Reproductive biology of the cockle Cerastoderma glaucum (Bivalvia:Cardiidae) from Lake Qarun, Egypt

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Abstract The cockle Cerastoderma glaucum is an important component of the benthic community in Lake Qarun, Egypt. Reproduction and gonad development in this species were investigated during the period from February 2008 to May 2009. Reproductive maturity was estimated by assessment of length–weight relationship, gonad index and microscopic examination of gonadal smears and sections. Results indicate lack of periodicity in the sexual cycle. An annual pattern of four spawnings was recorded. The depletion of ripe gametes during spawning was rapidly compensated by the onset of gametogenesis. Monthly changes in flesh and gonad weight reflect reproductive cycle with weight loss during spawning. C. glaucum is a gonochoric species without any hermaphrodites or sex reversals. The overall samples presented a male biased sex ratio (F:M = 1:1.29). The size at which 50% of the population reached maturity was 9.6 and 8.5 mm of shell length for females and males, respectively.

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Introduction

The lagoon cockle Cerastoderma (Cardium) glaucum syn. with C. lamarcki 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 (for review see Brock and Wolowicz, 1994; Malham et al., 2012).

Cerastoderma glaucum has been studied as a component of the macrobenthos of Lake Qarun (Abdel-Malek and Ishak, 1980; El-Shabrawy, 2001; Fishar, 2000). The cockle represented one of the most dominant species of the macrozoobenthos living in the lake (El-Shabrawy, 2001; Fishar, 2000). The standing crop and biomass of this cockle ranged from 11 to 93 ind. m\textsuperscript{-2} and from 6.9 to 70.7 g fresh weight\textsuperscript{-2}, respectively (El-Shabrawy, 2001). Several records of C. glaucum were
also undertaken from other Egyptian waters, e.g. Suez Canal Lakes (Barash and Danin, 1972), Lake Timsah (Mohammed et al., 1992) and Lake Bardawil (Fishar, 2005).

Ecological and biological studies on *C. glaucum* are scarce in Egypt (Mohammad, 2002; Mohammad et al., 2006, 2009). Studies on the reproductive condition of this cockle at the southern areas of its distribution in Lake Qarun are needed because no prior information exists from this region. Knowledge of the reproductive biology of *C. glaucum* is crucial for its cultivation as a food source for fish and/or as an indicator of the environmental conditions. Thus, the present study aims to evaluate the reproductive cycle, spawning pattern, sex ratio and size at onset of sexual maturity of *C. glaucum* in Lake Qarun.

**Materials and methods**

**Study area**

Lake Qarun (Fig. 1); which is one of the largest lakes of Egypt, occupies part of the basin of ancient Lake Mories, an immense freshwater palaeo-lake that persisted until the mid Holocene (Hassan, 1986). The basin is fed by the Nile River and occupies the lowest level of the El-Fayoum depression. The lake lies between 30°34′ E longitude and 29°25′ and 29°34′ N latitude at 44 m below the sea level. Lake Qarun covers, as a whole, an area of about 226 km² and 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 (Mansour et al., 2000).

**Sampling**

Samples of *C. glaucum* were collected from Lake Qarun (Shakshek area) at monthly intervals between February 2008 and May 2009 by dragging from a depth of nearly 2 meters. The sediments were washed out carefully *in situ* through one mm mesh size sieve. The materials retained by the sieve were put in labeled containers filled with 6% neutral formalin. A subsample (14–28 specimens) was fixed monthly in Bouin’s solution for histological studies.

**Length-weight relationships**

*C. glaucum* specimens were measured for shell length (SL) with a precision of 0.1 mm using a vernier caliper. The length of cockles was defined as the longest distance between the anterior and posterior shell margins. The flesh was dissected out of the shells. Gonads were carefully separated from somatic mass. Flesh weight (FW), gonad weight (GW) were determined separately for each specimen using top-loading digital balance (precision of 0.0001 g). Weight measurements were restricted to adult cockles as they are likely to exhibit more variations (due to spawning activity) than juveniles.

Relationships between SL and weight (W) were estimated by linear least-squares fit to log-transformed data:

\[
\log W = \log a + b \log SL
\]

where \(W\) is the weight, \(SL\) is the length, \(a\) is the ordinate at origin and \(b\) is the slope.

