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REPRODUCTION OF THE EGYPTIAN SOLE, *SOLEA AEGYPTIACA* (ACTINOPTERYGII: PLEURONECTIFORMES: SOLEIDAE), FROM PORT SAID, EGYPT, MEDITERRANEAN SEA

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Background. Understanding of reproduction of the Egyptian sole, *Solea aegyptiaca*, has been considered a major step toward understanding its population dynamics, especially in the eastern Mediterranean Sea. In Egypt this species has highly commercial value and it has recently been successfully bred in aquaculture, but more data on the reproductive biology is still needed. So, the present work aimed to study the population structure and the reproductive dynamics of *S. aegyptiaca* over an annual reproductive cycle.
Materials and Methods. A total of 594 specimens of *S. aegyptiaca* were obtained from October 2004 to September 2005 in a monthly basis from the commercial catch. Sex ratio, age, and length at first maturity, gonado-somatic index, maturity stage, oocyte diameter, and fecundity were analysed in order to increase our knowledge on the reproductive dynamics of *S. aegyptiaca*.
Results. The overall ratio between males and females was 1.0 : 1.15 and showed no significant deviation from the expected 1 : 1 ratio, males are dominant among small size, while females are dominant among larger size. Females attained their maturity at the length of about 15.0 cm. The reproductive activity of *S. aegyptiaca* took place between January and June with a peak on January, when the majority of oocyte growth (> 400 µm in diameter) occurred. Hydrated oocytes reach 1000 µm immediately before spawning. Absolute fecundity ranged from 9898 to 38505 and can be expressed as a function of total length.
Conclusion. *S. aegyptiaca* is a winter spawner, and the female attains its maturity at 15.0 cm of total length. So, fishing should be prohibited during the period from January to June to conserve the existing stock of the target species. Regulations should also be directed to reduce the fishing potential of 18.0 cm total length. It is important to give each fish the chance to reproduce at least once in its lifetime.

Keywords: *Solea* aegyptiaca, reproduction, Port Said, Egyptian Mediterranean Sea

INTRODUCTION

Understanding the reproductive biology of a species is the central aspect of providing sound scientific advice for fisheries management. Reproductive biology plays an important role in determining productivity and therefore a population's resiliency to exploitation by fisheries or to perturbation caused by other human activities (Morgan 2008). Aspects of the flatfish reproduction were described by many studies from Egypt (Zaki and Hamza 1986, Mehanna 2007, El-Gharabawy unpublished**, El-Husseiny unpublished***) and from other in parts of the world (Rajaguru 1992, Vallisneri et al. 2001, Türkmen 2003, Narimatsu et al. 2005, García-López et al. 2006.)

Quéro et al. (1986) and Bauchot (1987) considered *Solea aegyptiaca* Chabanaud, 1927 as a sibling species of *S. vulgaris*. *Solea aegyptiaca* and *S. vulgaris* seem to be differentiated by the number of vertebrae (NV) and allele structure (Quignard et al. 1982). According to Bauchot (1987), soles with NV = 39–44 were classified as *S. aegyptiaca* and those with NV = 46–52 as *S. vulgaris*. Both species co-occur in the Gulf of Lion, Adriatic Sea, and eastern Mediterranean Sea (Quignard et al. 1982, Quéro et al. 1986, Bauchot 1987).

Members of the genus *Solea* are recorded among the most important and valuable commercial flatfishes in Egypt and greatly appreciated by consumers of sea products (Gabr et al. 2003. Therefore, urgent fisheries managements are needed to recover these overfished stocks. One of the management measures that have been advocated is establishment of marine hatcheries to induce spawning of target species and restocking original habitats with fry or pre-adult fish (Amein unpublished****). In Egypt, common sole, *S. solea*, was successfully hatched for the first time in 1986 and juveniles were obtained and maintained in healthy conditions (Zaki and Hamza 1986).

Understanding of reproduction of the Egyptian sole, *Solea aegyptiaca*, is considered a major step toward

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** El-Gharabawy M.M. 1977. Biological studies on soles in the region of Abu-Kir Bay. MSc Thesis, Faculty of Science, Alexandria University, Egypt.

*** El-Husseiny M.M. 2001. Reproductive Biology of *Solea* sp. in Lake Quarun. MSc Thesis, Faculty of Science, Ain Shams University, Egypt.

