

Figure 10. Length-frequency plot of *C. glaucum* samples taken from Lake Qarun with superimposed growth curves estimated by ELEFAN 1 (L∞ = 28.35 3 mm and K= 0.450 yr^{-1}).

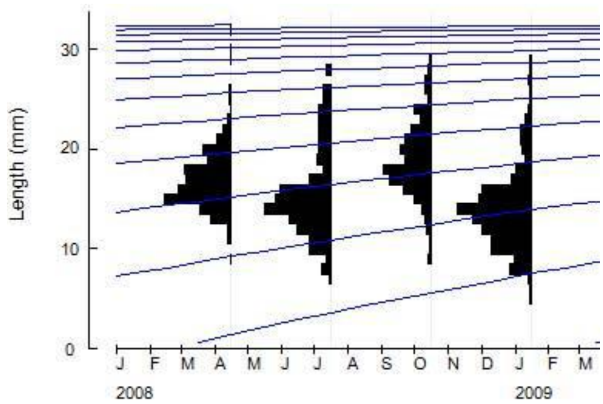

Figure 11. Length-frequency plot of *C. glaucum* samples taken from Lake Timsah with superimposed growth curves estimated by ELEFAN 1 (L∞ = 33.60 3 mm and K= 0.280 yr^{-1}).

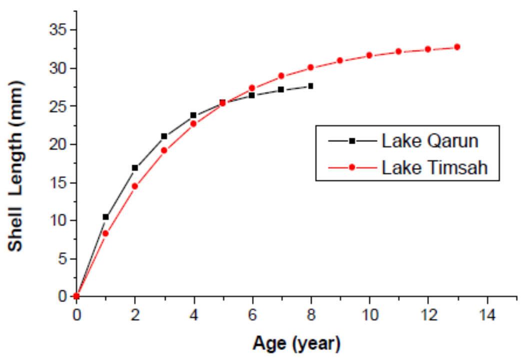

Figure 12. Von Bertalanffy growth curves in terms of age and size based on calculated growth parameters for *C. glaucum* collected from Lake Qarun and Lake Timsah.

are presented in Figure 12. For Lake Timsah population, the sizes attained were 8.2, 14.4 and 19.1 mm at the end of these ages, respectively (Figure 12). Therefore, the average growth rate of *C. glaucum* through the first three years of life was shown as similar values; 7.0 and 6.4 mm.yr^{-1} for Lake Qarun and Lake Timsah, respectively. However, the theoretical maximum age (T_{max}) was higher in Lake Timsah (T_{max}=12.6yr^{-1}) than in Lake Qarun (T_{max}=7.4 yr^{-1}).

Mortality and Exploitation Rate

Length-converted catch curve analysis produced total mortality (Z) for *C. glaucum* was 1.02 yr^{-1} (confidence interval; CI = 0.79 - 1.24) and 0.24 yr^{-1} (CI = -1.98 - 2.45) for Lake Qarun and Lake Timsah, respectively. The catch curves utilized in the estimation of Z are represented in Figures 13 and 14 for the two lakes, respectively. The darkened circles represent the points used in calculating Z through least square regression analysis. For Lake Qarun samples, the correlation coefficient (*r*) of the regression was -0.9999. The intercept (*a*) and slope (*b*) ±S.D. of the regression line performed on the selected data points were 6.34 ± 0.10 and -1.02 ± 0.02, respectively. On the other hand, the correlation coefficient of Lake Timsah samples was -0.8038. The intercept (*a*) and slope (*b*) ± S.D. of the regression line were 1.42 ± 1.63 and -0.24 ± 0.17, respectively.

Estimated value of natural mortality (M) from Pauly's empirical formula is higher (1.06 yr^{-1}) in Lake Qarun than in Lake Timsah (0.71 yr^{-1}). Fishing mortality (F) was estimated to be -0.04 and -0.47 yr^{-1} for the two lakes, respectively (Table 1). The rate of exploitation (E) was estimated at -0.04 for Lake Qarun and -1.98 for Lake Timsah.