Linear regression equations were calculated monthly for the logarithm of flesh weight (log FW) and gonad weight (log GW) versus logarithm of shell length (log SL).

Monthly changes in FW and GW of *C. glaucum* were investigated by following weight changes for standard-sized individuals, as calculated from monthly length-weight regressions. Standard individual of 15 mm SL was selected. This size is close to the mean size of the studied population over the sampling periods.

![Figure 1](image_url) Location map of Lake Qarun showing sampling site.  

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Gonad index

Gonad index (GI) is the most widely used quantitative method for estimating the reproductive activity of marine bivalves (Giese and Pearse, 1974). It was calculated individually as the ratio between gonad weight and flesh weight $\times$ 100 (Lee and Cho, 1985). GI was calculated monthly and expressed as mean ± S.D.

Histological studies

Gonads of mature individuals fixed in Bouin’s solution were dissected, dehydrated in alcohol, cleared in xylene, embedded in paraffin wax and sectioned (6–8 μm) at a standard point. Tissue sections were stained in Ehrlich’s hematoxylin and Eosin Y according to procedures outlined in Howard and Smith (1983). Histological sections of each specimen were staged on the basis of the degree of development of germ cells. Female specimens were categorized into five stages, whereas only four stages were detectable in males. The recognition of these stages was based upon the classification cited by Drummond et al. (2006) with some modifications based upon preliminary histological observations of the gonad. The description and criteria for each stage for females and males are summarized in the results. The relative frequency of each stage was calculated monthly and graphed for both sexes.

Gonadal sections were scanned at random. The diameters of about 50 oocytes and ova, already sectioned through nucleus (i.e. near the egg’s center = maximum diameter) were measured from each female gonad using a compound microscope fitted with a calibrated optical micrometer. Oocyte diameter data were expressed as frequency polygons as described by Pearse (1965).

Sex ratio and size at onset of sexual maturity

Smears of the sexual products were examined at 100x magnification. Each specimen was sexed and the sex ratio (expressed as the number of males per female, F:M) was determined.

For both sexes, the percentage of mature individuals in 1-mm intervals was calculated. A logistic curve was fitted to the data in order to estimate the length at which 50% of individuals were sexually mature (SM50).

Statistical analysis

Length-weight regressions were submitted to an analysis of variance (ANOVA) to estimate variance ratio ($F$) and the significance level of the determination coefficient ($r^2$). The deviation of the slope ($b$) value of the regression function from the isometric value ($b = 3$) was analyzed by means of a $t$-test, as expressed by the following equation (Monti et al., 1991):

$$t_s = \frac{(b - 3)}{s_b}$$

where $t_s$ = $t$-test value and $s_b$ = standard deviation of the slope ($b$). A significant deviation indicates a negative ($b < 3$) or positive ($b > 3$) allometric relationship.

Statistically significant deviations from the expected sex ratio of 1:1 were assessed by Chi-square ($\chi^2$) analysis with one degree of freedom (Bailey, 1995). Statistical analysis was carried out using MINITAB software (version 13, 2000). Statistical significance was considered at $P < 0.05$.

Results

Relationship between shell length and flesh weight

Monthly linear regressions between SL and FW for sexually mature $C. glaucum$ have coefficient of determination ($r^2$) ranging from 0.526 and 0.950 (Table 1). Slope values ($b$) fluctuated between 1.96 and 2.86. Student’s $t$-test revealed that FW increased slower than SL (negative allometric growth) in February–March 2008, December 2008, January 2009 and April–May 2009. In the other ten months, FW increased isometrically with SL.

Flesh weights of 15 mm standard-length computed from length-weight regressions showed seasonal fluctuations (Fig 2) with two major peaks in March 2008 (0.239) and January 2009 (0.239) and two minor peaks in June and Octo-
ber 2008 (0.199). The lowest value of flesh weight was recorded in May 2008 (0.139).

Relationship between shell length and gonad weight

Table 2 shows the results of regression analysis between SL and GW for sexually mature cockles collected from Lake Qarun. Coefficient of determination ($r^2$) varied between 0.211 and 0.940 throughout the study period. Slope values were not significantly deviated from 3 value ($P > 0.05$) indicating that gonad weight increased isometrically with shell length. Monthly variation in GW of a standard individual of 15 mm SL showed a maximum value of 0.04 g in April 2009 (Fig 2). A marked decline (<0.01 g) was recorded in May, July–September 2008, March and May 2009.