**** Amein A.M.M. 1996. A study of the biology and population dynamics of *Litherinus bungus* (Forsskål, 1775) in the Gulf of Suez, Egypt. MSc Thesis, Marine Science Department, Faculty of Science, Suez Canal University, Egypt.

revealing its population dynamics especially in the eastern Mediterranean area. Therefore, the present work aimed to study the reproductive dynamics of *S. aegyptiaca* including the description of gonad morphology, the determination of sex ratio, length at first maturity, gonado-somatic index (GSI), monthly variations in maturity stages, monthly variations in egg diameter, and fecundity over annual reproductive cycle.

MATERIALS AND METHODS

A total of 594 specimens (277 males and 317 females) of *S. aegyptiaca* were obtained in a monthly basis from October 2004 to September 2005 from commercial catches. Total fish length and total weight were determined to the nearest 0.1 cm and 0.1 g, respectively. Gonads were removed from the abdominal cavity, weighed to the nearest 0.001 g, and preserved in 10% formalin seawater solution. Sex was determined by macroscopic examination of the gonads.

Sex ratio indicates the proportion of males and females in the population. Variations from the 1 : 1 hypothesis are often observed in fish because of differential behaviour of sexes, environmental conditions, and fishing. Sex ratio studies may indicate segregation or aggregation of sexes according to feeding, breeding or migratory behaviours (Bal and Rao 1984). A chi-square (χ^2) test was used to detect differences in sex ratio of sampled fish.

The length at first sexual maturity is defined as the length at which 50% of fish reach sexual maturity (Pitt 1970). Such information is essential for the management of an exploited fish stock through the estimation of the minimum legal size of capture which is needed to secure that part of the fish population spawns. Length at maturity was estimated by fitting the maturation curve between the observed points of 1-cm class interval and the percentage maturity of fish corresponding to each length interval. Then L_{50} was estimated as the point on the X-axis corresponding to the 50% point on the Y-axis. The length at first capture L_{50} was estimated by the analysis of catch curve as described by Mehanna (2007).

The gonado-somatic index (GSI) is a method for studying the spawning season by following the seasonal changes in the gonad weight in relation to the fish's body weight (Bal and Rao 1984). GSI is calculated as $GSI = GW \cdot TW^{-1} \cdot 100$ (Albertine-Berhaut 1973), where GW is the wet weight of the gonad to the nearest (0.001 g), and TW is the wet total weight of the fish to the nearest 0.1 g.

The stage of maturity was determined for each gonad macroscopically based on the colour and shape of the ovary, as well as its size in relation to the body cavity. Five stages were considered in this study: immature, maturing, spawning, post-spawning, and resting-recovering according to a modified sexual maturity scale of Vallisneri et al. (2001). Male's maturity stages were difficult to determine because no marked variations in gonad morphology or size were observed in almost all fishes.

Oocyte diameter gives the information on either the fish spawns once or several times in a breading season. Oocytes were separated from ovarian tissues, put in a saline solution (0.9% NaCl), and measured in diameter to the nearest 0.01µm by using an eye-piece micrometer on the binuclear microscope at a power magnification of 4×. Fifty oocytes were taken randomly to determine the monthly mean oocyte diameter.

Absolute fecundity was estimated for 70 mature female fish in the laboratory by counting all ripening eggs found in 3 sub-samples of 0.01 g taken separately from anterior, posterior, and middle region of each ovary lobe. Absolute fecundity was correlated with total fish length and plotted graphically against absolute fecundity by applying regression equation as $F = aL^b$ (Bagenal 1971), where F is absolute fecundity and L is the total fish length.

Two terms are applied in studying fish fecundity; the absolute fecundity which is the total number of mature eggs in the ovary, and the relative fecundity which the total number of eggs per unit of fish length (Nikolsky 1963).

RESULTS

Sex ratio. Generally, there were more females (317 = 53.4%) than males (277 = 46.6%) in the sampled population. The overall sex ratio (male to female) of *S. aegyptiaca* was 1.0 : 1.15. Chi-square test showed non-significant difference between the overall sex ratio ($\chi^2 = 2.694$, $P = 0.101$).

The monthly variations in the sex ratio of *S. aegyptiaca* are given in Table 1. The sex ratio was not constant throughout the year; female's numbers were greater than those of males in the period from May to September. Female numbers were also high in December (58.0%) and January (86.0%) when the spawning season takes place.

