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Population structure of two Octopus species, *Amphioctopus aegina* and *A. membranaceus* in the Gulf of Suez, Egypt.

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ABSTRACT

Ageing of *Amphioctopus. aegina* and *A. membranaceus* revealed three different age groups, and the main bulk of the catch was represented in the second age group for the two species. Von Bertalanffy growth constants were determined as; L_∞= 11.76 cm DML, K= 0.39 year^{-1}, t_0= 0.11 year^{-1} and Ø= 1.73 for *A. aegina*, and L_∞= 11.47 cm DML, K= 0.45 year^{-1}, t_0= 0.33 year^{-1} and Ø= 1.77 for *A. membranaceus*. The total mortality (Z), natural mortality (M), fishing mortality (F) and exploitation rate (E) were calculated as 2.87, 1.17, 1.70 and 0.59 year^{-1}, respectively for *A. aegina*, and 2.70, 1.29, 1.41 and 0.52 year^{-1}, respectively for *A. membranaceus*. The length at recruitment (L_r) of *A. aegina* and *A. membranaceus* was 1.9 and 2.4 cm DML, that corresponding to age (t_r) of 0.56 and 0.85 year, respectively. Length at first capture (L_c) was 6.28 and 4.05 cm DML for *A. aegina* and *A. membranaceus*, respectively, and the age at the first capture (t_c) was 2.07 and 1.46 years, respectively. This study is very important for fisheries management in the Gulf of Suez, where, some recommendations to reduce the exploitation rates for the two Octopus species in the Gulf were proposed.

INTRODUCTION

The Gulf of Suez (Fig. 1) is characterized by the presence of a great diversity of highly economic fish and invertebrate species **(Sanders & Morgan, 1989)**. Also, annual mean range of water temperature and salinity was 23.69–25.11^{o}C and 40.89–41.55%, respectively **(Khedr *et al.*, 2019)**.

The increasing exploitation of finfish resources and the depletion of a number of major fish stocks that formerly supported industrial-scale fisheries, forces continued attention to the once-called 'unconventional marine resources', which include numerous species of cephalopods **(Jereb & Roper, 2010)**. Among the commercial cephalopod catches in the Gulf of Suez are the Octopus species, which are caught mainly as bycatch of the bottom trawl fisheries. Octopuses are relatively abundant in the trawl landings of the Gulf of Suez; they were discarded species till 1990's **(El Ganainy *et al.*, 2005)**, but currently they have a relatively high occurrence and commercial importance in the trawl landings, representing about 0.07% of the total trawl catch **(GAFRD, 2018)**.

Recent studies have shown that coastal and shelf cephalopod populations have increased globally over the last six decades. Although cephalopod landings are dominated by the squid fishery, which represents nearly 80% of the worldwide cephalopod catches, Octopuses and Cuttlefishes represent ~10% each. Total reported global production of Octopuses over the past three decades indicates a relatively steady increase in catch, almost doubling from 179,042 ton in 1980 to 355,239 ton in 2014 **(Sauer *et al.*, 2019)**. Global cephalopod catches have increased steadily in the last 45 years, from about 1 million metric tons in 1970 to more than 4 million metric tons in 2016 **(FAO, 2018)**.

Few studies have been done on the Octopus species in the Gulf of Suez **(Riad & Gabr, 2007; Riad, 2008; El Ganainy & Riad, 2008; Osman, 2013; Osman *et al.*, 2014)**. Little attentions have been recorded on the population structure (age, growth and mortality). So, the current work aims to examine some population stock parameters to estimate the exploitation status of *A. aegina* and *A. membranaceus* in the Gulf of Suez in order to assess their status and to provide the basic information required for their proper management.

