Quantitative Assessment of Gamete Production in Two Commercially Harvested Clams, *Venerupis aurea* and *Tapes decussata* (Bivalvia:Veneridae) in Lake Timsah, Suez Canal, Egypt

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ABSTRACT

Monthly relationships between shell length and gonad weight for two clams of commercial value; *Venerupis aurea* and *Tapes decussata* from El-Taawen area in Lake Timsah, Suez Canal, were determined between August 2004 and September 2005. Spawning frequency and individual gamete production (fecundity) under natural conditions were assessed by monitoring fluctuations in the gonad weight of standard-sized individuals. The results showed that the gonadal development and spawning continue throughout the year. There is no evidence of clearly defined reproductive cycles. The two species showed no "reproductive senility" and spawned several times per year. Gamete production, expressed as weight loss at spawning, occurred at different rates throughout the consecutive spawning periods and was positively correlated with body size. Spawning efficiency increased or decreased linearly with size. The relative amounts of reproductive material released by examined clams of different sizes reached 45.34 and 53.62% of the gonad weight during December 2004 for *V. aurea* and *T. decussata,* respectively. Both species exhibited remarkable reproductive effort in Lake Timash.

Key words: Fecundity, Lake Timsah, spawning, spawning efficiency, Veneridae, *Tapes decussata, Venerupis aurea.*

INTRODUCTION

Family Veneridae represents the most abundant and successful group of bivalves in Lake Timsah (Fouda and Abou-Zied, 1990; Ghobashy *et al*., 1992a; Mohammed *et al*., 1992). According to Ansell (1961), members of the Veneridae are suspension feeders and shallow-burrowing in relatively soft substrata. The most common venerids in Lake Timsah are *Venerupis aurea* (Gmelin, 1791) and *Tapes* (= *Ruditapes*) *decussata* (Linnaeus, 1758). The two species are indigenous to the Mediterranean Sea and have penetrated through the Suez Canal and successfully colonized Lake Timsah (Fouda and Abou-Zied, 1990). These two species were first recorded from the Canal by Tillier and Bavay (1905).

Both *Venerupis aurea* and *Tapes decussata* are of great economic importance; being consumed in large quantities in the Suez Canal region and exported to some European countries (Abou-Zied, 1991; Kandeel, 1992). Thus, they are extensively fished in Lake Timsah. Over fishing could result in depletion or destruction of their natural beds. Recently, the natural stock of *T. decussata* has been drastically decreased in Lake Timsah because this clam is the most favoured by consumers and also the most expensive followed by *V. aurea*. According to the FAO (2000), aquaculture production of these clams has increased in recent years. *T. decussata* had a world production in 1998 of approximately 4.874 Mt and was mainly cultured in Portugal (68.5%) and Spain (22.45%). To understand the life history of any bivalve species, manage its fishery, or attempt culture, it is essential to gain an understanding of the reproductive behaviour of the species (Kautsky, 1982; Barber and Blake, 1991). Recruitment, meat yields, quality of "roe on" product, spawning induction, and the duration of broodstock availability are all related to reproductive state, which can vary spatially and seasonally (O'Connor and Heasman, 1996). The study of reproduction forms the basis of most ecological studies because it provides important data on population structure and also enables accurate predictions to be made concerning recruitment of the population (Bayne, 1976).

In spite of the commercial importance and increasing demand of *Venerupis aurea* and *Tapes decussata* in Egypt, there have been few studies on the reproductive biology of these species in the region of the Suez Canal. Abou-Zied (1991) studied the reproductive cycle of two selected size groups of *V. aurea* using histological examinations and gonadal mass index of small number of clams. The reproductive biology of both *V. aurea* and *T. decussata* in Lake Timsah has been described in detail by Kandeel (1992). However, the total reproductive output was not assessed in this study.

This paper deals with quantitative estimates of individual gamete production in natural populations of *V. aurea* and *T. decussata* in order to provide data for energy flow models and to discuss aspects of recruitment in these species. Total reproductive output can be estimated by applying the data obtained in this paper on standing stock and size frequency data of the calm population.

