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Stock Assessment and Management of the Egyptian Sole *Solea aegyptiaca* Chabanaud, 1927 (Osteichthyes: Soleidae), in the Southeastern Mediterranean, Egypt

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Abstract: Aspects of the population dynamics of the Egyptian sole, *Solea aegyptiaca*, which is a commercially important endemic and demersal flatfish species in the Egyptian Mediterranean waters, were described based on materials collected monthly between February 2004 and May 2005 from the fishing harbor at Port Said city. Age and growth studies based on sagittal otoliths revealed that this species is relatively fast growing with a maximum age of 4 years. Marginal increment analysis suggested that bands on sagittae are deposited once a year during the winter. Mean back-calculated total lengths ranged from 17.75 cm at age I to 28.22 cm at age IV. Growth was best described by the von Bertalanffy growth model as L_t = 30.9 (l -$e^{-0.53(t + 0.33)}$). Estimates of total, natural, and fishing mortality were 2.56, 0.75, and 1.81 $year^{-1}$, respectively. The high value of exploitation rate (E = 0.71) indicated that this species is suffering from high fishing pressure. The yield per recruit analysis suggested that the *S. aegyptiaca* stock in the Eastern Mediterranean, Port Said region needs development of a management strategy to conserve and optimize its yields.

Key Words: Mediterranean, Port Said, *Solea aegyptiaca*, Soleidae, age and growth, stock assessment, reference points, management

Introduction

The Egyptian Mediterranean coast is about 1100 km, extending from El-Sallum in the West to El-Arish in the East. The mean annual fish production from this area does not exceed 45,000 t (1984-2005, General Authority for Fish Resources Development). There are 3 fishing methods conducted in the Egyptian Mediterranean: trawling, purse-seining, and long-lining by hand. The fishing grounds along the Egyptian Mediterranean coast are divided into 4 regions: Western region (Alexandria and El-Mex, Abu-Qir, Rasheed, El-Maadiya, and Mersa Matruh), Eastern region (Port Said and El-Arish), Demietta region, and Nile Delta region (Figure 1). The Port Said region is one of the most productive fishing grounds, constituting 24% of the total fish production in the Egyptian Mediterranean (GAFRD annual reports).

The soles (Soleidae) assume a very important place in the Egyptian Mediterranean fisheries, where Egyptian sole (*Solea aegyptiaca*) is the most common species. Soles contributed about 6.5% of the total catch of trawl fishery, forming about 13% of the gross revenue of the trawling. There are discrepancies regarding the taxonomy of the species *S. aegyptiaca*, because the examination of its morphometric characters shows that it cannot be separated from *Solea solea* (Ben-Tuvia, 1990). *S. aegyptiaca* is considered a valid species in some studies (Bauchot, 1987; Goucha et al., 1987; She et al., 1987). In some studies it is considered a synonym of *Solea solea* (Borsa and Quignard, 2001), while in some others it is synonymized under *S. vulgaris* (Tinti and Piccinetti, 2000).

Despite the great importance of soleid species to the economy of the Egyptian fisheries, they have been sparsely studied. El- Gharabawy (1977) studied the taxonomy of soles in Egyptian Mediterranean waters. Kirolus (1977) studied the meristic characters and used the vertebrae in age determination of *Solea vulgaris* in