Recruitment Pattern

The recruitment pattern (%) generated by FiSAT for *C. glaucum* at the two lakes was continuous throughout the year with two major pulses. The relative strength of these pulses was 16.85 and17.53% recruitment for Lake Qarun (Figure 14) and 15.52 and 12.40% recruitment for Lake Timsah (Figure 15).

Biometrics Tudies

Linear regression equations fitted between different shell dimensions of *C. glaucum* collected from Lake Qarun and Lake Timsah are shown in Table 2. Shell height and shell breadth are positively correlated with shell length in both Lakes. These

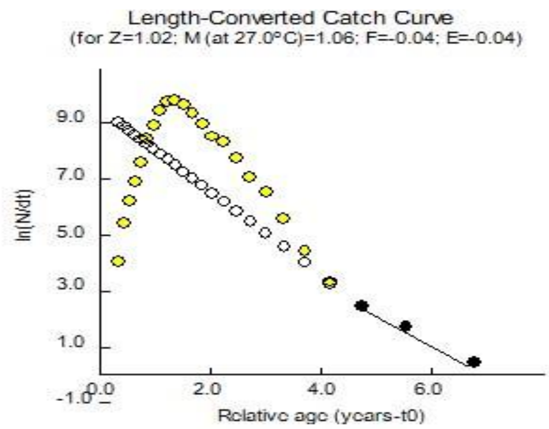

Figure 13: Length converted catch curve of *C. glaucum* collected from Lake Qarun.

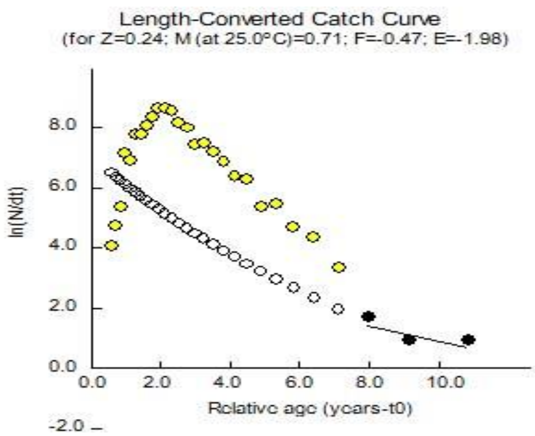

Figure 14. Length converted catch curve of *C. glaucum* collected from Lake Timsah.

results indicate that as *C. glaucum* increases in length, the shell becomes proportionally higher and wider.

Level of significance from isometry (p) indicates that shell breadth increased isometrically with shell length for the populations of the two Lakes. Student's t-test showed that shell breadth increased relatively slower than shell height (negative allometric growth) for the two Lakes. Slope value of shell height-shell length regression had isometric growth pattern for Lake Qarun population and departed significantly from isometry (P<0,05) indicating negative allometric relationship for Lake Timsah population.

Seasonal relationships between logarithmically transformed data of total weight (W) and shell length (L) of mature *C. glaucum* collected from Lake Qarun and Lake Timsah are shown in Table (3). The results displayed strong relationships ($p < 0.0001$) indicating that total weight changes much, although cockles grow steadily. For the populations of the two lakes, slope values (b) were not significantly deviated from 3 value ($p > 0.05$) indicating isometric growth pattern throughout the study seasons.

One-way ANOVA test comparing length-weight relationships among Lake Qarun and Lake Timsah throughout the four seasons was performed. The means of intercepts (log a) ($F_{3,4} = 0.95738$; $P > 0.05$) and slopes (b) ($F_{3,4} = 1.78488$; $P > 0.05$) are not significantly different between the two lakes.