MATERIALS AND METHODS

Study area

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 (Fig. 1). The role of the Suez Canal as a man-made link between the tropical Red Sea and the subtropical eastern Mediterranean, two different marine habitats, has been
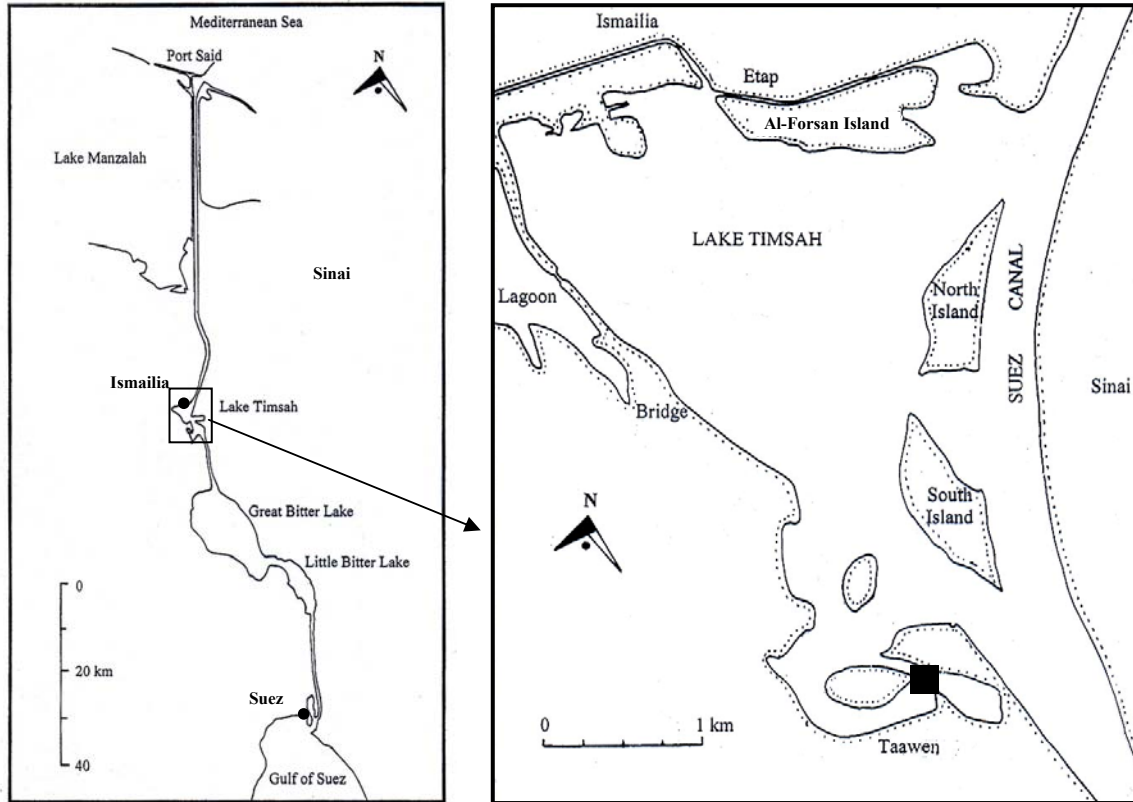
Figure (1): Map of the Suez Canal showing sampling site (■) in Lake Timsah

discussed by a number of investigators (for review see Kimor, 1972; Por, 1978). The number of bivalve species migrated from the Red Sea to the Suez Canal lakes is higher than those moved from the Mediterranean in the opposite direction (Tillier and Bavay, 1905; Fouda and Abou-Zied, 1990).

Lake Timsah, the area of this study, is a shallow body of water, 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 with a depth ranging from 6 to 13 m. On both sides of the Lake, there are many lagoons and gulfs, some of them are fairly deep (3m).

Lake Timsah has a wide variety of fauna, as being expected from the varying salt-content of its different regions (Gab-Alla *et al.*, 1990; Ghobashy *et al.*, 1992b). The southern part of the Lake at El-Taawen area is considered the main fishery ground of the two species concerned because they colonized an extensive area and were found in the greatest densities. The maximum values were 10664 individuals/m^2 for *Venerupis aurea* and 453 individuals/m^2 for *Tapes decussata* (personal estimations). The bottom of El-Taawen area is a suitable substratum for the larvae to settle down and for the adults to survive. Water temperature ranged from 16 to 30°C and salinity ranged from 35.4‰ to 43.2‰ over the study period.

Sampling

Venerupis aurea and *Tapes decussata* were sampled monthly from August 2004 to September 2005 at

El-Taawen area using quadrates measuring 25 x 25 cm. Sampling was done within a limited area because slight changes in microhabitat, particularly depth changes can markedly affect gonadal size (Himmelman, 1999). Being uncommon, it was difficult to use quadrates to collect enough samples of *T. decussata*. Thus, extra samples were obtained monthly from shellfish fishermen throughout the study period. This species was also collected through investigating the bottom and locating the animals by their siphon squirts. The hands were used to rake the bottom deposit to a depth of about 7cm. This method of collection was considered the best for sampling the greatest quantity of *T. decussata*.

Collected samples of the two species were kept in containers filled with 6% neutral formalin and then transported to the laboratory. Formalin preservation makes the gonads rigid and reduces weight loss during gonad separation. A sub-sample (5-10 specimens) from each species was fixed monthly in Bouin's solution for histological preparations.

Weight analysis

Weighing technique provides a rapid and quantitative estimate of gonad production which may be used in comparing reproduction in populations from different areas (Griffiths, 1977). In the laboratory, individual shell length (maximum anterior-posterior axis) was measured to the nearest 0.1 mm using a vernier caliper. Shell length was used as the reference measure for body size, because unlike tissues, it does not shrink under adverse

environmental conditions (MacDonald and Thompson, 1985). Gonad was carefully isolated from the visceral mass and weighed using a single-pan digital balance readout of 0.0001 g. In both species, the gonad is closely associated with the intestine, so that physical separation of the two tissues is very difficult. Therefore, the gonad and the intestine were considered to represent the gonadal tissue. The sex was determined by microscopic examination of smears of the sexual products.

The investigation was restricted to adult individuals as they are likely to exhibit more variations (due to spawning activity) than juveniles or youngs. Trematode-infected gonads (Hanafy et al., 1997) were excluded from all analyses reported here.

Histological studies

Weight analysis should be supported by histological studies to detect changes within the gonad that might affect weight such as build-up of reserve material and the presence of parasites. Cellular composition of the gonads and their changes were identified by microscopic examination of gonadal sections. Fixed gonads were dehydrated in graded ethanols, cleared in xylene, embedded in paraffin wax and sectioned at 6-8 μm. Sections were mounted and stained with Ehrlich's hematoxylin and Eosin Y according to procedures outlined in Howard and Smith (1983).