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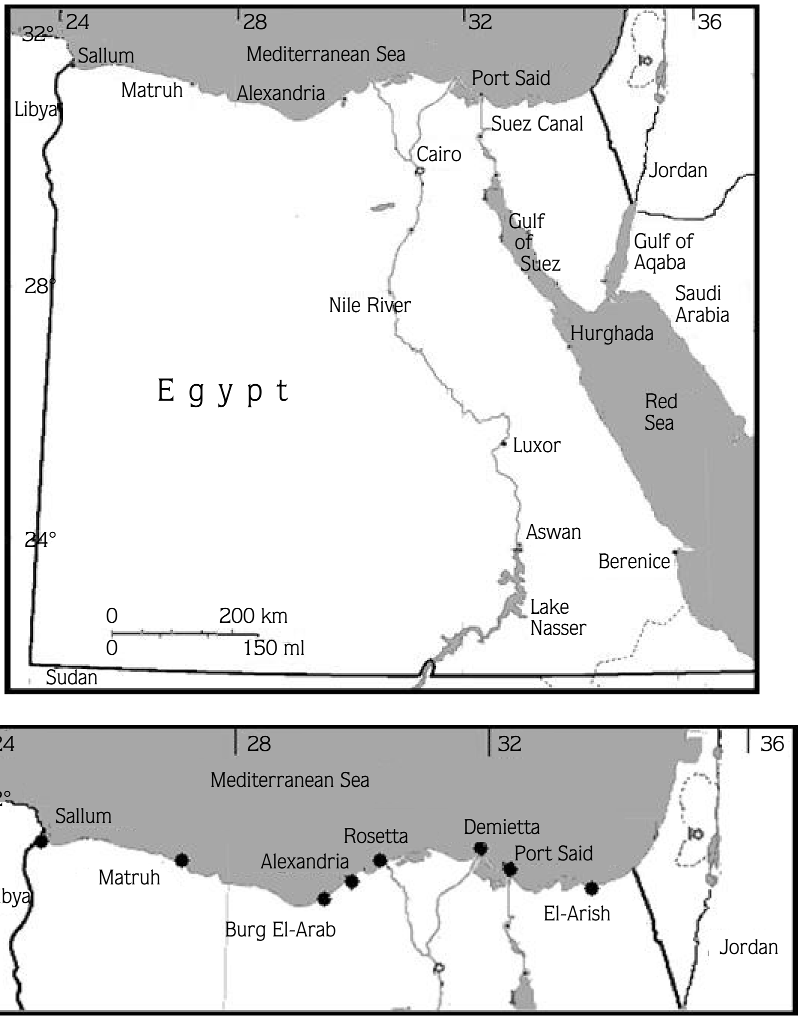

Figure 1. Map of Egyptian Mediterranean coast.

Lake Qarun. Ezzat et al. (1982) studied the age and growth of *Solea vulgaris aegyptiaca* in Abu-Qir Bay. El-Gammal et al. (1994) estimated the mortality and yield per recruit of *S. solea* from Lake Bardawil. Ali (1995) studied the biology of the Egyptian flatfish of the genus *Solea*.

For the rational exploitation and management of *Solea aegyptiaca* stock in the southeastern Mediterranean (Port Said region, Egypt), information on its dynamics and biology is essential. The present study was carried out to discuss and estimate the basic parameters required for assessing and managing the *S. aegyptiaca* stock at Port Said.

Materials and Methods

Random samples (640 fish ranging from 9.5 to 28.9 cm TL) were collected from the fishing harbor and local market in Port Said city from February 2004 to May 2005 in monthly intervals. The total length was measured to the nearest millimeter and total weight was measured to the nearest 0.1 g. Sex, maturity stage and otoliths were taken for each specimen of *S. aegyptiaca*.

Otoliths were removed, rinsed of any adhering tissues, and sorted dry in labeled vials until processing. Annual rings on the otoliths were counted using an optical system consisting of Nikon Zoom - Stereomicroscope focusing block and Heidenhain's electronic bidirectional read out system V R X 182, under transmitted light. The total radius of the otolith "S" and the distance between the focus and the successive annuli were measured to the nearest 0.001 mm. Lengths by age were back-calculated using Lee's (1920) equation.

The relation between the total length (L) and total weight (W) was computed using the formula $W = a L^b$, where a and b are constants whose values were estimated by the least square method. Confidence intervals of 95% were calculated for the slope (b) to see if these were significantly different from 3.

The back-calculated lengths were used to estimate the growth parameters of the von Bertalanffy growth model $L_t = L_\infty (1-e^{-K (t - to)})$ by fitting the Ford (1933) and Walford (1946) plot, while "t_o" was estimated by the equation $t_o = t + 1/K \ Ln (L_\infty - L_t / L_\infty)$.