Gonad index

Gonad index (GI) of females and males showed more or less similar trends in the mode of monthly variation (Fig 3). It decreased from the maximum values (10.2 for females and 9.5 for males) in February 2008 to reach the minimum values (~4) in summer. Then, fluctuations from 3.1 to 8.7 for females and from 3.3 to 9.4 for males were recorded indicating two major peaks in October 2008 and January 2009.

Stages of gonadal development

Female gonads

Five different stages were assessed in females. These stages are described as follows:

![Figure 4](image)

Figure 4 A–E: Gonad developmental stages for female *C. glaucum*. (A) Stage 1: early developing. (B) Stage 2: late developing. (C) Stage 3: ripe. (D) Stage 4: partially spawning. (E) Stage 5: completely spawning. Abbreviations: IFS, interfollicular space; FW, follicle wall; OG, oogonia; EO, early oocyte; GO, growing oocyte; RO, ripe ovum; OS, ovum sac; PS, perivitelline space; ES, empty sac; ROV, residual ovum; DO, degenerated ovum; L, lumen.
Stage 1 (early developing). Follicles are scarce, isolated, and small. Interfollicular space (IFS) is large (Fig. 4A). Numerous oogonia (OG) and early oocytes (EO) arise along the wall of the follicles. Follicle lumen (L) is empty and contains no ripe ova.

Stage 2 (late developing). Follicles become evident, increasing in size and number (Fig. 4B). They are occupied with early oocytes (EO) and growing oocytes (GO). Ripe ova (RO) appear in the center of some follicles but they are no longer packed.

Stage 3 (ripe). The follicles are fully distended and confluent with the absence of interfollicular space (Fig. 4C). Follicle lumens are almost filling of ripe ova compacted into a polygonal shape as a result of packing. Ripe ova are surrounded by an envelope. There is a great reduction of early stages of oogenesis.

Stage 4 (partially spawning). Empty spaces (ES) appear within the follicles due to partial emission of ripe ova (Fig. 4D). Ripe ova have become obviously rounded as the pressure within the follicles is reduced. The interfollicular space becomes wide.

Stage 5 (completely spawning). Follicles are empty and collapsed because of the major and final release of gametes (Fig. 4E). Interfollicular space (IFS) becomes very noticeable. A few residual ova (ROV) may be present in some follicles and can often be seen undergoing degeneration. Degenerated ovum (DO) is easily detected by the loss of its round shape. In some cases, the majority of the follicles are completely devoid of oocytes so that the sex determination is difficult.

Male gonads

Rapid spermatogenesis in males after completely spawning makes classifying the gonad into early and late active so difficult that the two stages were placed together into a single active stage.

Stage 1 (developing). The follicles are extended and filled with germinal cells in all stages of spermatogenesis (Fig. 5A). Spermatogonia (SG) and spermatocytes (SC) are the most numerous, occupying nearly all the available space of the lumen. Spermatozoa (SZ) appear in the center of a considerable number of follicles.

Stage 2 (ripe). Follicles are fully distended and closely compacted. Follicle lumens are filled with mature spermatozoa (SZ) with their tails pointing toward the center of the follicle forming concentric bands or plugs. There is a great reduction of early stages of spermatogenesis (Fig. 5B).

Stage 3 (partially spawning). The arrangement of spermatozoa seen in ripe stage was found to be disorganized in appearance as a considerable number of them were discharged (Fig. 5C). Follicle size decreases and the interfollicular space (IFS) appears.

Stage 4 (completely spawning). Testicular follicles have large lumina (L) with few undischarged strands of spermatozoa (SZ) which loosely fill the follicles. Degenerated spermatozoa were observed in some follicles. Inner walls of the follicles were

Figure 5  A–D: Gonad developmental stages for male C. glaucum. (A) Stage 1: developing. (B) Stage 2: ripe. (C) Stage 3: partially spawning. (D) Stage 4: completely spawning. Abbreviations: IFS, interfollicular space; SG, spermatogonia; SC, spermatocytes; SZ, spermatozoa; L, lumen. Scale bar on D = 100 μm and applies to all figures.
lined with narrow bands of spermatogonia and spermatocytes. Interfollicular space (IFS) is larger than that of partially spawning stage (Fig. 5D).