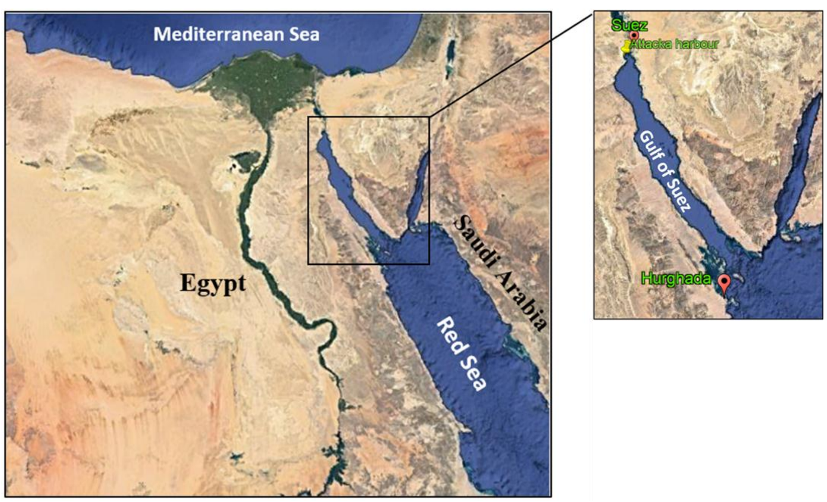

Fig. 1. Map of Suez Gulf showing the position of Attaka fishing harbor.

MATERIALS AND METHODS

During the fishing season (September 2017 - April 2018), monthly sampling (833 as a total individuals, 450 of *A. aegina* and 383 of *A. membranaceus*) was collected from the commercial fishing trawlers at Attaka harbor (Fig. 1). All measurements were measured to the nearest 0.1 cm in length and 0.1 gm in weight. The mantle length (ML) data obtained were grouped into mantle length classes at 0.5 cm intervals and subsequently the frequency of each class was determined.

The length frequency distribution were analysed using routines in FAO-ICLARM Stock Assessment Tools (FISAT) II software package **(Gayanilo *et al.*, 2005)**. In order to identify the different age groups (cohorts) and the mean length of each group, Battacharya's method **(Bhattacharya, 1967)** incorporated in the FISAT II software was applied. This method was developed for splitting of the composition distribution into its individual normal distribution. The analysis infers that each normal distribution represents one cohort (age group). This method is based on the logarithmic differences of the length class intervals. The separation index is explained as follows, a measure of separation of two adjacent normal distributions in standard deviation units (deviation from mean divided by standard deviation) **(Sparre & Venema, 1992)**. According to investigations by **Hasselblad (1966)**, the estimation of parameters of studied normal distributions is extremely difficult when the means are separated by less than 2.0 standard deviation units.

The growth parameters were assessed in terms of the **von Bertalanffy (1938)** equation:

$$L_t = L_\infty(1-e^{-K\,(t-to)})$$

Where, L_t is the mean of length at age t, L_∞ is asymptotic length, K is the growth coefficient and t_0 is the age at which the length is theoretically equals zero.

The three parameters (L_∞, K and t_0) need to be fitted by nonlinear regression. First **Powell-Wetherall (1986)** method as modified by **Pauly (1986)**, that is incorporated in the FISAT II software was employed in the estimation of the asymptotic length (L_∞) of the von Bertalanffy growth function (VBGF).

The estimated K and L_∞ were used in the calculation of t_0 using the following equation:

$$t_0 = t+(1/K)[\ln(1-L_t/L_\infty)]$$ **(Ricker, 1975)**

The growth performance index (Ø) was computed according to the equation of **Pauly & Munro (1984)** as follows:

$$Ø = \mathrm{Log}K+2\mathrm{Log}L_\infty$$

Where, Ø is Phi-prime, i.e. a length-based index of growth performance.