The growth performance index (ø) was computed according to the formula of Pauly and Munro (1984) as $ø = Log K + 2 Log L_\infty$.

The total mortality coefficient Z was estimated using the linearized catch curve method described by Pauly (1983a), which is based on the analysis of length-frequency data. The natural mortality coefficient M was estimated using the method of Alverson and Carney as: $M = 3 * K / [exp (t_{max} * 0.38 * K) – 1]$, where t_{max} is the age of the oldest fish while the fishing mortality coefficient was F = Z – M and the exploitation rate E was E = F/Z.

The length at first sexual maturity L_{50} (the length at which 50% of fish reach their sexual maturity) was estimated by fitting the maturation curve between the observed points of mid-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_c was estimated by the analysis of catch curve as described by Pauly (1984a, 1984b).

Recruitment pattern was detected by projecting length frequencies backward onto a 1-year time scale using the method reported by Moreau and Cuende (1991).

Relative yield per recruit (Y/R)' and relative biomass per recruit (B/R)' were estimated using Beverton and Holt's (1966) model as follows:

$$(Y/R)' = E\, U^{M/K} [1 - (3U/1 + m) + (3U^2/1 + 2m) - (U^3/1 + 3m)]$$

$$(B/R)' = (Y/R)'/F$$

where (Y/R)' is the relative yield per recruit and (B/R)' is the relative biomass per recruit

$$m = (1 - E)/(M/K) = K/Z$$

$$U = 1 - (L_c/L_\infty)$$

Z, M, and F are the total, natural, and fishing mortality coefficients, respectively.

E is the exploitation rate.

K is the growth parameter.

Results and Discussion

Description of trawl fishery

The number of trawlers operating in the Port Said fishery ranged between 140 and 220 fishing boats during the period from 1984 to 2005. The boat lengths varied between 18 and 22 m and their width varied from 4 to 6 m. Each boat was powered by a main engine of 100 to 500 hp. Some of them were equipped with echo-sounders. A fishing trip was about 7 to 10 days and the number of crew was about 5 to 10 people. The trawl fishery contributed about 31% of the total fish production of Port Said (Mehanna et al., 2005).

Catch composition

The most dominant fish species in the catch were elasmobranches (*Carcharhinus* spp.), soles (*Solea* spp. and *Pegusa* spp.), sparid fish (*Boops boops*, *Diplodus* spp., and *Sparus aurata)*, red mullet (*Upeneus* spp. and *Mullus* spp.), terapons (*Terapon puta*), and lizard fish (*Saurida undosquamis* and *Synodus saurus*). Invertebrates were represented by large shrimps *(Penaeus japonicus, P. semisulcatus, P. kerathurus*, *P. canaliculatus,* and *M. monoceros)***,** cuttlefish *(Sepia pharaoni, S. prashadi,* and *S. officinalis)***,** squid *(Loligo* spp.*)***,** crab *(Portunus* spp.), bivalves (*Donax trunculus* and *Circe corrugata*), and small shrimps (*Metapenaeus stebbingi*, *M. longirostris,* and *Trachipenaeus curvirostris*). The unsorted fish species or those of lesser importance were grouped as "others".

Age determination

Fishery management plans rely on accurate age determinations; if age estimations are not validated, errors in age determination could result in inaccurate mortality estimates, underestimation of strong year classes, and longevity (Beamish and McFarlane, 1983). Age estimates of bony fishes are commonly based on enumeration of growth increments in calcified structures like sagittal otoliths (Beamish and McFarlane, 1987). Techniques to accurately estimate age are of critical importance for the determination of age related phenomena, such as growth rates and age-specific survival. Such age-specific information is essential to understand the demography and population dynamics of any species; it is also needed for the development of functional management plans. In the present study, sagittal otoliths were used to age *S. aegyptiaca* in the Port Said region. The otoliths of *S. aegyptiaca* (Figure 2) were relatively thin and translucent and all the rings were visible; thus all the otoliths immersed in water were used for reading. By examining the mounting otoliths, the focus appears as a dark point followed by alternating hyaline and opaque zones. Each hyaline and opaque zone together makes an annual ring. Several findings indicate that rings on sole otoliths were true annuli. These findings are as follows:

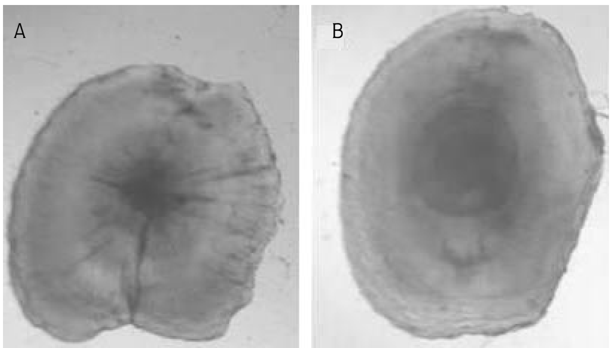

Figure 2. Otolith of *Solea aegyptiaca* (A: age group 1 and B: age group 2).

- Body length-otolith radius relationship (Figure 3) showed a strong correlation between the body length and otolith radius.
- The increase in fish size is accompanied by an increase in the number of annuli on the otolith. Thus, the otoliths of larger fish show more annuli than those of smaller ones.
- The presence of alternatively wide and close narrow spaced circuli, which represent rapid growth during the summer and slow growth during the winter.

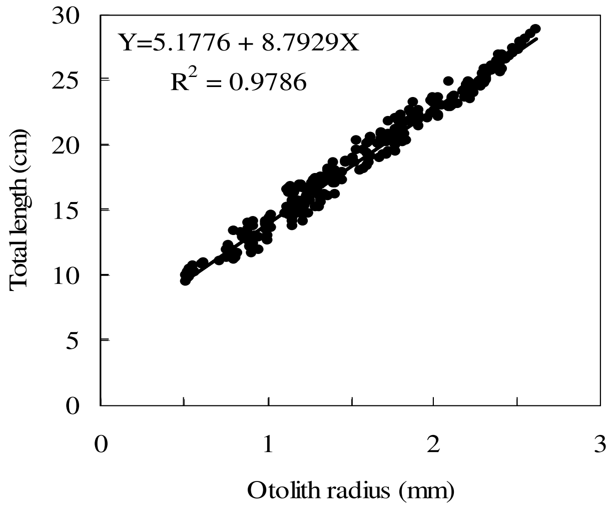

Figure 3. Total length-otolith radius of *Solea aegyptiaca* from Port Said.

- Samples collected during January and February have true annuli on the marginal region or close to it. Samples collected from March to the following January show variation in the marginal growth of the otolith. The marginal increment increases progressively from March to December, where the highest value was recorded.
- The close approximation between the observed and calculated lengths for any age group is additional evidence of the validity of the annulus as a true year mark.

Otolith readings of 640 specimens were analyzed to determine the age of *S. aegyptiaca* in the Port Said region and the maximum life span was found to be 4 years. The back-calculated lengths are given in Table 1. The only available work dealing with age determination of *S. aegyptiaca* was conducted by Ali (1995) along the Alexandria coast, who found the maximum lifespan as 3 years corresponding to the lengths of 15.66, 19.96, 23.61, and 26.1 cm for age groups 0, I, II, and III for females and 13.48, 16.36, 22.58, and 23.03 cm for males.

Length-Weight Relationship

Length and weight measurements of 640 specimens were used to describe the length-weight relationship of *S. aegyptiaca* (Figure 4). The total length varied from 9.5 to 28.9 cm, while the total weight ranged between 8.5 and 250 g. The obtained equation was

$$W = 0.0086\ L^{3.0054}\ (r^2 = 0.987 \text{ and } SE = 0.042)$$

Table 1. Back-calculated lengths (cm) at the end of each year of life for *Solea aegyptiaca* from Port Said.