Discussions

The derived L∞ and K values from the length-frequency data of *Cerastoderma glaucum* samples collected from Lake Qarun (Figure 11) were 28.35 mm and 0.450 yr^{-1}, respectively. On the other hand, higher L∞ (33.60 mm) and lower K (0.280 yr^{-1}) values were obtained from the data of samples collected from Lake Timsah (Figure 12). L∞ derived from Lake Qarun population proved to be smaller compared to Lake Timsah population due to the lake

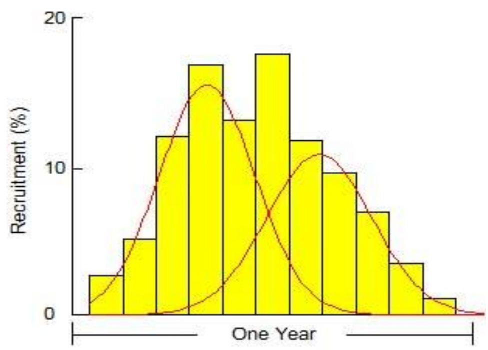

Figure 15. Predicted recruitment pattern of *C. glaucum* population in Lake Qarun.

Table 2: Relationships between different shell dimensions of *C. glaucum* collected from Lake Qarun and Lake Timsah. Value of *t-test* (t), significance level of t-test for allometry (p), determination coefficient (r^2), variance ratio (F) and number of observations (N) are also given.

Relationship		Lake Qarun								Lake Timsah							
Y	X	equation	β	t	p	Allometric relationship	r^2	F	N	equation	β	t	p	Allometric relationship	r^2	F	N
Shell height	Shell length	Y= 0.052 + 0.987 X	1	0.33	N.S.	isometry	0.715	627.2	252	Y= 0.425 + 0.610 X	1	6.96	<0.05	-allomertry	0.291	115.8	284
Shell breadth	Shell length	Y= 0.246 +1.040 X	1	2.22	N.S.	isomerty	0.929	327.2	252	Y= -0.008 + 0.851 X	1	3.92	N.S	isometry	0.638	496.2	284
Shell breadth	Shell height	Y= 0.101 + 0.786 X	1	6.90	<0.05	-allometry	0.724	654.4	252	Y= 0.284 + 0.640 X	1	8.78	<0.05	allomertry	0.461	241.4	284

All relationships were highly significant (P< 0.0001), β = 1, isometric value of the slope, N.S. = non-significant (P> 0.05).

Table 3. Seasonal variation in regression parameters (log a and b) of shell length (mm) and total weight (g.) relationships of *C. glaucum* collected from Lake Qarun and Lake Timsah. Values of Student's t- test (t), level of significance from isometric value of the slope; $\beta = 3$ (p), coefficient of determination (r^2), variance ratio (F), and number of animals examined (N) are also given

Length-Weight relationship Season	Lake Qarun							Lake Timsah						
	Log a ± S.D.	b ± S.D.	t	p	r^2	F	N	Log a ± S.D.	b ± S.D.	t	p	r^2	F	N
Spring 2008	-3.59±0.14	3.01±0.13	0.1	N.S.	0.845	572.5	107	- 3.67 ± 0.04	3.14 ± 0.04	3.5	N.S	0.972	5134.4	120
Summer	-3.18±0.10	2.65±0.08	4.4	N.S.	0.917	990.9	92	- 3.90 ± 0.05	3.28 ± 0.04	3.0	N.S	0.983	5831.4	101
Autumn	-3.52±0.06	2.97±0.05	0.6	N.S.	0.966	2956.1	106	-3.14 ± 0.07	2.70 ± 0.05	6.0	N.S	0.965	2647.3	99
Winter 2009	-3.04±0.09	2.59±0.07	5.9	N.S.	0.975	1322.9	38	-3.44 ± 0.07	2.98 ± 0.05	0.4	N.S	0.974	3012.3	82

All relationships were highly significant (P< 0.0001), N.S. = non-significant (P> 0.05).

of bigger sizes (Figure 3). Total shell length ranges were 4.0 - 27.0 and 5.0 - 32.0 mm for the two lakes, respectively (Table 1).

There are several estimations of the growth parameters for *Cerastoderma glaucum* and its congeneric *C. edule* in the literatures (Table 4). Differences in the results for growth coefficient of *C. glaucum* in the present study and those of Mohammed *et al* (2006) might be driven by differences in the ecosystems investigated and the responses of species to environmental gradients. Saeedi *et al* (2010) have suggested several key factors affecting growth at the local scale in bivalves inhabiting the northern Persian Gulf including individual's difference, climate, latitude, and longitude.