Reproductive cycle

Monthly proportions of the cockles classified in each gonadal stage are represented in Fig. 6A for females and in Fig. 6B for males. Both sexes showed monthly variation in the percentage occurrence of the different stages and lack of periodicity. The gametogenic cycles were asynchronous, as evidenced by the simultaneous occurrence of two or three stages in most of the monthly samples.

Ripe stage was recorded in 75% of the investigated females during February and October 2008. All males examined during February 2009 and January 2009 were in ripe stage. However, the occurrence of this stage was 75.0% and 60.0% of the total examined males in October and December 2008, respectively.

Spawning in both sexes appeared on a large scale, as suggested by the presence of partially and completely spawning (spent) individuals in most of the year.

Oocyte size-frequency

Monthly size-frequency distributions of oocyte diameter (grouped in 3 μm size class) are illustrated in Fig. 7. Large percentages of small oocytes (7–15 μm) occurred during March–April 2008 and February–May 2009 indicating the beginning of oogenesis. A marked reduction in the relative frequency of large oocytes was observed in April–May 2008, September 2008, and February–March 2009.

Sex ratio

Out of 1862 cockles examined microscopically, 35.87% were sexed as females, 46.46% as males and 17.67% as sexually undefined. The overall ratio of females, to males (1 F:1.29 M) was statistically different from the theoretical sex ratio of 1:1 ($X^2 = 25.32, P < 0.005$) indicating the prevalence of males.

8-Size at onset of maturity

The relationship between shell length and the percentage of mature *C. glaucum* for both sexes is illustrated in Fig 8. The

Figure 6  Monthly variations in the percentage of gonadal developmental stages for female (A) and male (B) *C. glaucum* collected from Lake Qarun. (See legend).
size at which 50% of the population reached maturity (SM₅₀) was 9.6 and 8.5 mm SL for females and males, respectively. For both sexes, the smallest mature cockles were 6 mm SL and the largest immature ones were 12 mm SL (Fig. 8).

Discussion

Flesh weight of *C. glaucum* from Lake Qarun increased relatively slower than shell length during February–March 2008, December 2008–January 2009 and April–May 2009 (Table 1). Spawning activity may explain this pattern of negative allometry. Monthly changes in flesh weight and gonad weight of 15 mm standard-length had many similarities in the mode of variation. Four periods of weight loss as a result of spawning bouts (April–May, July, November 2008 and February–March 2009) were evident (Fig. 2). Ansell et al. (1972) considered using body weight changes to assess spawning seasons as a method depending on a degree of close synchronization of spawning activities in the population to be effective. The degree of spawning synchronization seemed to vary among species and within populations of the same species in different parts of their geographic range (Sastry, 1979). Spawning activity of *C. glaucum* in Lake Qarun is not closely synchronized. Many cockles were found to be in partially and completely spawning stages at nearly all months.

![Figure 7](image.png)

**Figure 7** Relative distribution of oocyte-ova diameter of various size classes in female gonads of *C. glaucum* collected from Lake Qarun (oocyte-ova size grouped in 3 µm size classes).
were in spawning condition (Fig. 6).

2009) when large proportions of the population (42.9–100%) (July–September), late winter and early spring (February–April)

The lowest values of GI (3.1–4.9) were recorded during summer

during February and October 2008 and January 2009 when

in Lake Qarun. The highest values (8.7–10.2) were recorded

of female and male maturity for

Figure 8

The annual pattern of four spawnings was confirmed by the presence of polymodal distributions in the oocyte size–frequency at nearly all months (Fig. 7). The polymodal oocyte size–frequency distributions appeared to be a result of production of successive oocyte generations (Morvan and Ansell, 1988).

Monthly changes in gonad index (GI) were considered a reliable tool for measuring the reproductive activity of C. glaucum in Lake Qarun. The highest values (8.7–10.2) were recorded during February and October 2008 and January 2009 when the majority of the population (>66.7%) was in ripe stage. The lowest values of GI (3.1–4.9) were recorded during summer (July–September), late winter and early spring (February–April 2009) when large proportions of the population (42.9–100%) were in spawning condition (Fig. 6).