Regression analysis

The relationship between gonad weight (W, g) and shell length (L, mm) was described by the general allometric model:

$$W = aL^b \quad \text{(Ricker, 1975)}$$

Where a and b are regression constants representing the origin and the slope of the fitted line. By logarithmic transformation, the following linear regression equation was calculated using the MINITAB Release 13 statistical package:

$$\log W = \log a + b \log L$$

When growth is isometric, the slope (b) =3 and weight proceeds in the "same" dimension as the cube of length. When $b \neq 3$, weight growth is allometric meaning that it proceeds in a different dimension (differing from length). If weight growth is increasing relatively faster than shell length, then the relation is said to be positive allometric growth ($b>3$). Negative allometric growth ($b<3$) indicates that weight increases relatively slower than length.

The values of slope (b) were tested for statistical significance of difference from theoretical isometry (3) using a Student's t-test as follows:

$$t = \frac{|b\text{-}3|}{S_b} \quad \text{(Monti et al., 1991)}$$

S_b being the standard deviation of b.

Regression equations of gonad weight against shell length were determined separately for each species and sampling date. Since no significant differences between sexes were observed (paired t-test, $P>0.05$) for each species, data for males and females were pooled.

Monthly changes in gonad weights were investigated by tracing weight changes throughout the study period for standard-sized adults of 17, 22, 27 and 32 mm shell length, as calculated from monthly length-weight regressions. These standard individuals were chosen to represent the normal size range of the population sampled. Using standard-sized individuals to investigate monthly variations in gonad weight was applied to the giant scallop Placopecten magellanicus by Bonardelli and Himmelman (1995) and the doughboy scallop Chlamys (Mimachlamys) asperrima by O'Connor and Heasman (1996). Himmelman (1999) reported that monthly changes in gonadal mass of standard-sized adults have the advantage of illustrating the mass of gametes liberated during individual or sequential spawning events.

Estimation of gamete production and spawning efficiency

Individual gamete production of the different sizes was calculated as the difference between regression predicted gonad weight before and after each spawning event (Bonardelli et al., 1996).

$$\text{Gamete production (GP)} = W_{bs} - W_{as}$$

Where W_{bs} is gonad weight before spawning and W_{as} is gonad weight after spawning. W_{bs} and W_{as} are generally measured and expressed in the same unit. Relationships between shell length (L, mm) and gamete production (GP, g) were determined at major spawning times using the log-linear power regression formula:

$$\log GP = \log a + b \log L.$$

Four major spawning events were identified for each species as decreasing in gonadal mass. However, the mass of gametes librated outside these major periods can be regarded as quantitatively negligible.

The spawning efficiency, i.e. the percentage proportion of the gamete which the animals are able to discharge during the spawning period, was expressed as:

$$\text{Spawning efficiency (SE)} = \frac{\text{Gamete production}}{W_{bs}} \times 100$$

(Yankson, 1986)

To determine the relation between shell length (L) and spawning efficiency (SE), the following linear regression equation was performed,

$$SE = a + bL.$$

RESULTS

Gonad position and structure

Both Venerupis aurea and Tapes decussata are dioecious. The gonad is a discrete organ, occupies a large part of the visceral mass, lies ventral to the pericardium, surrounds the intestinal loop and spreads greatly over the digestive gland in ripe stage (Fig. 2). Gonads are diffuse organs consisting of highly branched follicles surrounded by a thin layer of germ cells at
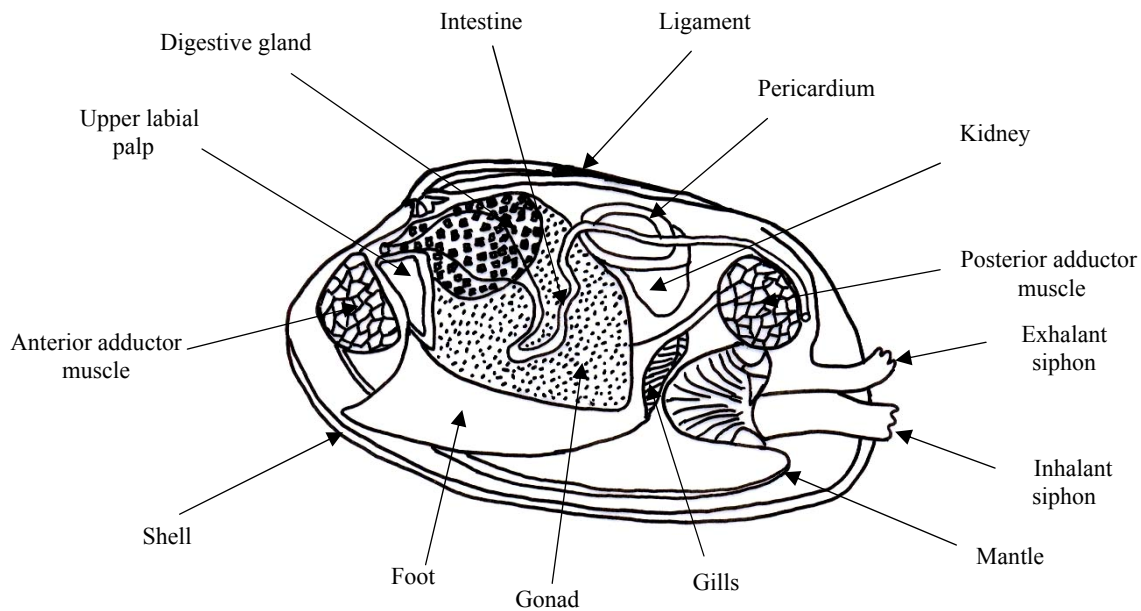
Figure (2): Sketch of the internal anatomy of clam showing the position of the gonad. The left gill lamina and mantle lobe have been removed.

different stages of development depending up on the reproductive condition of the species (Kandeel, 1992).

