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

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**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), Demieta 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...

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
differently significant from 3.

The back-calculated lengths were used to estimate
the growth parameters of the von Bertalanffy growth
model L_t = L_∞ (1 - e^{-K (t - t_0)}) by fitting the Ford (1933)
and Walford (1946) plot, while "t_0" was estimated by the
equation t_0 = t + 1/K Ln (L_∞ - L_t / L_0).

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

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

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

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

(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/L_c)

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 Synodusaurus).

Invertebrates were represented by large shrimps
(Penaeus japonicus, P. semisulcatus, P. kerathurus, P.
canaliculatus, and M. monoceros), cuttlefish (Sepia
pharaonis, 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
curviostris). 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:

- 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.

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

\[ W = 0.0086 L^{3.0354} \]  

\( R^2 = 0.9876 \) and SE = 0.042
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.

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

<table>
<thead>
<tr>
<th>Age (year)</th>
<th>Observed length</th>
<th>Back-calculated lengths (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>18.68</td>
<td>17.75</td>
</tr>
<tr>
<td>II</td>
<td>23.94</td>
<td>17.66</td>
</tr>
<tr>
<td>III</td>
<td>26.81</td>
<td>17.51</td>
</tr>
<tr>
<td>IV</td>
<td>28.52</td>
<td>17.42</td>
</tr>
<tr>
<td>Increment</td>
<td>17.75</td>
<td>5.41</td>
</tr>
<tr>
<td>%</td>
<td>62.90</td>
<td>19.17</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Age (year)</th>
<th>Calculated weights (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>48.85</td>
</tr>
<tr>
<td>II</td>
<td>46.89</td>
</tr>
<tr>
<td>III</td>
<td>46.17</td>
</tr>
<tr>
<td>IV</td>
<td>48.85</td>
</tr>
<tr>
<td>Increment</td>
<td>48.85</td>
</tr>
<tr>
<td>%</td>
<td>24.82</td>
</tr>
</tbody>
</table>

**Growth parameters**

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

For growth in length

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

For growth in weight

$$W_t = 0.0086 L^{3.0054}$$

$$R^2 = 0.987$$

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
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 \( (\phi) \)**

The growth performance index \( (\phi) \) 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

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

<table>
<thead>
<tr>
<th>Locality and species</th>
<th>( K ) (year(^{-1}))</th>
<th>( L_\infty ) (TL)</th>
<th>( \phi^* )</th>
<th>( M ) (year)</th>
<th>( \text{Age} )</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Sea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Solea solea</em></td>
<td>0.18</td>
<td>31.2</td>
<td>2.24</td>
<td></td>
<td></td>
<td>De Veen, 1976</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td>30.1</td>
<td>2.42</td>
<td></td>
<td></td>
<td>(1960)</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>28.2</td>
<td>2.30</td>
<td></td>
<td></td>
<td>(1966)</td>
</tr>
<tr>
<td>Brittany</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pegusa impar</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.56</td>
<td>27.0</td>
<td>2.61</td>
<td></td>
<td></td>
<td>Deniel, 1990</td>
</tr>
<tr>
<td>Female</td>
<td>0.55</td>
<td>29.1</td>
<td>2.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>P. lascaris</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.45</td>
<td>25.5</td>
<td>2.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.38</td>
<td>28.7</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Bardawil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td>0.33</td>
<td>30.04</td>
<td>2.47</td>
<td>0.21</td>
<td>6</td>
<td>El-Gammal et al., 1994</td>
</tr>
<tr>
<td>Izmir Bay</td>
<td>0.28</td>
<td>34.7</td>
<td>2.53</td>
<td></td>
<td></td>
<td>Hossucu et al., 1999</td>
</tr>
<tr>
<td>Tunis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. aegyptiaca</em></td>
<td>0.116</td>
<td>38.8</td>
<td>2.24</td>
<td>0.22</td>
<td></td>
<td>Jarboui et al., 2001</td>
</tr>
<tr>
<td>Iskenderun Bay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tunis, 2003</td>
</tr>
<tr>
<td><em>S. solea</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.22</td>
<td>26.03</td>
<td>2.17</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.18</td>
<td>29.95</td>
<td>2.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mediterranean (Port Said fishery)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The present study</td>
</tr>
<tr>
<td><em>S. aegyptiaca</em></td>
<td>0.53</td>
<td>30.9</td>
<td>2.7</td>
<td>0.75</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

* \( \phi \) estimated by the present author
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.

**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
of E (0.71) was higher than that gives the maximum Y'/R. Moreover, the current exploitation rate is higher than the exploitation rate (E<sub>0.5</sub>) that maintains the 50% of the stock biomass. For management purposes, the exploitation rate of <i>S. aegyptiaca</i> 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 different values of L<sub>c</sub> (16 and 18 cm). The results (Figure 10) indicated that with an increasing L<sub>c</sub> a higher Y'/R can be obtained. When L<sub>c</sub> became 16 cm, the maximum Y'/R was obtained at E = 0.69 (current E = 0.71). The values obtained for E<sub>0.1</sub> and E<sub>0.5</sub> were 0.61 and 0.36, respectively. When L<sub>c</sub> was 18 cm, the estimated values of E<sub>max</sub>, E<sub>0.1</sub>, and E<sub>0.5</sub> 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 <i>S. aegyptiaca</i> 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.
References


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