Thalassia Salentina
Thalassia Sal. 39 (2017), 123-136
ISSN 0563-3745, e-ISSN 1591-0725
DOI 10.1285/i15910725v39p123
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SIZE AT THE ONSET OF SEXUAL MATURITY IN 7 BIVALVE SPECIES IN EGYPTIAN WATERS

SUMMARY

Egyptian beaches have extended over long distances and it has become necessary to look at how the exploitation of bivalves inhabiting these beaches. Onset of sexual maturity for 7 bivalve species in 4 sites of Egyptian waters was reported. Specimens were collected during summer and winter seasons. A total of 1870 individuals belonging to 4 families were examined under the microscope. The trend of decreasing size at maturity with increasing water temperature was reported. The trend of increasing size at maturity with decreasing latitude was much less clear in this study. The size at 50% maturity (SM_{50}) varied between 9.2 mm SL (for *Cerastoderma glaucum* in summer) and 16.6 mm SL (for *Venerupis aurea* in winter), and showed an average value of 12.7 mm SL (± 2.4 S.D.) for 5 commercial clams.

INTRODUCTION

The shell length at which the gonad begins to develop from rudimentary virgin state (undifferentiated or juvenile gonad) to the state at which the gonad is sexually differentiated is, usually, taken to be the size at onset of sexual maturity. The size at onset of maturity is important as it provides a minimum size limit for the control of exploitative fishing of young individuals (Agostinho, 2000). It also indicates population changes caused by pollution, overfishing or others (Weng, 1994).

Not all members of a species mature at the same size (length) and many species reach sexual maturity at a particular age which corresponds to a broad range of individual lengths. Therefore, the estimation of the size at onset of maturity is important as it gives a particular size which represents the maturity size of the species. Weng (1994) and Roa *et al.* (1999) reported that the size at onset of maturity is commonly accepted as the "average size at which 50% of a population is mature".

The onset of sexual maturity varies in the different species and in the same species under different ecological conditions (Yankson, 1986; Darrigran *et al.,* 1999). Water temperature is thought to be the major factor in the regional and seasonal differences in the size at maturity.

Family Veneridae represents the most abundant and successful group of bivalves in Lake Timsah (Fouda and Abou-Zied, 1990; Ghobashy *et al.,* 1992; Mohammed *et al.,* 1992). The most common Veneridae in the Lake are *Venerupis aurea* (Gmelin, 1791) and *Tapes (= Ruditapes) decussata* (Linnaeus, 1758). The two species are indigenous to the Mediterranean Sea and successfully colonized Lake Timsah by penetrating the Suez Canal (Fouda and Abou-Zied, 1990). *V. aurea* was first recorded from Lake Qarun by El-Shabrawy (2001). Both *V. aurea* and *T. decussata* are of great economic importance; being consumed in large quantities in the Suez Canal region and exported to some European countries (Kandeel, 2006).

Donacidae inhabit exposed intertidal sandy beaches and form the largest group living in such highly dynamic environments (Brown and McLachlan, 1990). *Donax variabilis* (Say, 1822) and *D. trunculus* (Linnaeus, 1758) spreading in the Mediterranean coast of Egypt are the favorite food among the populations of the coastal cities (El-Ghobashy *et al.,* 2011).

The lagoon cockle *Cerastoderma glaucum* (Poiret, 1789) (Family: Cardiidae) represents one of the historically most dominant species of the macrobenthos of Lake Qarun, Fayoum Depression (Fishar, 2000; El-Shabrawy, 2001) and Lake Timsah, Suez Canal (Mohammed *et al.,*1992; 2006). *C. glaucum* plays an important direct and indirect role in nutrient cycles. It is eaten by human and considered as a very cheap resource due to their occurrence in high densities. The indirect role is by sharing in food chain as some marine animals prey upon them (Kandeel *et al.,* 2017).

Mussels living in salt or brackish water are classified in the family Mytilidae which includes many genera such as *Modiolus, Brachidontes* and *Mytilus* (Seed and Suchanek, 1992). Two Indo-Pacific mytilids; *M. arcuatulus* (Hanley, 1843), and *B. variabilis* (Krauss, 1848) were found in high densities and create most of the fouling problems in the Suez Canal (Ghobashey *et al.,* 1992; Mohammed *et al.,* 1992). The study of the size at onset of maturity may provide information for future researches in biofouling of these mussels.