Length at first sexual maturity. It was difficult to identify the maturity stages for males *S. aegyptiaca*; because the testes were very small and did not exhibit any macroscopically detectable morphological changes during maturation.

The percentage frequency of immature and mature females of *S. aegyptiaca* in each length group of 1.0 cm interval is represented in Fig. 1. The first mature females were recorded for length group 13.5–14.4 cm (25.0%). The female's length at first maturity was estimated at 15.0 cm.

Gonado-somatic index (GSI). The monthly changes in males and females GSI were represented in Fig. 2. Males GSI of *S. aegyptiaca* was lower than females. The lowest value of males GSI (0.037) was recorded in August, when it started to increase slightly in September, October, and November. It sharply increased in December and reached the highest value (0.129) in January. GSI decreased from February till August.

Females GSI showed a similar pattern than the males. It attained the lowest value (0.644) in June and increase slightly during July, August, September, and October. It sharply increased in November and December, reaching the highest value in January. Female GSI decreased in period from February to June. GSI of both sex were showed a definite breeding season which extends from January to June.

Monthly variations in maturity stages. The monthly variations in female sexual maturity of *S. aegyptiaca* were represented in Fig. 3. Immature ovaries started to appear in May (7.4%), increased in June (23.5%), and recorded the highest value in July (35.7%). Maturing ovaries started to appear in September (22.2%), increased in October (40.0%), and reached the maximum in November (57.9%). The first sign of spawning ovaries were observed in November (10.5%), increased in December (62.1%), and recorded the highest value in January (69.8%). Spawning ovaries decreased from February on (39.1%). Post-spawning ovaries appeared in January (16.3%), increased in February (60.9%) and became dominant in March (77.8%). Resting-recovering ovaries were dominated during the period from June until September, reaching the maximum value in August (72.4%).

Egg diameter. The oocyte diameters for different months of *S. aegyptiaca* were illustrated in Fig. 4. During the period from June until August, no mature or resting oocytes were detected. Their diameters did not exceed 110.0 µm with an average of 73.39 µm. A sharply increase in oocyte diameter was evident in September (145.18 µm), increased in October (150.94 µm) and November (267.97 µm), and reached the maximum mean value of 410.84 µm in January. The average oocyte diameter decreased from February (374.57 µm) to May (121.47 µm).

Table 1

Monthly variations of sex ratio of *Solea aegyptiaca* in the Mediterranean Sea

Month	*n*	Male		Female		χ^2*	*P***
		n	%	*n*	%		
Oct. 2004	50	30	60.0	20	40.0	2.000	0.157
Nov.	50	31	62.0	19	38.0	2.880	0.090
Dec.	50	21	42.0	29	58.0	1.280	0.258
Jan. 2005	50	7	14.0	43	86.0	25.920	0.001
Feb.	49	26	53.1	23	46.9	0.184	0.668
Mar.	50	32	64.0	18	36.0	3.920	0.048
Apr.	50	39	78.0	11	22.0	15.680	0.001
May	48	21	43.8	27	56.3	0.750	0.386
Jun.	49	15	30.6	34	69.4	7.367	0.007
Jul.	48	20	41.7	28	58.3	1.333	0.248
Aug.	50	21	42.0	29	58.0	1.280	0.258
Sep.	50	14	28.0	36	72.0	9.680	0.002
Total	594	277.0		317.0		2.694	0.101
%		46.6		53.4			

* χ^2 = chi-square test values.
** Accepted level of significance at $P \leq 0.0$.