Histological studies revealed that gametogenesis was continuous throughout the year. Gonads of the two species consist essentially of gametes and the accumulation of reserve materials (glycogen and fat) was not evident. Older individuals occurred in a reproductively active state and had gametogenic pattern similar to that of smaller animals.

Gonad weight-shell length regression

The linear relationship between logarithmically transformed data of gonad weight (W) and shell length (L) of mature clams collected monthly could be expressed by the regression equation in the following form:

$$\log W = \log a + b \log L$$

Intercepts (log a), slopes (b), level of significance from isometry (P) and coefficients of correlation (R) for these equations are given in Tables (1 and 2) for *Venerupis aurea* and *Tapes decussata,* respectively. All regressions were highly significant ($P<0.0005$) having correlation coefficients with values varying between 0.685 and 0.979 for *V. aurea* and between 0.921 and 0.985 for *T. decussata.* For *V. aurea,* the slope of the regression lines ranged from 0.91 to 3.56 and departed significantly from isometry indicating negative allometric growth during August-November 2004 and May-September 2005 (Table 1). Slope values of *T. decussata* ranged from 2.47 to 3.80 and were not significantly deviated from 3 value ($P>0.05$) indicating isometric growth pattern throughout the study period except May 2005 (Table 2). In this month, gonad growth increased relatively faster than shell length indicating positive allometric growth.

Monthly changes in gonad weights

Figure (3) shows monthly variations in gonad weights of standard lengths of 17, 22, 27 and 32mm, derived from gonad weight-shell length regressions over 14 month period. The different standard lengths showed more or less similar trends in the mode of variation. Gonad weight of 17 mm standard length fluctuated only between 0.0447 and 0.0997g and between 0.0368 and 0.0860g for *Venerupis aurea* and *Tapes decussata,* respectively. However, more pronounced seasonal changes were observed in 22, 27 and 32mm standard lengths assuming a high contribution of these sizes in the reproductive activity of the two populations. Concerning standard length of 32 mm, gonad weight ranged from 0.1658 to 0.4249g for *V. aurea* and from 0.2031 to 0.5627g for *T. decussata.*

Decline in gonad weight was observed during September 2004, December 2004 and April 2005 for the two species, July 2005 for *V. aurea*, and August 2005 for *T. decussata.* Histological studies showed that these decreases in the gonad weight coincided with spawning (Kandeel, 1992). Outside these major spawnings, a decline in gonad weight was observed in 27 and 32mm standard lengths during May 2005 for *V. aurea* and June 2005 for *T. decussata.* This decline may be due to an extended spawning period or a small delay in spawning.

Gamete production and spawning efficiency

Individual gamete production in relation to shell length at the different spawning times is given in Table (3) for both *Venerupis aurea* and *Tapes decussata.*

Table (1): *Venerupis aurea*. Monthly variation in regression constants (log *a* and *b*) of shell length (mm) and gonad weight (g) relationships of adult clams. Value of Student's *t*-test *(t),* level of significance from isometry (*P*), correlation coefficient (*R*) and the number of pairs (*N*) are also given*.

Month	Log *a* ± SD	*b* ± SD	*t*	*P*	*R*	*N*
2004						
August	-3.90 ± 0.09	2.26 ± 0.07	10.57	<0.05	0.979	49
September	-3.72 ± 0.12	2.00 ± 0.09	11.11	<0.05	0.949	58
October	-3.75 ± 0.12	2.14 ± 0.08	10.75	<0.05	0.960	57
November	-3.77 ± 0.14	2.25 ± 0.10	7.50	<0.05	0.947	57
December	-4.25 ± 0.12	2.44 ± 0.09	6.22	NS	0.970	52
2005						
January	-3.87 ± 0.20	2.24 ± 0.15	5.07	NS	0.901	55
February	-5.73 ± 0.22	3.56 ± 0.16	3.50	NS	0.957	49
March	-5.25 ± 0.19	3.24 ± 0.14	1.71	NS	0.958	50
April	-4.65 ± 0.12	2.70 ± 0.08	3.75	NS	0.977	53
May	-2.15 ± 0.19	0.91 ± 0.14	14.93	<0.02	0.685	51
June	-3.40 ± 0.13	1.88 ± 0.10	11.20	<0.05	0.933	59
July	-3.55 ± 0.19	1.89 ± 0.14	7.93	<0.05	0.887	54
August	-2.90 ± 0.15	1.44 ± 0.11	14.18	<0.02	0.880	53
September	-3.35 ± 0.11	1.92 ± 0.08	13.50	<0.02	0.960	48

*All regressions were highly significant (*P*<0.0005), SD = standard deviation, NS = non significant (*P*>0.05).

Table (2): *Tapes decussata*. Monthly variation in regression constants (log *a* and *b*) of shell length (mm) and gonad weight (g) relationships of adult clams. Value of Student's *t*-test *(t),* level of significance from isometry (*P*), correlation coefficient (*R*) and the number of pairs (*N*) are also given*.