Age (year)	Observed length	Back-calculated lengths (cm)			
		1	2	3	4
I	18.68	**17.75**			
II	23.94	17.66	**23.16**		
III	26.81	17.51	22.97	**26.35**	
IV	28.52	17.42	22.89	26.27	**28.22**
Increment		17.75	5.41	3.19	1.87
%		62.90	19.17	11.30	6.63

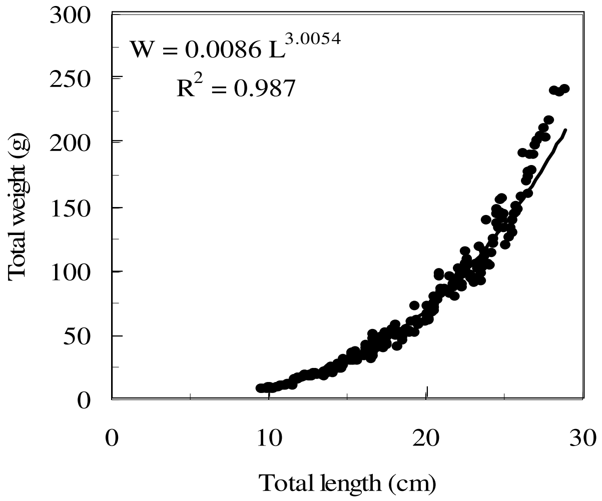

Figure 4. Length weight relationship of *Solea aegyptiaca* from Port Said.

Table 2. Calculated weights (g) at the end of each year of life for *Solea aegyptiaca* from Port Said.

Age (year)	Calculated weights (g)			
	1	2	3	4
I	**48.85**			
II	48.11	**108.66**		
III	46.89	106.01	**160.14**	
IV	46.17	104.90	158.69	**196.79**
Increment	48.85	59.81	51.48	36.65
%	24.82	30.39	26.16	18.62

Isometric growth was observed for *S. aegyptiaca* in Port Said (95% confidence interval for b was 2.9776-3.0836). The calculated weights by age groups are given in Table 2. The growth rate in weight was much slower during the first year of life. Then the annual growth increment in weight increased, reaching its maximum at the end of the second year of life, after which a decrease in the growth increment was observed. Therefore, the age at first capture should be around 2 years to achieve the maximum yield.

Growth parameters

The back-calculated lengths were applied according to Ford (1933) and Walford (1946) plot to estimate the von Bertalanffy growth parameters (L_∞ and K). The obtained equations were as follows:

For growth in length

$$L_t = 30.9\ (1 - e^{-0.53\ (t + 0.33)})$$

For growth in weight

$$W_t = 258.48\ (1 - e^{-0.53\ (t + 0.33)})^{3.0054}$$

Table 3 demonstrated the values of growth parameters obtained from the present study compared with those reported by other researchers for some related species. The difference in growth parameters

Table 3. Population parameters for some sole species from different localities.

Locality and species	K (year^{-1})	L_∞ (TL)	Ø*	M	Age (year)	Author
North Sea						De Veen, 1976
Solea solea	0.18	31.2	2.24			(1960)
	029	30.1	2.42			(1062)
	0.25	28.2	2.30			(1966)
Brittany						Deniel, 1990
Pegusa impar						
Male	0.56	27.0	2.61			
Female	0.55	29.1	2.67			
P. lascaris						
Male	0.45	25.5	2.47			
Female	0.38	28.7	2.50			
Lake Bardawil						El-Gammal et al., 1994
S. solea	0.33	30.04	2.47	0.21	6	
İzmir Bay						Hossucu et al., 1999
S. solea	0.28	34.7	2.53			
Tunis						Jarboui et al., 2001
S. aegyptiaca	0.116	38.8	2.24	0.22		
İskenderun Bay						Turkmen, 2003
S. solea				0.5	8	
Male	0.22	26.03	2.17			
Female	0.18	29.95	2.21			
Mediterranean (Port Said fishery)						The present study
S. aegyptiaca	0.53	30.9	2.7	0.75	4	

* Ø estimated by the present author

between different localities can be attributed to the difference in size-composition of the same species and to the differences among species.