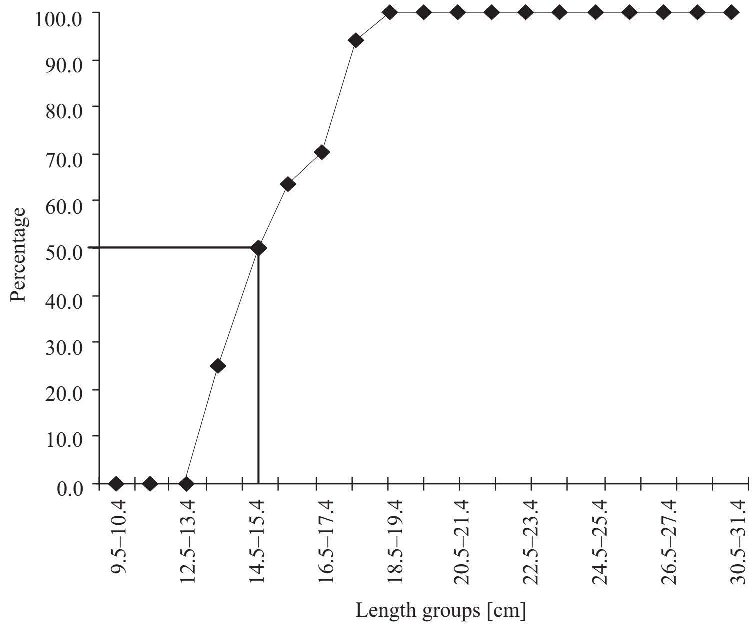

Fig. 1. Length at first maturity for females *Solea aegyptiaca*, in the Mediterranean Sea

Fecundity. A total of 70 mature females of *Solea aegyptiaca* were collected during the spawning season for estimation of absolute fecundity. The relation between absolute fecundity and fish body length is given in Table 2. Absolute fecundity ranged from 9898 to 38505 while the relative fecundity ranged from 627.17 to 1262.48 eggs per cm for length ranging from 15.8 to 30.5 cm. The absolute fecundity and the total body length relation gave significant correlation ($r^2 = 0.9375$, $P = 0.001$) and can be represented by the following equation: $F = 16.913\ L\ 2.2653$.

DISCUSSION

In the present work, the overall ratio between males and females of *Solea aegyptiaca* was 1.0 : 1.15 and chi-square test showed no significant deviation from the expected 1 : 1 ratio. However, the sex ratio varied monthly and were significant deviations from the expected 1 : 1 was sometimes observed. Such deviation could be due to a partial segregation of mature forms through habitats preference (Reynolds 1974) or due to migration and/or behavioural differences between sexes thus rendering one sex to be more easily caught than another. Sex ratio of *S. aegyptiaca* found in this study are in agreement with that of Rajaguru (1992) who found a 1 : 1 sex ratio in the tongue fishes *Cynoglossus lida* and *C. arel* (Family: Cynoglossidae). These ratios also varied monthly and chi-square values showed significant difference in both species. Also, Türkmen (2003) recorded that the overall ratio of males and females of *Solea solea* from Turkey were 1.03 : 1.

The length at first sexual maturity varies greatly from one species to another and within the same species that might experience different environmental conditions such