Month	Log *a* ± SD	*b* ± SD	*t*	*P*	*R*	*N*
2004						
August	-4.55 ± 0.11	2.76 ± 0.08	3.00	NS	0.985	38
September	-4.41 ± 0.21	2.47 ± 0.15	3.53	NS	0.928	45
October	-4.50 ± 0.15	2.77 ± 0.11	2.09	NS	0.966	48
November	-4.72 ± 0.26	2.97 ± 0.19	0.16	NS	0.921	47
December	-5.27 ± 0.15	3.15 ± 0.10	1.50	NS	0.977	45
2005						
January	-5.95 ± 0.19	3.67 ± 0.13	5.15	NS	0.972	46
February	-5.83 ± 0.19	3.59 ± 0.13	4.54	NS	0.973	42
March	-5.82 ± 0.18	3.62 ± 0.13	4.77	NS	0.974	47
April	-5.56 ± 0.17	3.39 ± 0.12	3.25	NS	0.973	44
May	-6.06 ± 0.12	3.80 ± 0.09	8.89	<0.05	0.985	60
June	-5.02 ± 0.13	3.05 ± 0.10	0.50	NS	0.976	54
July	-4.77 ± 0.14	2.91 ± 0.10	0.90	NS	0.971	54
August	-4.89 ± 0.16	2.97 ± 0.11	0.27	NS	0.967	49
September	-4.99 ± 0.19	3.03 ± 0.14	0.21	NS	0.952	52

*All regressions were highly significant (*P*<0.0005), SD = standard deviation, NS = non significant (*P*>0.05).

regressions that describe this relation have highly significant (*P*<0.0005) positive correlations. Correlation coefficient (R) values ranged from 0.983 to 1.000 and from 0.953 to 1.000 for the two species, respectively. This indicates that the mass of gametes released during spawning increases with shell length.

Gamete production expressed as the percentage of gonad weight before spawning (spawning efficiency) showed highly significant (*P*<0.0005) correlations with shell length (Table 4). For the two species, spawning efficiency increased with shell length during September 2004 and April 2005 and decreased with shell length during December 2004, July and August 2005. Spawning efficiency of the different sizes ranged from the minimum of 4.47 and 2.20% during April 2005 to the maximum of 45.34 and 53.62% of the gonad weight before spawning during December 2004 for *V. aurea* and *T. decussata,* respectively.
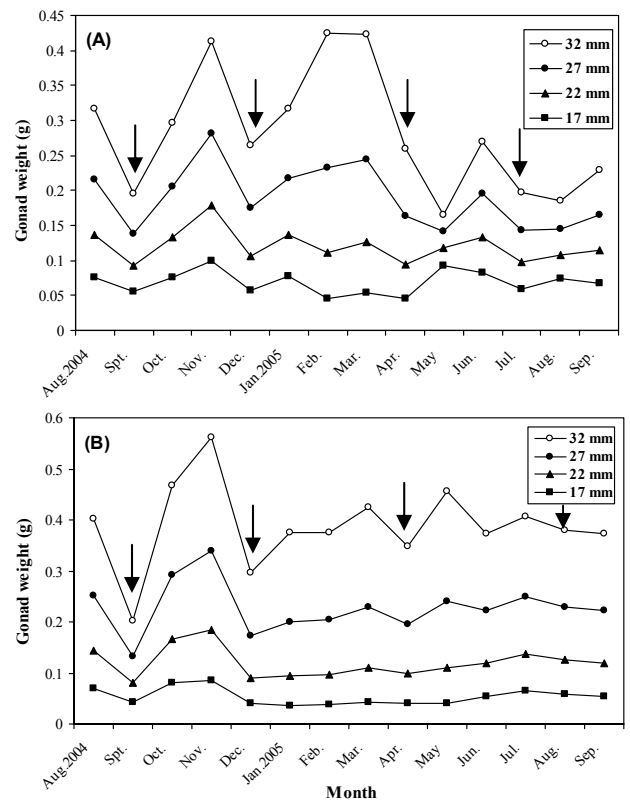

Figure (3): Monthly variations in the gonad weight of 17, 22, 27 and 32 mm standard lengths computed from gonad weight-shell length regressions of *V. aurea* (A) and *T. decussata* (B). Vertical arrows show major times of spawning.

From Figure (4) it is clear that spawning efficiency of *V. aurea* is lower than that of *T. decussata* during September and December 2004. In the other spawning periods (April, July or August 2005), spawning efficiency of *V. aurea* is greater than that of *T. decussata*. This means that individuals of *V. aurea* which had recently completed spawning contained more or less greater unspawned gametes than *T. decussata* depending on the pattern of spawning, complete on partial. In other words, the spawning of *V. aurea* was partial while that of *T. decussata* was relatively complete during September and December 2004. The reverse is true in April, July and August 2005.

DISCUSSION

Spawning pattern

Various spawning strategies, ranging from a single spawning event per year (Urrutia *et al.*, 1999; Ojea *et al.*, 2004) to protracted or repeated spawning bouts (kandeel, 1992) have been recorded for the populations of *Ruditapes decussatus*. Laruelle *et al.* (1994) reviewed data on reproductive patterns in *R. decussatus* throughout its geographical range and concluded that temperature has a positive effect on both the extent of the breeding period and the number of annual spawnings. A similar conclusion has been reported for the Manila clam *Tapes philippinarum* (Ponurovsky and

Table (3): Regression constants (log *a* and *b*) of shell length (L, mm) and gamete production (GP, g) relationships, log GP= log *a* + *b* log L, for *V. aurea* and *T. decussata* at major spawning times. Value of Student's *t*-test *(t),* level of significance form isometry (*P*), correlation coefficient (*R*), number of pairs (*N*) and length range (L, mm) are also given*.