The negative correlation between L∞ and K invalidates comparison based on individual parameters (Pauly and Munro, 1984). As a result, comparison of the growth performance of population of bivalve is better fitted by the growth index phi prime (Φ′). This criterion was used to characterize not only similar species (Pauly and Munro, 1984), but also related species as in the case of scallops (Del Norte, 1988). The value of (Φ′) obtained in the present study (2.56) is consistent with those previously calculated for other studies (Table, 4). Values ranged from 2.49 to 2.59 and from 1.32 to 3.25 with means of 2.54 and 2.78 for *C. glaucum* and *C. edule*, respectively.

Total mortality rate of *C. glaucum* population was higher at Lake Qarun ($Z = 1.02$ yr^{-1}) than at Lake Timsah ($Z = 0.24$ yr^{-1}). Natural mortality ($M = 1.06$ yr^{-1}) and total mortality ($Z = 1.02 yr^{-1}$) of the cockle in Lake Qarun have the same value as there is no fishery in the study area (Gayanilo and Pauly, 1997). A similar observation was recorded for the clam *Barbatia decussata* in the northern Persian Gulf, Iran (Zeinalipour *et al*, 2014). Mortality of *C. glaucum* is generally natural and may occasionally be caused by anthropogenic activities (e.g., habitat modification and habitat degradation). Habitat degradation resulting from receiving runoff and discharge of pollutants from drainage water may be the major reason underlying the relatively high natural mortality (1.06 yr^{-1}) for *C. glaucum* in Lake Qarun. However, commercial harvesting of the venerids, *Venerupies aurea* and *Tapes decussata* causes disturbances and higher mortality for the cockle *C. glaucum* in Lake Timsah (personal observation). Thus, Natural mortality of *C. glaucum*in Lake Timsah ($M= 0.71$ yr^{-1}) was slightly higher than total mortality ($Z = 0.24$ yr^{-1}). Earlier studies have shown that commercial harvesting can reduce the fitness of bivalves on intertidal areas leading to their higher mortality (Robinson and Richardson 1998).

Predation and parasitism are the main biotic factors which controlled the population dynamics of cockles (Beukema and Dekker, 2005; Thieltges, 2006). Main predators of adult cockles in Lake Qarun include many fishes e.g., *Tilapia zilli*, *Solea vulgaris*, *Sparus aurata* and 288 *Mugil sp.*. These predators can be important in structuring cockle populations. Several reports have been made attributing infections in Cardiidae species to trematode infestations throughout their area of distribution (Derbali *et al*, 2009). Such trematode infections lead to reduced growth (Wegeberg and Jensen 2003), and enhanced mortality (Desclaux *et al*, 2004, Thieltges, 2006). Derbali, *et al* (2009) stated that 15% of *C. glaucum* from the Gulf of Gabes (southern Tunisia) were found infected by digenean trematode species. The number of cockles showing digenean infestations differed with size class with a tendency to increase significantly with cockle size. Trematode infection was observed in gonadal sections of *C. glaucum* collected from Lake Qarun for studying the reproductive biology (Kandeel *et al*, 2014).

Population dynamics of cockles are controlled also by abiotic factors such as salinity, temperature, immersion time, water velocity and sediment

Table 4. Values of von Bertalanffy growth parameters (*K* and *L*∞) and growth performance indices (ϕ,) of *Cerastoderma glaucum* 1 and its congeneric *C. edule* in different localities; ϕ, = log K + 2 log L∞; * Mean value for males and females