This study reports the onset of sexual maturity for 7 bivalve species in the Mediterranean coast (Damietta shore), Lake Timsah, The Great Bitter Lake and Lake Qarun. The possible role of water temperature was discussed, also.

MATERIALS AND METHODS

Damietta shore (Mediterranean coast) and three lakes: Lake Timsah, Great Bitter Lake, Lake Qarun (supporting information online at https://www.in-

gimage.com) were sampled to collect 7 species of bivalves belonging to 4 families (Table 1).

Venerupis aurea and *Tapes decussata* were collected using quadrate measuring 25 x 25 cm. Quadrates were dug to a depth of 10 cm and sieved in the field through 1-mm screen. *Donax variabilis* and *D. trunculus* were sampled using a specially designed hand dredge (75 cm wide) similar to that used by local fishermen but incorporating a smaller mesh size bag (3 mm) to collect enough samples of juveniles. *Cerastoderma glaucum* was collected using 20 x 20 cm stainless steel grab sampler randomly placed in the substratum at about 2 m depth. *Brachidontes variabilis* sampling was carried out by quadrates; each measuring 10 x 10 cm. Mussels inhabiting the area of the quadrates were scraped from the rock surface using a sharp knife. For *Modiolus arcutulus*, core samples of sediment were taken from the surface of the mussel bed using 14 cm diameter circular plastic pipe. Samples were washed out carefully in situe through one mm size sieve. Collection of samples was carried out in summer (July/August) 2015 and winter (January/February) 2016. Collected samples were kept in labeled containers filled with 6% formaldehyde-seawater solution and then transported to the laboratory.

In the laboratory, shell lengths (SL); (maximum distance on the anterior-posterior axis) of the entire specimens were measured to the nearest 0.1 mm by using a Vernier caliper. Smears of the sexual products (growing or mature oocytes in females and morphologically ripe spermatozoa in males) were examined under the microscope. Each specimen was categorized as immature (juvenile) or mature (adult). For each species, the percentage of sexually mature individuals was plotted against shell length. The length at which 50% of the populations are sexually mature (SM_{50}) was then estimated by fitting a logistic curve to the percentage mature by size using the methods discussed in Somerton (1980) and Torroglosa and Giménez (2016). The length at maturity was estimated for the samples collected during the two seasons.

RESULTS

Sample descriptive statistics and parameters of logistic curves of 7 bivalve species belonging to 4 families and collected from Egyptian waters are reported in Table 1.

Venerupis aurea

The minimum size at maturity for *V. aurea* collected from Lake Timsah was 12 and 15 mm shell length during summer and winter seasons, respectively (Fig. 1). Estimated sexual maturity (SM_{50}) was 11.0 and 16.4 mm SL, respectively. For samples collected from Lake Qarun during summer and winter, the

smallest mature clam was 12 and 15 mm SL and SM_{50} were 12.1 and 16.6 mm SL, respectively (Fig. 2).

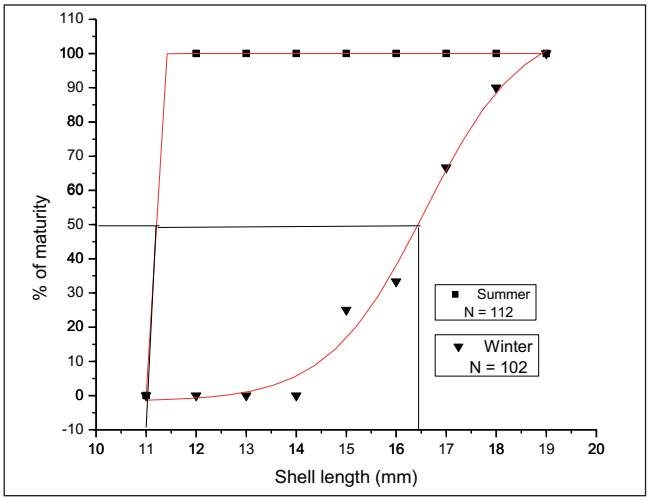

Fig. 1. The percentage of maturity plotted against shell length (mm) of *V. aurea* collected from Lake Timsah during summer and winter seasons. The size at 50% maturity (11.0 and 16.4, respectively) is demonstrated. N = number of individuals examined.