Reproduction of C. glaucum occurred throughout the year in a poorly defined pattern with some annual variations in the timing and intensity of spawning (lack of periodicity). Variations in flesh weight, gonad weight and gonad index were quite different in 2008 and 2009. Mass spawning during April–May 2008 came earlier (February–March) in 2009. Annual variation in the time of spawning was recorded for C. glaucum and C. edule in Danish waters (Navarro et al., 1989; Yankson, 1986a). Jaramillo and Navarro (1995) suggested that spawning could be induced by a combination of internal and environmental factors, and that their interaction may vary seasonally, producing annual variations in the onset and intensity of spawning. Lack of periodicity in the reproductive cycle has been observed by many authors (e.g. Garcia-Dominguez et al., 1994, 1996; Malachowski, 1988; Mohammad, 2002; Seed and Brown, 1977). This mode of reproduction makes a precise prediction of spawning events, or of subsequent recruitment pulses very difficult (Hooker and Creese, 1995). Walker and Heffernan (1994) found that temporal variations in gametogenic cycle were detected in populations with either a polymodal or a prolonged spawning season.

Spawning periods of C. glaucum and its counterpart C. edule in different localities are summarized in Table 3. Various spawning strategies, ranging from a short single spawning event to a continuous gamete release, were recorded. The marked differences in the spawning times of the same species among the different localities were attributed to the geographical differences in sea water temperature (Chang et al., 1985; Hesselman et al., 1989) and time of food abundance (Chang et al., 1985).

The pattern of protracted or repeated spawning bouts has been described for the oyster Pinctada mazatlanica (García-Dominguez et al., 1996), the scallop Hinnites giganteus (Malachowski, 1988), the clam Megapitaria aurantia (García-Dominguez et al., 1994) and the mussels Limnoperna fortunei, Perna perna and Mytilus galloprovincialis (Darrigran et al., 1999; Idhalla et al., 1996). Also, this spawning pattern

<table>
<thead>
<tr>
<th>Month</th>
<th>Log a ± S.D.</th>
<th>b ± S.D.</th>
<th>t</th>
<th>P</th>
<th>r²</th>
<th>F</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 2008</td>
<td>−3.68 ± 0.07</td>
<td>2.55 ± 0.06</td>
<td>7.5</td>
<td>&lt; 0.05</td>
<td>0.935</td>
<td>1688.6</td>
<td>120</td>
</tr>
<tr>
<td>March</td>
<td>−2.96 ± 0.17</td>
<td>1.98 ± 0.15</td>
<td>6.8</td>
<td>&lt; 0.05</td>
<td>0.638</td>
<td>169.3</td>
<td>98</td>
</tr>
<tr>
<td>April</td>
<td>−4.11 ± 0.16</td>
<td>2.86 ± 0.14</td>
<td>1.0</td>
<td>N.S.</td>
<td>0.793</td>
<td>401.6</td>
<td>107</td>
</tr>
<tr>
<td>May</td>
<td>−3.19 ± 0.24</td>
<td>1.96 ± 0.22</td>
<td>4.7</td>
<td>N.S.</td>
<td>0.526</td>
<td>78.8</td>
<td>73</td>
</tr>
<tr>
<td>June</td>
<td>−3.92 ± 0.16</td>
<td>2.70 ± 0.14</td>
<td>2.1</td>
<td>N.S.</td>
<td>0.891</td>
<td>173.2</td>
<td>95</td>
</tr>
<tr>
<td>July</td>
<td>−3.76 ± 0.20</td>
<td>2.52 ± 0.17</td>
<td>2.8</td>
<td>N.S.</td>
<td>0.709</td>
<td>219.4</td>
<td>92</td>
</tr>
<tr>
<td>August</td>
<td>−4.07 ± 0.14</td>
<td>2.81 ± 0.12</td>
<td>1.6</td>
<td>N.S.</td>
<td>0.891</td>
<td>588.8</td>
<td>74</td>
</tr>
<tr>
<td>September</td>
<td>−4.02 ± 0.10</td>
<td>2.79 ± 0.08</td>
<td>2.6</td>
<td>N.S.</td>
<td>0.930</td>
<td>1175.4</td>
<td>90</td>
</tr>
<tr>
<td>October</td>
<td>−3.92 ± 0.07</td>
<td>2.72 ± 0.26</td>
<td>4.7</td>
<td>N.S.</td>
<td>0.950</td>
<td>1946.5</td>
<td>106</td>
</tr>
<tr>
<td>November</td>
<td>−3.67 ± 0.15</td>
<td>2.48 ± 0.13</td>
<td>4.0</td>
<td>N.S.</td>
<td>0.780</td>
<td>382.4</td>
<td>110</td>
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<tr>
<td>December</td>
<td>−3.65 ± 0.06</td>
<td>2.49 ± 0.05</td>
<td>10.2</td>
<td>&lt; 0.05</td>
<td>0.950</td>
<td>2061.4</td>
<td>110</td>
</tr>
<tr>
<td>January 2009</td>
<td>−3.37 ± 0.09</td>
<td>2.33 ± 0.07</td>
<td>9.6</td>
<td>&lt; 0.05</td>
<td>0.914</td>
<td>1071.1</td>
<td>103</td>
</tr>
<tr>
<td>February</td>
<td>−3.92 ± 0.20</td>
<td>2.70 ± 0.16</td>
<td>1.9</td>
<td>N.S.</td>
<td>0.887</td>
<td>282.7</td>
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<tr>
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<td>2.64 ± 0.11</td>
<td>3.3</td>
<td>N.S.</td>
<td>0.932</td>
<td>550.7</td>
<td>42</td>
</tr>
<tr>
<td>April</td>
<td>−3.41 ± 0.08</td>
<td>2.27 ± 0.07</td>
<td>10.4</td>
<td>&lt; 0.05</td>
<td>0.930</td>
<td>1038.1</td>
<td>80</td>
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<tr>
<td>May</td>
<td>−3.60 ± 0.08</td>
<td>2.42 ± 0.07</td>
<td>8.3</td>
<td>&lt; 0.05</td>
<td>0.938</td>
<td>1173.1</td>
<td>79</td>
</tr>
</tbody>
</table>