Growth Performance Index (ø)

The growth performance index (ø) of *S. aegyptiaca* was computed as 2.7. This value is consistent with other estimates (Table 3).

Mortality and Exploitation Rates

The total (Figure 5), natural, and fishing mortality coefficients of *S. aegyptiaca* from Port Said fishery were 2.56, 0.75 and 1.81 year^{-1} respectively.

Exploitation rate "E" was computed as 0.71. Gulland (1971) suggested that the optimum exploitation rate for any exploited fish stock is about 0.5 at F_{opt} = M. Recently, Pauly (1987) proposed a lower optimum F that equals 0.4 M. In the present study, F was higher than the 2

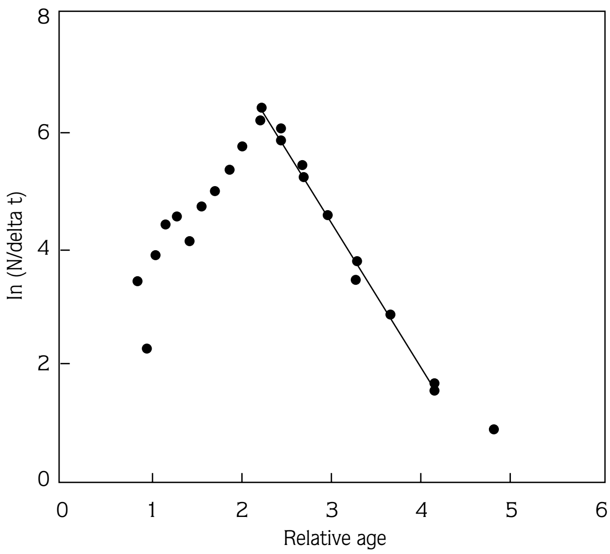

Figure 5. Z-estimation of *Solea aegyptiaca* from Port Said.

values of F_{opt} given by these authors, indicating that the stock of *S. aegyptiaca* in Port Said is being overexploited.

Length at first sexual maturity

Length at first sexual maturity (L_{50}) has a great importance in the determination of optimum mesh size. The L_{50} of *S. aegyptiaca* was estimated as 14.2 cm for males and 15.1 cm for females (Figure 6). The smallest length recorded in the catch was 9.5 cm, which is smaller than the L_{50}. This means that the exploited *S. aegyptiaca* must be protected in order for them to spawn at least once before being fished. Therefore, the mesh sizes used in Port Said should be increased to catch fish of lengths greater than 17 cm.

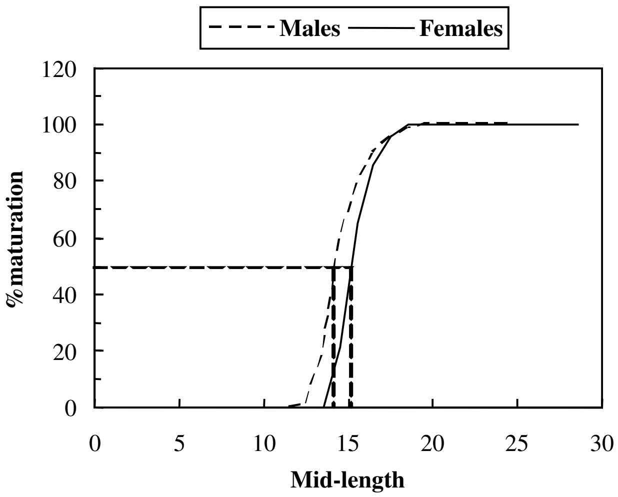

Figure 6. Length at first maturity for *Solea aegyptiaca* from Port Said.