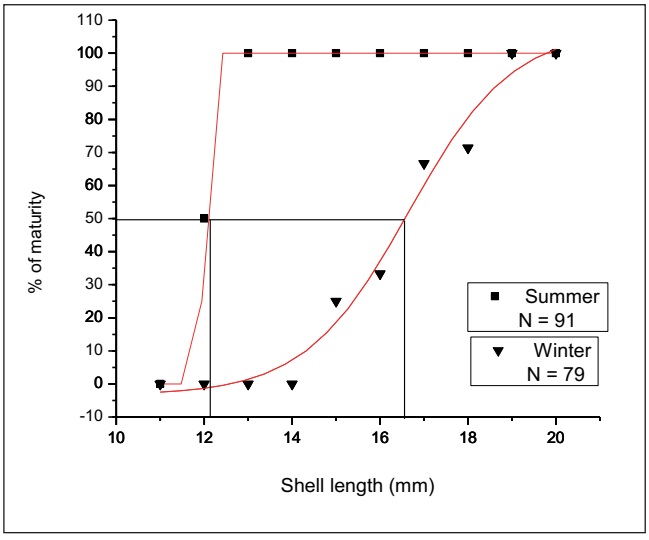

Fig. 2. The percentage of maturity plotted against shell length (mm) of *V. aurea* collected from Lake Qarun during summer and winter seasons. The size at 50% maturity (12.1 and 16.6, respectively) is demonstrated. N = number of individuals examined.

Tapes decussata

The smallest mature specimens of *T. decussata* collected from Lake Timsah during summer and winter were 10 and 13 mm SL, respectively. The maximum size of immaturity was 13 and 17 mm SL and the SM_{50} was 11.1 and 15.2 mm SL for the two seasons, respectively (Fig. 3).

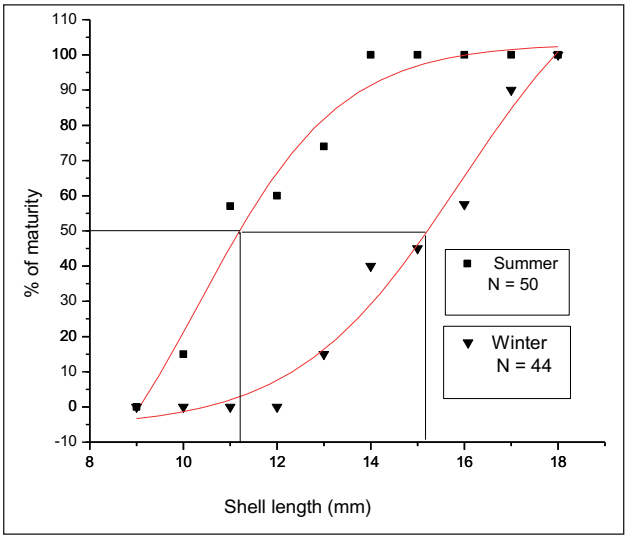

Fig. 3. The percentage of maturity plotted against shell length (mm) of *T. decussata* collected from Lake Timsah during summer and winter seasons. The size at 50% maturity is demonstrated (11.1 and 15.2, respectively) is demonstrated. N = number of individuals examined.

Donax variabilis

D. variabilis collected from Damietta shore reached sexual maturity at a smaller size during summer than that reported for samples collected during winter (Fig. 4). The minimum size of maturity was 11 and 13 mm SL and SM_{50} were 12.2 and 14.7 mm SL for the two seasons, respectively.

Donax trunculus

The smallest mature *D. trunculus* collected from Damietta shore during summer and winter were 11 and 13 mm SL, respectively. The maximum size of juveniles was 13 and 15 mm SL and the SM_{50} were 12.4 and 14.8 mm SL for the two seasons, respectively (Fig. 5).

Cerastoderma glaucum

The minimum size at maturity for *C. glaucum* collected from Lake Timsah was 8 and 10 mm SL during summer and winter seasons, respectively (Fig. 6).