Species	*K* *yr*$^{-1}$	*L*∞ (mm)	ϕ'	Location	Source
C. glaucum	0.215*	38.07*	2.49	Lake Timsah, Suez Canal, Egypt.	Mohammed et al, (2006)
	0.255*	39.31*	2.59		
C. glaucum	0.450	28.35	2.56	Lake Qarun, Fayoum Depression, Egypt.	Present study
C. glaucum	0.280	33.60	2.50	Lake Timsah, Suez Canal, Egypt.	Present study
Mean	0.30	34.83	2.54		
C. edule	0.600	40.00	2.98	South Bull, Dublin Bay, Irish Sea.	West et al, (1979)
C. edule	1.609	26.50	3.05	Rias Atlas, North Spain.	Catoria et al, (1984)
C. edule	0.248	54.00	2.86	Langerak, Aggersborg, Denmarck. Langerak, Aggersborg, Denmarck.	Brock (1980)
	0.386	40.70	2.81		
C. edule	0.640	34.36	2.88	The Bay of Saint-Brieuc, north coast of Britany	Ponsero et al,(2009)
C. edule	0.404	40.00	2.81	Wadden Sea, German	Ramon (2003)
C. edule	0.436	49.10	3.02	Dundalk Bay, Ireland Saint-Brieuc Bay, France	Fahy et al (2005)
	0.640	34.36	2.88		
C. edule	0.026	28.27	1.32	Mundaca estuary, north Spain	Iglesias and Navarro (1990)
C. edule	1.300	30.50	3.08	Merja Zerga, Moroccan Atlantic Coast Arcachon Bay, French Atlantic Coast	Gam et al (2010)
	1.330	36.75	3.25		
C. edule	0.180	36.00	2.37	Algeciras Bay, South Spain	Guevara and Niell (1989)
Mean	0.650	37.55	2.78		

dynamics (Gam *et al*, 2010; Malham *et al*, 2012). Salinity may be the main factor affecting macrobenthos abundance in Lake Qarun. It shows a negative correlation with the majority of the species (El-Shabrawy, 2001). Rygg (1970) tested the tolerance of *C. glaucum* in a range from 3 to 60 ‰ and found that this species lived in a wide range of salinities from 11 to 45 ‰ though it has suffered high mortality rates. Fishar (2000) concluded that increasing salinity of Lake Qarun has remarkably affected most of the benthic fauna and reduced their standing crop. El-Shabrawy (2001) found that average standing crop of *C. glaucum* in 1994 was 36 ind.m^{-2} and reduced to reach 31 ind.m^{-2} in 1999-2000. Salinity in Lake Qarun reached high values of 30.9 and 45.3‰ during 1971 and 1994-5, respectively (Anon, 1997). Soliman (1989) stated that the rate of increase in total salt is expected to remain constant until 2050, while average salinity of the Lake may show a progressive increase with time, which eventually must lead to the loss of most of Lake Fauna. Boyden (1972) stated that maximum age of the cockle *C. glaucum* is reduced within hypersaline environments. Therefore, salinity increase may interpret the low representation (26%) of large sizes (> 16mm shell length) in the population (Figure 3) and the occurrence of great numbers of dead shells of *C. glaucum* (personal observations) on the shores of Lake Qarun. Accordingly, the theoretical maximum age (T_{max}) was lower in Lake Qarun (7.4 yr^{-1}) than in Lake Timsah (12.6 yr^{-1}).

Reproduction of *C. glaucum* in Lake Qarun and Lake Timsah occurred throughout the year in a poorly defined pattern (lack of periodicity). An annual pattern of four spawnings was recorded (Kandeel *et al*, 2014; Mohammed, 2002). The lack of periodicity in the reproductive cycle makes a precise prediction of spawning events, or of subsequent recruitment pulses very difficult (Hooker and Creese, 1995). Recruitment of *C. glaucum* in the two lakes was year-round and exhibited two major pulses (Figure15 and 16). This pattern of recruitment is typical for tropical bivalves, which are fast-growing and short-lived species (Del Norte 1988; Del Norte-Campos 2004; Mohammed and Yassien 2003). However, recruitment pulses were not found to be correlated with the spawning pattern in the study areas.

The cockle *C. glaucum* produces eggs which are pelagic with larvae being both benthic and pelagic before settling on the sediment and becoming benthic adults (Malham *et al*, 2012). Reduction in cockle recruitment success by high predation rates and the presence of high densities of adult macrofauna led to recruitment failures (Beukema and Dekker, 2005; Flach, 2003). Predation of larval cockles by adult cockles through larviphagy can lead to reductions of up to 40% of the population (Andre and Rosenberg, 1991; Malham *et al*, 2012). Also, cockles are sensitive to a wide variety of chemical contaminants found in costal environments and early developmental stages are often represent a critical period in their life cycle (Malham *et al*, 2012). Salinity tolerances of larvae (20-25 ‰) are lower compared with adults (15-35 ‰) of *C. glaucum* (Boyden and Russell, 1972). Furthermore, they are unable to undergo metamorphosis at salinities of 45 ‰ (Kingston, 1974).