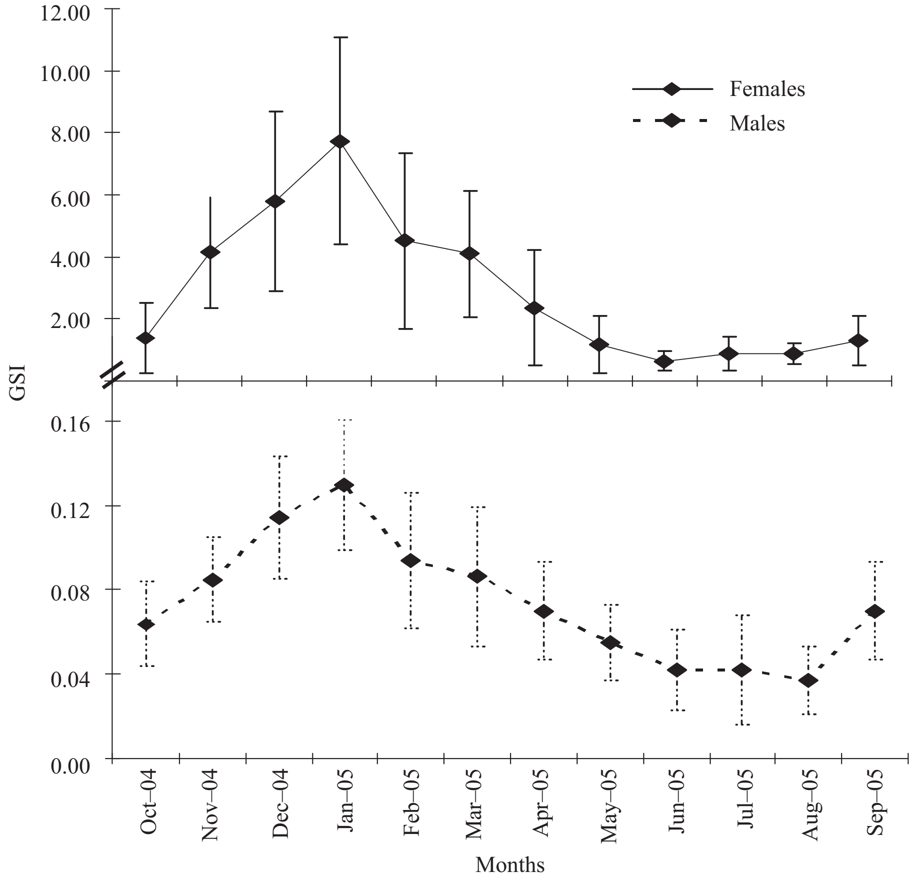

Fig. 2. Monthly variations of the average gonad index *Solea aegyptiaca* in Mediterranean Sea

Table 2

Relation between fecundity and total fish length of *Solea aegyptiaca* in Mediterranean Sea

Total Length [cm]		*n*	Absolute Fecundity		Relative Fecundity (*F*/*L*)
Range	Mean		Observed	Calculated	
14.9–16.8	15.8	18	9898.79	8757.51	626.51
16.9–18.8	17.8	15	10968.02	11440.86	616.18
18.9–20.8	19.5	17	13676.69	14177.30	701.37
20.9–22.8	21.7	12	15129.11	17996.64	697.19
22.9–24.8	23.3	4	19475.38	21059.20	835.85
24.9–26.8	25.6	3	32514.47	26114.64	1270.09
28.9–30.8	30.5	1	38505.65	38945.44	1262.48

as water salinity and temperature. In the current work, the length of first maturation of female *S. aegyptiaca* was 15.0 cm. This result is in accordance with those of Kirollus (unpublished*) on *S. solea*, El-Husseiny (unpublished*) on *S. aegyptiaca* from Lake Quarun, Türkmen (2003) on *S. solea*, from Iskenderun Bay (Turkey). In the present study, maturity stages of males of *S. aegyptiaca* were not detected because the testes were extremely small and there were no clear external morphological changes in terms of shape.

Gonado-somatic index (GSI) reflects the physiological activity of the gonads, where the increase is an indication of the beginning of the breeding season of the fish. The monthly changes in GSI of males and females *S. aegyptiaca* showed a definite breeding season which extends from January to June. Both sexes reached the highest values of GSI in January, while the minimum was in June and August for females and males respectively. El-Husseiny (unpublished*) reported that the GSI of female of *S. aegyptiaca*, in Lake Quarun, increased pro-