All regressions were highly significant (P < 0.0001), S.D. = standard deviation, N.S. = non-significant (P > 0.05).
was reported for Lake Timsah population of *C. glaucum* by Mohammed (2002). Protracted spawning season and multiple spawnings have been reported to have many advantages in terms of the survival of the species (Lambert and Ware, 1984; Weng, 1995). Multiple spawning with intervals between batches may reduce intraspecific competition by allowing each cohort a virtually independent food supply (Lambert and Ware, 1984).

The reproductive cycle of bivalves usually takes the following forms: a progressive development from a condition in which the gonads are undifferentiated, through differentiation of the gonad (gametogenesis and maturation of the gametes), to spawning (with partial or complete release of gametes), and a return to one of these earlier stages (Boyden, 1971). A similar sequence of events has been reported for population of *C. glaucum* from Lake Qarun. However, gametogenesis and maturation of the gametes were divided into three stages in females (early active, late active and ripe stages) and only two stages in males (active and ripe stages). This indicates that gametogenesis in males was rapid and continuous.

The depletion of ripe ova in female gonads during April–May (spring) 2008 and February–March (winter) 2009 was rapidly compensated by the onset of oogenesis. Oocyte size–frequency distribution (Fig. 7) indicated the presence of large oocytes at the periods of ripe ova depletion. This explains the absence of sexual quiescence (inactive or rest stage) seen in *C. glaucum* from Crouch estuary, Essex, England (Boyden, 1971); South Wales (Yankson, 1986a); Lake Tunis, the Bou Grara Sea and Gulf of Gabes, Tunisia (Derbali et al., 2009; Zaouali, 1980). Trotta and Cordisco (1998) found active gonads throughout the year for *C. glaucum* from Lesina Lagoon, southern Italy. It is common for the same species from the same geographical area to show differences in its reproductive cycle from one site to another. This could be explained by the environmental variability (temperature, salinity, food availability, etc.) involved in defining and controlling gametogenesis (Derbali et al., 2009; Lubet and Mann, 1987).

The end of the spawning season of *C. glaucum* was usually marked by gamete atresia (degeneration and phagocytosis) within the follicles. The occurrence of this atresia appears to be a common phenomenon linked to the reproductive strategy (Pazos et al., 1996). Darriba et al. (2004) enumerated three possible reasons for oocyte atresia: (1) a limited capacity of the follicle and a control mechanism covering cell number; (2) a self cleaning process at the end of gametogenic cycle in preparation for the next cycle; and (3) a response to environmental or contaminating stress condition.