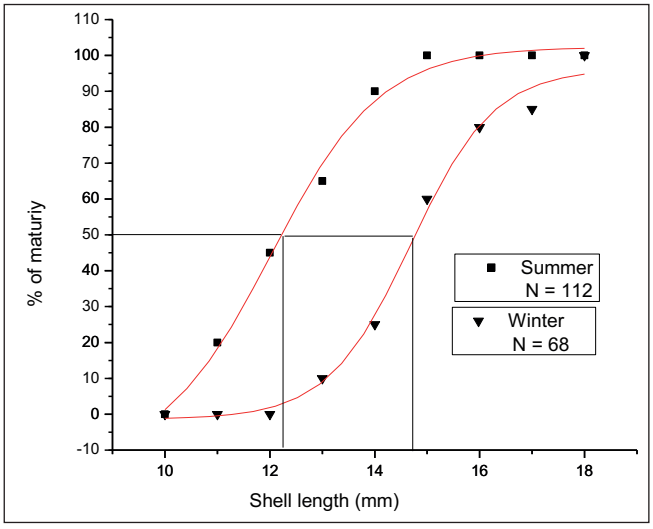

Fig. 4. The percentage of maturity plotted against shell length (mm) of *D. variabilis* collected from Damietta shore during summer and winter seasons. The size at 50% maturity (12.2 and 14.7, respectively) is demonstrated. N = number of individuals examined.

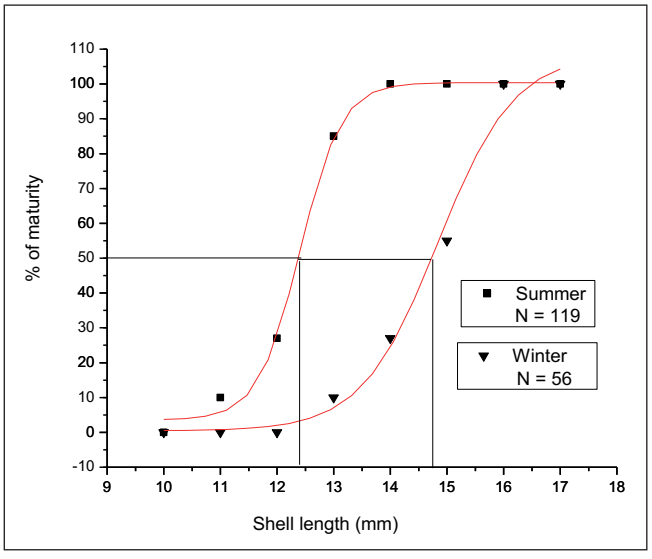

Fig. 5. The percentage of maturity plotted against shell length (mm) of *D. trunculus* collected from Damietta shore during summer and winter seasons. The size at 50% maturity (12.4 and 14.8, respectively) is demonstrated. N = number of individuals examined.

Estimated SM_{50} was 9.2 and 11.1 mm SL, respectively. For samples collected from Lake Qarun during summer and winter, the smallest mature clams were 9 and 7 mm SL and SM_{50} was 9.8 and 11.1 mm SL mm, respectively (Fig. 7).

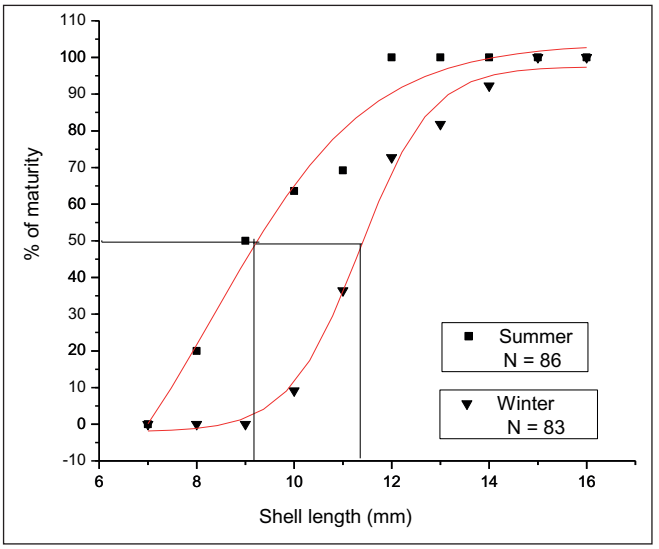

Fig. 6. The percentage of maturity plotted against shell length (mm) of *C. glaucum* collected from Lake Timsah during summer and winter seasons. The size at 50% maturity (9.2 and 11.3, respectively) is demonstrated. N = number of individuals examined.