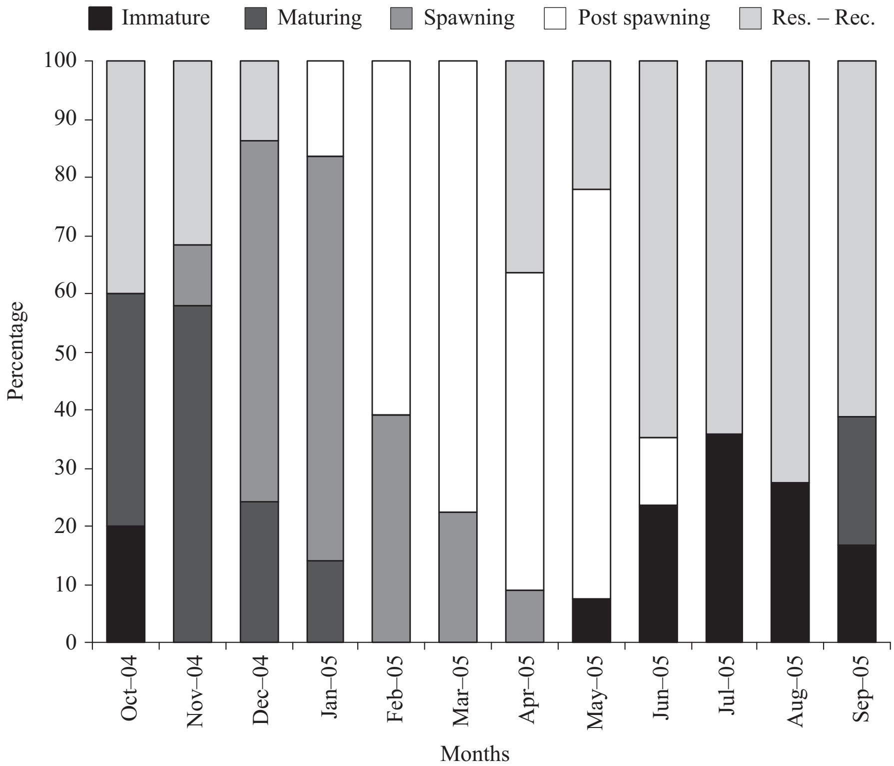

Fig. 3. Monthly variations of female's sexual maturity stages of *Solea aegyptiaca* in Mediterranean Sea (Res.–Rec. = resting–recovering stage)

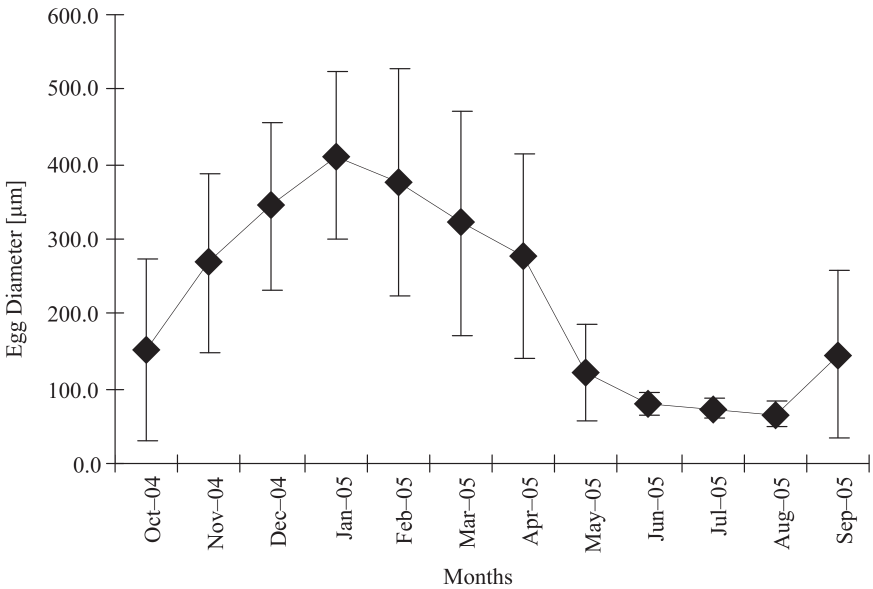

Fig. 4. Monthly variations of egg diameter (µm) of *Solea aegyptiaca* in Mediterranean Sea

* Kirollus S.Y. 1977. Biological studies of *Solea vulgaris* Quensel, 1806. MSc Thesis, Faculty of Science, Cairo University, Cairo. Egypt

gressively to reach its maximum value in January, while the minimum value was recorded in July.

Data on monthly variations in the stage of maturity of *S. aegyptiaca* and ova diameters confirmed that the spawning season extends from January to June. This finding runs parallel with that obtained by El-Husseiny (unpublished*), who concluded that the spawning season extended from January to July. The results on ova diameter are in agreement with many authors that worked on flatfishes; for example El-Gharabawy (unpublished*) on *S. solea* from Abu-Kir Bay, Zaki and Hamza (1986), El-Husseiny (unpublished*) on *S. aegyptiaca*. They all concluded that these flatfishes are winter spawners.

The relative fecundity of *S. aegyptiaca* females ranged between 616.18 and 1270.09 egg per cm of total body length, while the absolute fecundity was found to vary between 9898 and 39505 eggs for lengths between 15.8 and 30.5 cm, respectively. El-Husseiny (unpublished*) studied the relative fecundity of *S. aegyptiaca* and found that it ranged between 1745.2 and 2394.6 egg per cm. The absolute fecundity was found to vary between 20800 and 64949 eggs for the lengths of 16.5 and 22.5 cm. In the present work, a high correlation coefficient (r^2) was determined between fecundity and total length (0.94). Horwood and Walker (1990) found that fecundity of *S. solea*, from Bristol Channel, was strong correlated with fish total length. Rajaguru (1992) pointed out that fecundity in flatfishes (*Cynoglossus arel*) was highly correlated with total length, while fecundity in *C. lida* was dependant only on ovary weight.

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* see footnote *** on page 161