Morphometric relationships are highly variable among bivalve species and between different geographical areas. This type of information has been successfully used for the improvement of dredge selectivity (Gasper *et al*, 2002). It has also been applied to the technical design of bivalve sorting equipment which allows the separation of catches according to the species' minimum catchable sizes.

Shell height of *C. glaucum* increased isometrically with shell length for Lake Qarun population and departed significantly (P<0,05) from isometry indicating negative allometryfor Lake Timsah population (Table 2).Shell breadth increased isometrically with shell length for cockles collected from the two lakes. Also, isometric growth was found between weight-length relationships (Table 3) and this is in agreement with the Cardiidae *Corbula gibba* and other bivalves from the Algarve Coast, southern Portugal (Gaspar *et al*, 2001) and the pearl oyster *Pinctada radiata* in Qatari waters, Arabian Gulf (Mohammed and Yassien, 2003). However, *C. glaucum* showed positive allometric growth in Mediterranean, Atlantic and Baltic coastal habitats (Leontarakis *et al*, 2009; Mariani *et al*, 2002). This means that, as the animal grows, its breadth, height

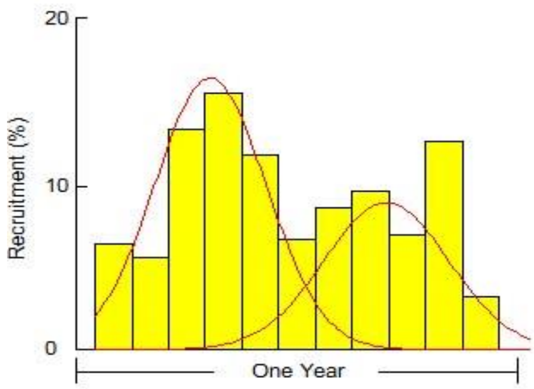

Figure 16. Predicted recruitment pattern of *C. glaucum* populations in Lake Timsah.

and weight increase faster than length: as a result, this species tends to assume a more "spherical" shape during growth. On the contrary, *C. glaucum* maintains a more elongated shape in the present study. Bivalve shell growth and shape are influenced by abiotic and biotic factors (Gasper *et al*, 2002). Mariani *et al* (2002) could be stressed that the different allometric patterns of the cockle is functional responses to different habitat topologies.

The strong relationship between shell length and total weight of *C. glaucum* in the present study ($p <$ 0.0001) indicates that weight changes much, although cockles grow steadily. Also, the results showed that *C. glaucum* shell length is a good estimator for the weight in the studies on biomass and production estimates as reported for other bivalves (Ross and Lima, 1994; Zeinalipour *et al*, 2014).Weight-length relationships have uses in the conversion of growth-in-length equations to growth-in-weight, for prediction of weight-at-age and subsequent use in stock assessment models (Pauly, 1993).However, the strong correlation between shell length and weight for *C. glaucum* in the present study (Table 3) and in earlier studies (Derbali *et al*, 2012; Gontikakiet *et al*, 2003; Leontarakis *et al*, 2009) is similar to that reported for other bivalves (Gaspar *et al*, 2001; Zeinalipour *et al*, 2014).

The present paper is the first report on population structure, growth, mortality, and exploitation status of *C.glaucum* along Egyptian waters. It will be a crucial baseline study to assess the stock position of the cockles. The data may help to determine future quantitative changes indicating trends in Egyptian waters that are exposed to various factors of environmental conditions and human activities. This information is required for its cultivation as a food source for fish and/or as an indicator of environmental conditions. Further studies are needed to explore the association between spawning and recruitment for *C. glaucum* with environmental variables. Also, the change in salinity must be monitored and controlled carefully in Lake Qarun.

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