Brachidontes variabilis

The smallest mature specimens of *B. variabilis* collected from Great Bitter Lake during summer and winter was 7 mm SL (Table 1). The maximum size of immaturity was 10 and 11 mm SL and the SM_{50} was 8.3 and 9.2 mm SL for the two seasons, respectively (Fig. 8).

Modiolus arcutulus

The minimum size at maturity for *M. arcutulus* collected from Great Bitter Lake was 4 and 6 mm SL during summer and winter seasons, respectively. Estimated SM_{50} was 4.6 and 6.2 mm SL, respectively (Fig. 9). For samples collected from Lake Timsah during summer and winter, the smallest mature mussel was 4 mm SL. The SM_{50} was 4.6 and 4.4 mm SL and the maximum size of a juvenile were 5 and 6 mm SL for the two seasons, respectively (Fig. 10).

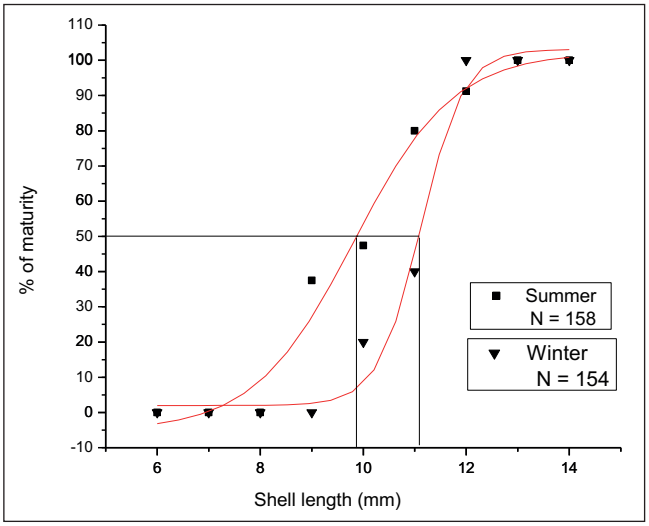

Fig. 7. The percentage of maturity plotted against shell length (mm) of *C. glaucum* collected from Lake Qarun during summer and winter seasons. The size at 50% maturity (9.8 and 11.1, respectively) is demonstrated. N = number of individuals examined.

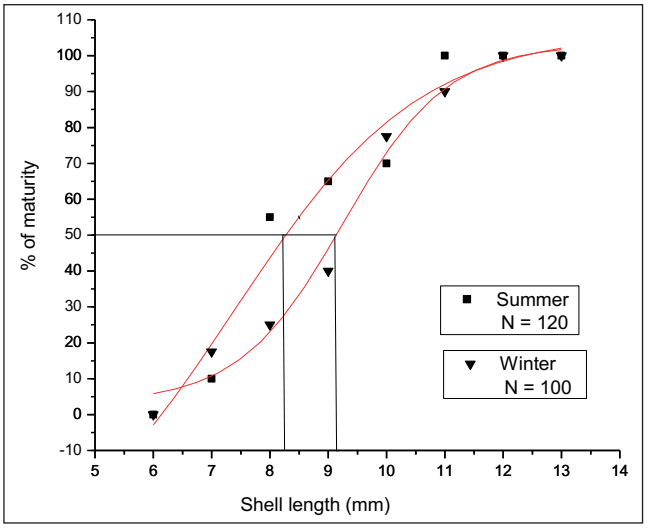

Fig. 8. The percentage of maturity plotted against shell length (mm) of *B. variabilis* collected from The Great Bitter Lake during summer and winter seasons. The size at 50% maturity (8.3 and 9.2, respectively) is demonstrated. N = number of individuals examined.