As with most bivalves, *C. glaucum* is dioecious with no external morphological differences between the sexes. Hermaphrodites or even sex reversals were not identified in this study. The sex ratio (1.00 F: 1.29 M) differed significantly ($X^2 = 25.32, P < 0.005$) from the expected 1:1 ratio indicating that males outnumbered females. Similar observations were recorded for two populations of *C. glaucum* at Sussex, north-east coast of England (Kingston, 1974). However, sex ratio was not significantly divergent from parity for *C. glaucum* from the north coast of Sfax, Gulf of Gabes, Tunisia (Derbali et al., 2009), three European populations; the Baltic Sea, the North Sea and the Mediterranean Sea (Tarnowska et al., 2009) and from Berre Lagoon, French coast, Mediterranean Sea (Tarnowska et al., 2012).

Male biased sex ratio for Lake Qarun population might be explained by the following possibilities: (1) the presence of sexually undifferentiated individuals at completely spawning stage in females. A similar explanation was recorded for female biased sex ratio in *C. edule* (Boyden, 1971; Martinez-Castro and Vazquez, 2012); (2) reflections of differences in developmental tempo of the two sexes and (3) females are more sensitive to unfavorable environmental conditions. The preponderance of males in *Modiolus modiolus* (Jasim, 1986) was explained in terms

### Table 2

<table>
<thead>
<tr>
<th>Month</th>
<th>Log a ± S.D.</th>
<th>b ± S.D.</th>
<th>t</th>
<th>P</th>
<th>$r^2$</th>
<th>F</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 2008</td>
<td>−5.23 ± 0.26</td>
<td>3.05 ± 0.23</td>
<td>0.2</td>
<td>N.S.</td>
<td>0.799</td>
<td>179.4</td>
<td>47</td>
</tr>
<tr>
<td>March</td>
<td>−5.14 ± 0.39</td>
<td>2.95 ± 0.36</td>
<td>0.1</td>
<td>N.S.</td>
<td>0.561</td>
<td>67.6</td>
<td>55</td>
</tr>
<tr>
<td>April</td>
<td>−3.22 ± 0.50</td>
<td>1.06 ± 0.45</td>
<td>4.3</td>
<td>N.S.</td>
<td>0.940</td>
<td>5.6</td>
<td>56</td>
</tr>
<tr>
<td>May</td>
<td>−4.05 ± 0.48</td>
<td>1.61 ± 0.44</td>
<td>3.2</td>
<td>N.S.</td>
<td>0.211</td>
<td>13.7</td>
<td>53</td>
</tr>
<tr>
<td>June</td>
<td>−6.83 ± 0.60</td>
<td>4.23 ± 0.53</td>
<td>2.3</td>
<td>N.S.</td>
<td>0.571</td>
<td>63.8</td>
<td>50</td>
</tr>
<tr>
<td>July</td>
<td>−6.85 ± 0.97</td>
<td>3.99 ± 0.85</td>
<td>1.2</td>
<td>N.S.</td>
<td>0.312</td>
<td>22.2</td>
<td>51</td>
</tr>
<tr>
<td>August</td>
<td>−6.22 ± 0.40</td>
<td>3.44 ± 0.32</td>
<td>1.4</td>
<td>N.S.</td>
<td>0.707</td>
<td>113.4</td>
<td>49</td>
</tr>
<tr>
<td>September</td>
<td>−4.73 ± 0.45</td>
<td>2.26 ± 0.35</td>
<td>2.1</td>
<td>N.S.</td>
<td>0.445</td>
<td>42.2</td>
<td>55</td>
</tr>
<tr>
<td>October</td>
<td>−5.48 ± 0.34</td>
<td>3.16 ± 0.29</td>
<td>0.6</td>
<td>N.S.</td>
<td>0.714</td>
<td>119.7</td>
<td>50</td>
</tr>
<tr>
<td>November</td>
<td>−5.30 ± 0.35</td>
<td>2.93 ± 0.28</td>
<td>0.3</td>
<td>N.S.</td>
<td>0.671</td>
<td>108.2</td>
<td>55</td>
</tr>
<tr>
<td>December</td>
<td>−5.34 ± 0.58</td>
<td>2.98 ± 0.49</td>
<td>0.1</td>
<td>N.S.</td>
<td>0.398</td>
<td>36.4</td>
<td>57</td>
</tr>
</tbody>
</table>

January 2009:
- February 2009:
- March 2009:
- April 2009:
- May 2009:

All regressions were highly significant ($P < 0.0001$), S.D. = standard deviation, N.S. = non-significant ($P > 0.05$).
Table 3  Spawning periods of Cerastoderma glaucum and its congeneric C. edule in different localities. (See below-mentioned references for further information.)