Species and spawning time	Log *a* ± SD	*b* ± SD	*t*	*P*	*R*	*N*	L (mm)
V. aurea							
September 2004	-5.04 ± 0.076	2.74 ± 0.055	4.73	NS	0.996	22	14-35
December 2004	-3.78 ± 0.005	1.96 ± 0.003	346.67	<0.001	1.000	22	14-35
April 2005	-8.29 ± 0.287	5.01 ± 0.209	9.62	<0.05	0.983	22	14-35
July 2005	-3.93 ± 0.001	1.85 ± 0.001	1150.00	0.00	1.000	23	14-36
T. decussata							
September 2004	-5.39 ± 0.009	3.11 ± 0.006	18.33	<0.02	1.000	25	15-39
December 2004	-4.84 ± 0.264	2.82 ± 0.185	0.97	NS	0.953	25	16-40
April 2005	-9.53 ± 0.203	5.60 ± 0.143	18.18	<0.02	0.993	24	15-38
August 2005	-4.88 ± 0.022	2.19 ± 0.015	54.00	<0.01	0.999	26	15-40

* All regressions were highly significant (*P*<0.0005), SD = standard deviation.

Table (4): The relationship between shell length (L) and spawning efficiency (SE) for *V. aurea* and *T. decussata.* Correlation coefficient (*R*), mean value (±SD) and range of spawning efficiency are also given*.

Species and spawning time	Regression equation	*R*	Spawning efficiency		
			Mean ± SD	Range	
				Min.	Max.
V. aurea					
September 2004	SE = 15.1 + 0.74L	0.988	33.32 ± 4.88	23.88	39.95
December 2004	SE = 51.4 - 0.49L	-0.995	39.52 ± 3.17	34.92	45.34
April 2005	SE = -14.5 + 1.69L	0.983	27.06 ± 11.20	4.47	41.62
July 2005	SE = 27.7 - 0.03L	-0.988	26.92 ± 0.21	26.61	27.29
T. decussata					
September 2004	SE = 29.6 + 0.61L	0.986	46.15 ± 4.56	37.02	52.29
December 2004	SE = 58.6 - 0.35L	-0.992	48.88 ± 2.56	45.25	53.62
April 2005	SE = -7.52 + 0.79L	0.988	13.47 ± 5.67	2.20	21.18
August 2005	SE = 13.50 - 0.21L	-0.993	7.66 ± 1.63	5.35	10.69

* All regressions were highly significant (*P*<0.0005), SD = standard deviation.
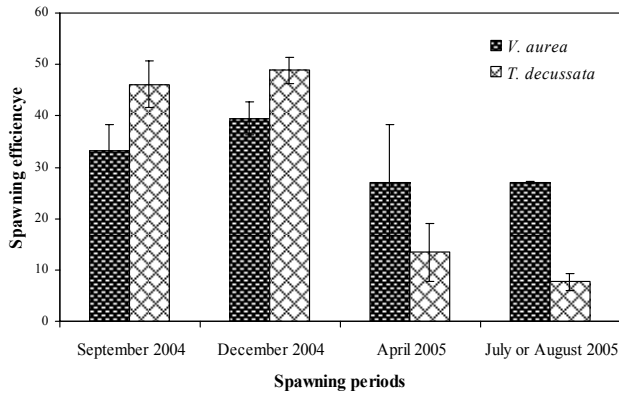

Figure (4): Variation in the mean values (±S.D.) of spawning efficiency over the consecutive spawning periods of *V. aurea* and *T. decussata*.

Yakovlev, 1992; Xie and Burnell, 1994; Drummond *et al*., 2006).

This study revealed that gonad development and spawning of *Venerupis aurea* and *Tapes decussata* continue throughout the year in a poorly defined pattern. This mode of reproduction makes precise prediction of spawning events or of subsequent recruitment pulses, very difficult (Hooker and Creese, 1995). Mass spawning occurred during September and December 2004 and April 2005 for the two species, July 2005 for

V. aurea and August 2005 for *T. decussata*. This annual pattern of four spawning periods was confirmed by the presence of four annual cohorts of small oocytes and four peaks in the proportion of ripe ova in female gonads throughout the year (Kandeel, 1992). Each cohort of these took approximately three months for maturation and spawning.

Poorly defined seasonal reproductive cycles were also recorded in *Aulacomya ater* from South Africa (Griffiths and King, 1979), The brooding hermaphroditic clam *Lasaea subviridis* from Monterey Bay, California (Beauchamp, 1986), the red clam *Megapitaria aurantiaca* at Isla Espiritu Santo, Mexico (Garcia-Dominguez *et al*., 1994), The pipi *Paphies australis* from northeastern New Zealand (Hooker and Creese, 1995) and in *Modiolus arcuatulus* and *Brachidontes variabilis* from Suez Canal lakes (Kandeel, 2002).