Family	Species	Locality	Latitude	Longitude	T_{oC}	L_{limt}	N	$L_{min.}$	SM_{50}	$L_{max.}$
Veneridae	*Venerupis aurea*	Lake Timsah, Suez Canal	30° 33` - 30°35.0` N	32°16` - 32°19` E						
				Summer	29.7	11-12	112	12	11.0	11
				Winter	16.3	14-19	102	15	16.4	18
		Lake Qarun, Fayoum Depretion	29° 25` - 29° 34.0` N	30°34` - 30° 49` E						
				Summer	28.6	11-13	91	12	12.1	12
				Winter	15.7	14-19	79	15	16.6	18
	Tapes decussata	Lake Timsah, Suez Canal	30° 33` - 30° 35.0` N	32° 16` - 32°19` E						
				Summer	29.7	9-14	50	10	11.1	13
				Winter	16.3	12-18	44	13	15.2	17
Donacidae	*Donax variabilis*	Damietta shore, Mediterranean coast	31° 26.8` - 31° 28.6` N	31°36.5` - 31°44.4` E						
				Summer	31.0	10-15	112	11	12.2	14
				Winter	16.5	12-18	68	13	14.7	17
	Donax trunculus		31° 26.8` - 31° 28.6` N	31°36.5` - 31°44.4` E						
		Damietta shore, Mediterranean coast		Summer	31.0	10-14	119	11	12.4	13
				Winter	16.5	12-16	56	13	14.8	15
Cardiidae	*Cerastoderma glaucum*	Lake Timsah, Suez Canal	30° 33` - 30° 35.0` N	32°16` - 32°19` E						
				Summer	29.7	7-13	86	8	9.2	12
				Winter	16.3	9-15	83	10	11.3	14
		Lake Qarun, Fayoum Depretion	29° 25` - 29° 34.0` N	30°34` - 30° 49` E						
				Summer	28.6	8-13	158	9	9.8	12
				Winter	15.4	6-11	154	7	11.1	10
Mytilidae	*Brachidontes variabilis*	Great Bitter Lake, Suez Canal	30°20` - 30°33` N	32°23` - 32° 38` E						
				Summer	29.3	6-10	120	7	8.3	10
				Winter	16.3	6-12	100	7	9.2	11
	Modiolus arcutulus	Great Bitter Lake, Suez Canal	30°20` - 30°33` N	32°23` - 32° 38` E						
				Summer	29.3	3-6	74	4	4.6	5
				Winter	16.3	5-8	102	6	6.2	7
		Lake Timsah, Suez Canal	30° 33` - 30°35.0` N	32°16` - 32° 19` E						
				Summer	29.7	3-6	74	4	4.6	5
				Winter	16.3	3-7	104	4	4.4	6

Tab. 1. Sample descriptive statistics and parameters of the onset of sexual maturity of 7 bivalve species collected from Damietta shore (Mediterranean coast) and 3 Lakes of Egyptian waters. T_{oC}, mean water temperature; L_{limt}, size limit at onset of maturity; N, number of individuals examined; $L_{min.}$, minimum size at maturity; SM_{50}, the size of 50% maturity; $L_{max.}$, maximum size of immaturity.

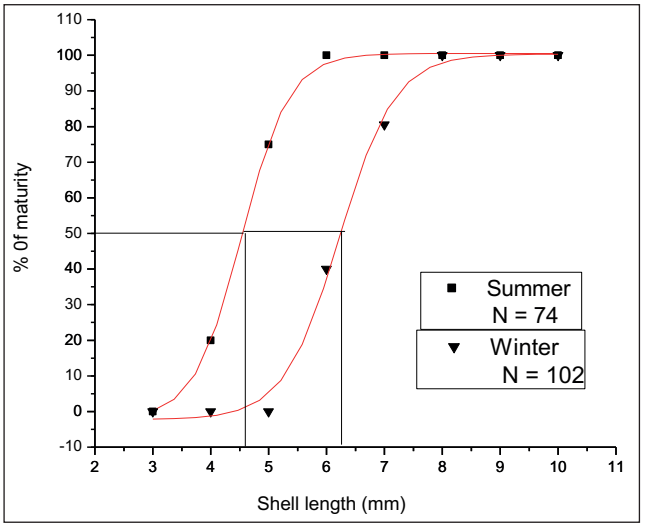

Fig. 9. The percentage of maturity plotted against shell length (mm) of *M. arcutulus* collected from The Great Bitter Lake during summer and winter seasons. The size at 50% maturity (4.6 and 6.2, respectively) is demonstrated. N = number of individuals examined.