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Spawning periods</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. glaucum</td>
<td>Lake Tunis and the Bou Grara Sea, Tunisia.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. glaucum</td>
<td>North coast of Sfax, Gulf of Gabes, southern Tunisia.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. glaucum</td>
<td>The Gulf of Gabes, Balice Sea, Poland.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. glaucum</td>
<td>Lake Veere, North Sea, the Netherlands.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. glaucum</td>
<td>Berre Lagoon, Mediterranean Sea, France.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. glaucum</td>
<td>Lake Timimah, Suez Canal, Egypt.</td>
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<tr>
<td>C. glaucum</td>
<td>Lake Tunis, Tunisia.</td>
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<tr>
<td>C. edule</td>
<td>Ria of Vigo, NW of Spain.</td>
<td></td>
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</tr>
<tr>
<td>C. edule</td>
<td>Danish brakish water areas, Denmark.</td>
<td></td>
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</tr>
<tr>
<td>C. edule</td>
<td>Strangford Lough, Northern Ireland.</td>
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<td></td>
</tr>
<tr>
<td>C. edule</td>
<td>Tamarr Estuary, Cornwall, England.</td>
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<td></td>
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<tr>
<td>C. edule</td>
<td>Ria of Noia, N of Spain.</td>
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<tr>
<td>C. edule</td>
<td>Guadiana River estuary, SW of Spain.</td>
<td></td>
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<tr>
<td>C. edule</td>
<td>The French Channel and Atlantic coasts.</td>
<td></td>
<td></td>
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<tr>
<td>C. edule</td>
<td>Saint-Pol-de-Leon, North Brittany.</td>
<td></td>
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<tr>
<td>C. edule</td>
<td>Dutch Wadden Sea, Northwestern Europe.</td>
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<tr>
<td>C. edule</td>
<td>The Ria de Vigo, Galicia, Northwest Spain.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References


Durrigan, G.A., Penchaszadeh, P.E., Dumborenea, M.C., 1999. The reproductive cycle of Limnoperna fortunei (Dunker, 1857) of sex-specific mortality. Increased female mortality after spawning owing to the high coast of gonad maturation and spawning was reported in some bivalves, like Chlamys islandica (Brokordt and Guderley, 2004) and Mytilus trossulus (Wolowicz et al., 2006).

For Lake Qarun population of C. glaucum, the length at which 50% of the population reached maturity (SM50) was 9.6 and 8.5 mm for females and males, respectively. For comparing C. glaucum from the Gulf of Gabes (southern Tunisia), female SM50 and male SM50 estimated to be 16.78 and 15.14 mm shell length, respectively (Derbali et al., 2009), were larger than our records for Lake Qarun population. Higher temperature in this Lake; monthly values ranged from 16 to 30 °C compared to 12.3–26.8 °C for Gulf of Gabes, is important for an early recruitment into the breeding population. The rate of filtration by bivalves increases by a rise in the temperature (Foe and knight, 1986) and it is expected to accelerate the initiation of gamete development and maturation for the first time in life. Maturation of 7 week old C. glaucum (4 mm shell length) laboratory reared spat has been reported and although no fertilization experiments were conducted, gamete morphology was comparable to those of adults from natural populations (Yunksone, 1986b).

In conclusion, results of the present study indicate that C. glaucum is well adapted to the specific environmental conditions of Lake Qarun in order to maximize its reproductive success. The reproductive periodicity is less confined to a specific season and the onset of sexual maturity is precocious. This baseline study can serve as a reference for assessment and management of C. glaucum as well as for future research on the use of this species as a bio-indicator. However, further research is needed to obtain data on population dynamics.
Reproductive biology of the cockle Cerastoderma glaucum (Bivalvia:Cardiidae) from Lake Qarun