Continuous gamete production in *V. aurea* and *T. decussata* may refer to the availability of their food in Lake Timsah throughout the year. Also it seems that the relatively moderate water temperature in winter (monthly mean = 16°C) and warm in summer (monthly mean = 28.9°C) are both within range of the clam's normal metabolism. Localized environmental conditions have been found to cause a switch from highly

synchronized discrete spawning events to a more protracted spawning period in the pectinid scallop *Placopecten magellanicus* (Langton *et al*., 1987). Multiple spawnings have been recorded for Lake Timsah populations of *Modiolus arcuatulus* (Kandeel, 2002), *Cerastoderma glaucum* and *Papyridae papyracea* (Mohammad, 2002) and the Great Bitter Lake populations of *M. arcuatulus and Brachidontes variabilis* (Kandeel, 2002). The pattern of protracted or repeated spawning bouts has also been documented by several studies (Griffiths and King, 1979; Bachelet, 1980; Beauchamp, 1986; Del Norte, 1988; Garcia-Dominguez *et al*., 1994; Tirado *et al*., 2003).

Although, the cue or cues which have been reported to trigger spawning in bivalves are diverse (Giese and Pearse, 1974), strong environmental cues which trigger spawning were not recorded in the Suez Canal lakes. The factors inducing spawning in continuously spawning bivalves are not fully understood, but a combination of long-term conditioning factors, particularly food availability, and short-term triggering factors, such as temperature shock, may explain the repeated spawning bouts in these bivalves. This hypothesis was suggested to explain the pattern of three spawnings, of variable intensity, each year in the ribbed mussel *Aulacomya ater* (Griffiths and King, 1979).

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 spawnings with interval between batches may reduce intraspecific competition by allowing each cohort a virtually independent food supply (Lambert and Ware, 1984).

The state of quiescence (inactive or rest phase) seen in some venerids during winter e.g, *Venerupis decussata* (Breber, 1980), *Tapes rhomboides* (Morvan and Ansell, 1988), *Ruditapes decussatus* (Ojea *et al*., 2004) and *Tapes* (= *Ruditapes*) *philippinarum* (Drummond *et al*., 2006) was not recorded during this study. In this respect, the results agree with that found in the venerids *Venerupis aurea* by Gallois (1977) and *Venus verrucosa* by Tirado *et al*., (2003) and in other bivalves (Griffiths, 1981; Del Norte, 1988; Ghobashy *et al*. 1991; Villalba, 1995).

Fecundity

Several methods have been applied to estimate fecundity or reproductive output in marine bivalves: (1) soft tissue weight just prior to and after spawning (e.g. Griffiths, 1977, 1981; Griffiths and King, 1979; Kautsky, 1982; Pouvreau *et al*., 2000). This method is inappropriate because changes in meat condition as a result of spawning may be masked by rapid growth during the same period (Hancock and Franklin, 1972), (2) egg counts in squash preparations (e.g. Galinou-Mitsoudi and Sinis, 1994; Harvey and Gage, 1995). The entire egg mass could not be separated from the body and not all of the eggs were released from the excised tissue (Park and Choi, 2004). Counting only the released eggs would give a grossly low estimate, (3) counting or weighing the eggs released after inducing mature females to spawn in the laboratory using various chemicals or thermal shock (Walker *et al*., 1996; Kent *et al*., 1999; Chung *et al*., 2001). This technique and the previous one preclude the inclusion of males in the estimation and are suitable only for species which have a definite spawning season during which all the ripe eggs are shed at approximately the same time, (4) the application of enzyme-linked immunosorbent assay (ELISA), a high sensitive and rapid method for quantifying egg or sperm proteins produced annually by marine bivalves (Kang *et al*., 2003; Park and Choi, 2004). Park and Choi (2004) believed that the fecundity deduced from the ELISA data is the maximum estimate, as an entire clam is homogenized and the total gonadal protein in the clam is measured, (5) the difference in the gamete volume fraction (GVF) immediately before and after the spawning period. This method has been used to advantage by Yankson (1986), Morvan and Ansell (1988) and Urrutia *et al*., (1999). The GVF is a direct measure of the proportion of the gonadal tissue which is actually devoted to gamete production, (6) by comparison of gonad weight before and after spawning (e.g. Bonardelli *et al*., 1996). This method is applicable here to both *Venerupis aurea* and *Tapes decussata* because it was easy to apply and gave a better estimate for the following reasons:

(A) The gonad is a discrete organ and its weight may be determined directly after dissecting it from the body. In some other bivalves, it is impossible to separate the gonad from the body (Griffiths, 1977; Yankson, 1986; Ghobashy *et al*., 1991; Kandeel 2002).

(B) The histological preparations of the gonad did not reveal the accumulation of reserve materials which are sometimes deposited in the body perior to gamete formation (Griffiths, 1981). Thus, monthly changes in gonad weight of *V. aurea* and *T. decussata* quantify gamete production. However, gonad weight analysis based on the assumption that no spawning occurs during gonad development prior to the major spawnings and during spawning gametogenesis ceases entirely. Kandeel (1992) found that gamete release was rapidly compensated by rapid regeneration of the gonad. This means that this method may underestimate the true reproductive output.

Mature gonads constituted between 22.3 and 34.6% and between 14.6 and 26.2% of total soft body weight of *Venerupis aurea* and *Tapes decussata,* respectively (Kandeel, 1992). Spawning efficiency reached 45.34 and 53.62% of the gonad weight before spawning for the two species, respectively. Fecundity and spawning efficiency estimates indicated that both clams exhibited improved reproductive effort in Lake Timash.