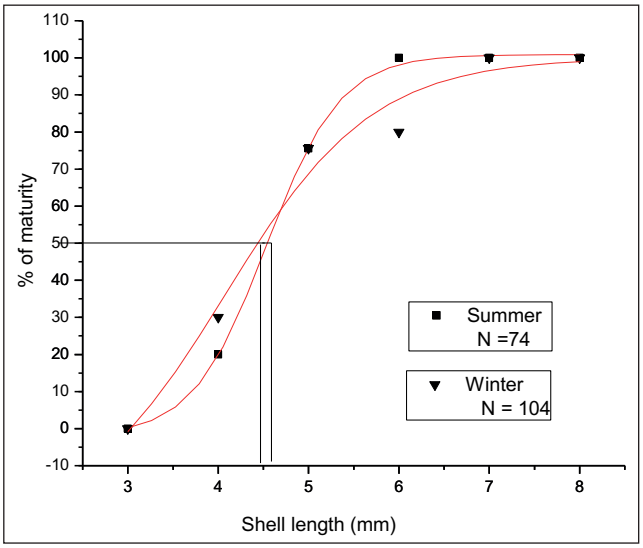

Fig. 10. The percentage of maturity plotted against shell length (mm) of *M. arcutulus* collected Lake Timsah during summer and winter seasons. The size at 50% maturity (4.6 and 4.4, respectively) is demonstrated. N = number of individuals examined.

DISCUSSION

Temperature is considered the main environmental factor which regulates bivalve reproduction (Sastry, 1979). In venerid clams like *Venerupis japonica* (Holland and Chew, 1974), *Mercenaria mercenaria* (Manzi *et al.,* 1985) and *Tapes philippinarum* (Meneghetti *et al.,* 2004) a clear relation between temperature and gonadic activity has been established. Ojea *et al.* (2004) observed a positive relationship between temperature and gonad condition index (GCI) in *Ruditapes decussatus*. Laruelle *et al.* (1994) reviewed data on reproductive patterns in *R. ducussatus* throughout its geographical range and concluded that temperature has a positive effect on gametogenesis that may directly affect the metabolic rate of the animal, or indirectly affect the availability of the food.

Venerupis aurea and *Tapes decussata* exhibited remarkable reproductive effort and spawned several times in Lake Timsah (Kandeel, 2006). Continuous gamete production and repeated spawning bouts have also been documented for the mytilides *Modiolus arcutulus* and *Brachidontes variabilis* in Suez Canal Lakes (Kandeel, 2002) and the cardiids *Cerastoderma glaucum* in Lake Qarun (Kandeel, *et al.,* 2013). Continuous gamete production may refer to the availability of food in Suez Canal Lakes and Qarun Lake through the

year. Also, it seems that the relatively moderate water temperature in winter (monthly mean =16.3 °C) and warm in summer (monthly mean = 29.3 °C) are both within range of the clam's and mussel's normal metabolism. For this reasons enough samples of juveniles (N = 1870) were examined in the present study.

For the studied species, samples collected during summer season reached sexual maturity at a size smaller than that reported for samples collected during winter. Also, the trend of increasing size at maturity with decreasing temperature was observed. Early maturation in warm environments and delayed maturation in cold environments were, also reported for the majority of ectotherms (Angilleta *et al.,* 2004). *Venerupis aurea* collected from Lake Timsah, Suez Canal (approximately 30° 33` - 30°35` N latitude) matures at a relatively smaller size (SM_{50} = 11.0 and 16.4 mm SL for summer and winter, respectively) than do individuals from Lake Qarun, Fayoum Depretion (approximately 29° 25 `- 29° 34.0` N latitude). SM_{50} was 12.1 and 16.6 mm SL for the two seasons, respectively. However, the trend of increasing size at maturity with decreasing latitude was much less clear in all studied species. A distinct latitudinal variation in the patterns of shell growth and sexual maturation was detected in the venerid bivalve *Phacosoma japonicum* (Reeve) in the Japanese coast (Sato, 1994).

Juveniles of *C. glaucum* from Lake Timsah (Mohammed *et al.,* 2006), *M. arcutulus* from Great Bitter Lake and Lake Timsah and *B. variabilis* from Great Bitter Lake (Kandeel, 2002) are capable of spawning in the same year in which they themselves were spawned. Yankson (1986) reported that juvenile clams of *C. glaucum* mature and spawn within the same spawning season from which they themselves originated. However, additional studies are necessary to detect the accurate age at the onset of sexual maturity in the studied species.

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