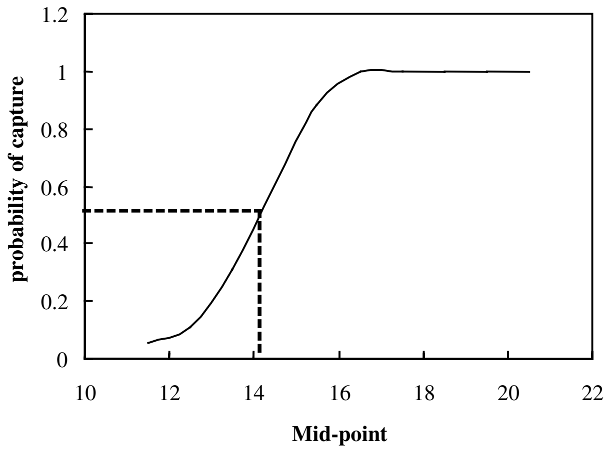

Figure 7. Length at first capture for *Solea aegyptiaca* from Port Said.

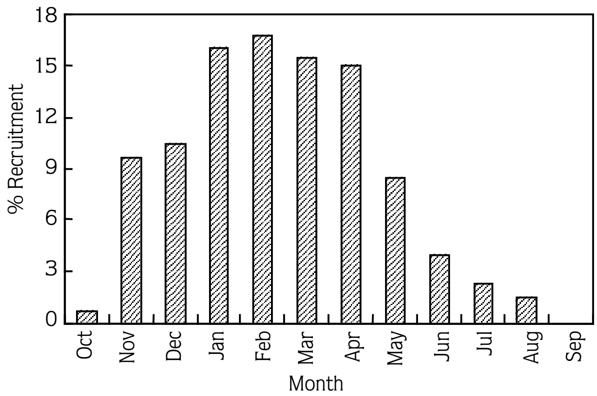

Figure 8. Recruitment pattern for *Solea aegyptiaca* from Port Said.

Length at first capture

The length at first capture (the length at which 50% of the fish at that size are vulnerable to capture) was estimated as a component of the length-converted catch curve analysis. The value obtained was 14.15 cm corresponding to an age of 0.82 year (Figure 7). The estimated L_c was less than the L_{50}, which was further evidence of over-fishing.

Recruitment pattern

The recruitment pattern of the stock of *S. aegyptiaca* from Port Said suggested that there is only one main pulse of annual recruitment (Figure 8). The recruitment extends from November to May with a peak in January and February. This is in agreement with that obtained for the same species in Abo Qir (El-Gharabawy, 1977), *S. solea* from West Alexandria (Zaki and Hamza, 1986), and *S. vulgaris* from the northwestern part of the Red Sea (Mosaad and El-Sayed, 1991b) based on gonadal examinations.

Per recruit analysis and reference points

The plot of relative yield per recruit Y'/R against the exploitation rate E (Figure 9) gives an optimum level of exploitation rate at E = 0.66. Both $E_{0.1}$ (the level of exploitation at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E) and $E_{0.5}$ (the exploitation level that will result in a reduction of the unexploited biomass by 50%) were estimated. The obtained values of $E_{0.1}$ and $E_{0.5}$ were 0.57 and 0.35, respectively. The present level

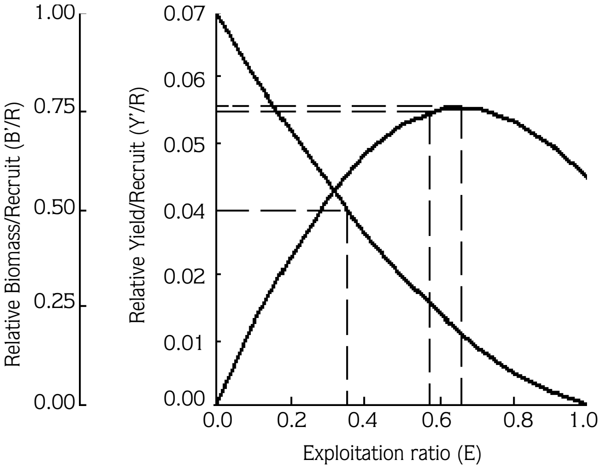

Figure 9. E_{max} as biological reference point and $E_{0.5}$ as target reference point for *Solea aegyptiaca* from Port Said.