Gamete production of the two species increased with increasing shell length as in the venerids *Transennella tantilla* (Kabat, 1985) and *Tapes rhomboides (*Morvan

and Ansell, 1988). Size-related fecundity was also recorded by many investigators (Sloan and Robinson, 1984; Beauchamp, 1986; Langton *et al.*, 1987; Galinou-Mitsoudi and Sinis, 1994; Harvey and Gage, 1995; Walker *et al.*, 1996; Park and Choi, 2004).

Reproductive senility

Reproductive senility in bivalves occurs when older age-classes achieve lower reproductive success than expected (Peterson, 1983). Using weight analysis of gonadal material of both *Venerupis aurea and Tapes decussata* proved that reproductive senility does not occur in older individuals. Histological studies also showed that older Individuals occurred in a reproductively active state and had a gametogenic pattern similar to that of smaller adults. Similar observations were described for other bivalves. In populations of *Arctica isalandica,* Pacific geoduck *Panopea abrupta,* and northern quahog *Mercenaria mercenaria,* Thompson *et al.* (1980), Sloan and Robinson (1984) and Peterson (1983 and 1986), respectively, determined that reproductive senility does not occur even though *A. islandica, P. abrupta and M. mercenaria* may live to 150, 107, and 46 years, respectively. They based their conclusion on the fact that the relative amount of gonadal material present in the visceral mass did not decrease with increasing size or age. On the basis of gamete viability, an important factor in the estimation of senility (Peterson, 1983), Walker and Heffernan (1996) concluded that reproductive senescence was not occurring in old–aged (38 years) *M. mercenaria.* The reproductive activity of the date mussel *Lithophaga lithophaga* appeared to continue throughout the life of the mussels, since even the oldest individual (54[+] years) had active gonads (Galinou-Mitsoudi and Sinis, 1994). Scott (1988) has reported that reproduction and growth of bivalves does no stop, and may result in greater reproductive potential. However, reproductive senescence has been shown in populations of the Iceland scallop *Chlamys islandica* (Vahl, 1985) and bay scallop *Argopecten irradians* (Bricelj and Krause, 1992).

Conclusion and recommendations

Because of their considerable economic importance and the high market demand, over-exploitation of both *Venerupis aurea* and *Tapes decussata* has largely depleted their natural stocks, thereby boosting the aquaculture industry. In order to improve the methods of cultivating these clams and for a better management of their fishery, detailed knowledge of the reproductive behaviour is fundamental. Both species exhibited high reproductive potential in Lake Timash. They have high fecundity, rapid gonad recovery, repeated spawning bouts and high spawning efficiency. These trends are important in allowing the two species to successfully invade the lake ecosystem. According to the data of this study, the next points are recommended:

1. Closed season should be established during September and December when there is intense release of gametes in the two populations.
2. Older individuals of the two clams are valuable reproductive resources and should be protected to ensure the continuation of the fishery.
3. The availability of spawnable broodstock throughout most of the year in Lake Timsah could be of advantage in the hatchery production of the two species and in the provision of embryos for ecotoxilogical studies.
4. In order to maintain the catch of the two species, it is necessary to supply the shellfish fishermen with scientific advice to manage these resources.
5. There should be available information about clam fishery in Lake Timsah to evaluate the degree of exploitation of these marine living resources.
6. El-Taawen area represents the most suitable area for the cultivation of both *V .aurea* and *T. decussata* in Lake Timsah.
7. The present work can be used as a base line and should be linked to long-term further investigations.

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التقدير الكمي لإنتاج الأمشاج لنوعين إقتصاديين من المحار وهما الجندوفلى الناعم والجندوفلى الخشن
(ذوات المصراعين ـ الفصيلة الفينيريدية) فى بحيرة التمساح، قناة السويس، مصر

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الملخص العربــى

تم تعيين العلاقات الشهرية بين طول الصدفة ووزن المنسل لنوعين إقتصاديين من المحار هما الجندوفلى الناعم والجندوفلى الخشن، تم جمعهما من منطقة التعاون في بحيرة التمساح، قناة السويس في الفترة من أغسطس 2004 إلى سبتمبر 2005. وقد تم تقييم تكرار التفريغ والإنتاج الفردي للجاميتات تحت الظروف الطبيعية بمراقبة التغير في وزن المنسل والذي تم تحديده لأحجام قياسية بأستخدام العلاقات الشهرية بين طول الصدفة ووزن المنسل. وقد فسرت الزيادة في وزن المنسل ببناء الجاميتات، بينما النقصان فسر بالتفريغ. أما الأجناس فهى منفصلة ويستمر نمو المناسل والتفريغ على مدار العام وليس هناك دليل على وجود دورات تناسلية محددة. كلا النوعان لا يصلان إلى مرحلة الشيخوخة في التكاثر، بل يتكاثران عدة مرات على مدار العام.

أما إنتاج الجاميتات معبرا عنه بالتناقص فى الوزن عند التفريغ فيحدث بمعدلات مختلفة خلال فترات التفريغ المتتالية ويرتبط إيجابيا بحجم الحيوان وتزداد كفاءة التكاثر أو تتناقص بشكل خطى مع الحجم، وتصل الكميات النسبية للمادة التكاثرية المنطلقة من قبل الأحجام المختلفة التي تم فحصها إلى 45.34 % و 53.62 % من وزن المنسل أثناء ديسمبر 2004 للجندوفلى الناعم و الجندوفلى الخشن على التوالي. وكلا النوعين يظهر أن كفاءة تكاثرية عالية في بحيرة التمساح.