of E (0.71) was higher than that that gives the maximum Y'/R. Moreover, the current exploitation rate is higher than the exploitation rate ($E_{0.5}$) that maintains the 50% of the stock biomass. For management purposes, the exploitation rate of *S. aegyptiaca* should be reduced from 0.71 to 0.35 (50.7%) to maintain a sufficient spawning biomass because the maximum Y'/R is not the target point but the maximum constant yield (the maximum constant catch that is estimated to be sustainable, with an acceptable level of risk, at all probable future levels of biomass) is the target reference point in fisheries assessment (Sissenwine, 1978; Smith et al., 1993; Caddy and Mahon, 1995; Sinclair et al., 1996). Furthermore, it is always safe to be on the left of the maximum Y'/R than to use its current value.

To determine the most appropriate length at first capture, which is related to the mesh size, the Y'/R was estimated using a different value of L_c (16 and 18 cm). The results (Figure 10) indicated that with an increasing L_c a higher Y'/R can be obtained. When L_c became 16 cm, the maximum Y'/R was obtained at E = 0.69 (current E = 0.71). The values obtained for $E_{0.1}$ and $E_{0.5}$ were 0.61 and 0.36, respectively. When L_c was 18 cm, the estimated values of E_{max}, $E_{0.1}$, and $E_{0.5}$ were 0.72, 0.62, and 0.37, respectively.

From the results mentioned above, all the features of the sole fishery point to the need for a conservative approach to management and we can say that the *S. aegyptiaca* stock in the Port Said fishery is overexploited. To maintain this valuable resource, the present level of exploitation should be reduced and the spawning stock and recruits should be safeguarded. If the direct reduction of the fishing efforts seems to be impossible for socio-economic reasons, we can reduce the duration of the fishing season by suggesting a closure period. Furthermore, increasing the length and age at first capture by increasing the mesh sizes will lead to an increase in annual catches.

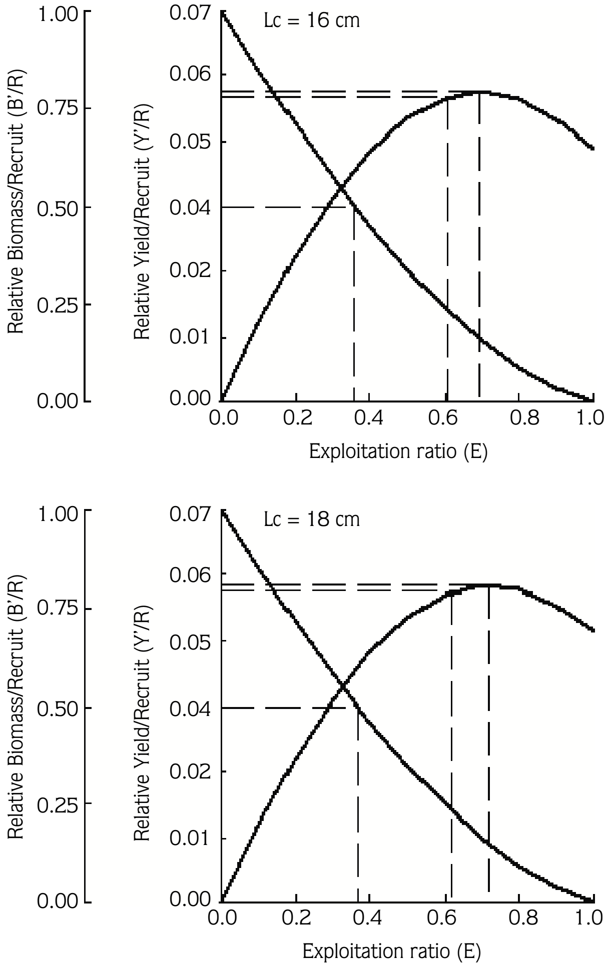

Figure 10. Y'/R and B'/R analysis for *Solea aegyptiaca* from Port Said with different values of L_c.

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