The total mortality (Z) was estimated by applying the length converted catch curve of **Pauly (1983)** method incorporated in FISAT (II) software **(Gayanilo *et al.*, 2005)**. While the natural mortality (M) was estimated as a mean annual temperature recorded (an increase in water temperature will lead to the increase in natural mortality). The fishing mortality (F) was determined as follow:

$$F = Z - M$$ **(Pauly, 1984)**

The exploitation rate (E) is the death of animal expected due to fishing. It can be estimated according to **Sparre & Venema (1992)** as follow:

$$E = F / Z$$

The length at recruitment (L_r) was determined as the smallest animal in the catch, while the corresponding age at recruitment (t_r) was calculated by the conversion of L_r using the following version of the **Beverton & Holt (1957)** formula:

$$t_r = t_0 - (1/K*\ln[1-(L_r/L_\infty)])$$

The length at first capture (L_c) was evaluated by the analysis of catch curve using the model of **Pauly (1984)**, while the corresponding age at first capture (t_c) was calculated by converting L_c to age using the von Bertalanffy growth equation:

$$t_c = t_0 - (1/K*\ln[1-(L_c/L_\infty)])$$

RESULTS

Age determination

Using the modal progression method, Bhattacharya’s analysis allowed the separation of three different cohorts in the population of *A. aegina* and *A. membranaceus* collected from the Gulf of Suez during the period from September 2017 till April 2018 (separation index “S.I.” > 2). The mean lengths of these cohorts were; 3.48 and 3.49 cm (the first age group), 6.18 and 6.40 cm (the second age group) and, 8.00 and 8.25 cm (the third age group) DML for *A. aegina* and *A. membranaceus*, respectively. The main bulk of the catch was represented in the second age group for the two species (Tables 1, 2 and Figures 2, 3).

Table (1): Computed mean length (cm), standard deviation (SD), No. of individuals (N) and separation index (SI) of each age group using Bhattacharya’s method for population of *A. aegina* from the Gulf of Suez during 2017/2018.

Age groups	Computed mean length (cm)	S.D.	N.	S.I.
I	3.48	0.630	96.90	n.a
II	6.18	0.740	727.77	2.650
III	8.00	0.620	80.22	2.130

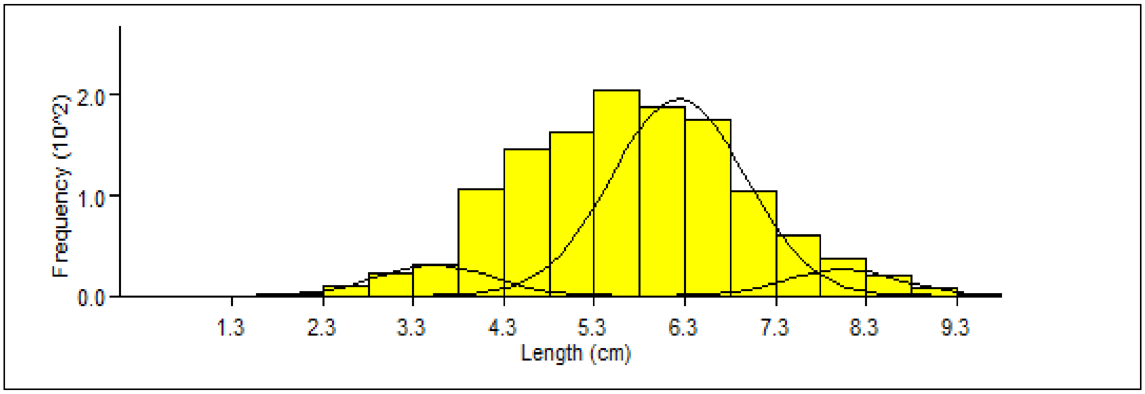

Figure (2): Age groups determination by length frequency distribution for the population of *A. aegina* from the Gulf of Suez during 2017/2018.

Table (2): Computed mean length (cm), standard deviation (SD), No. of individuals (N) and separation index (SI) of each age group using Bhattacharya's method for population of *A. membranaceus* from the Gulf of Suez during 2017/2018.

Age groups	Computed mean length (cm)	S.D.	N.	S.I.
I	3.49	0.570	143.34	n.a
II	6.40	0.700	457.58	2.800
III	8.25	0.480	7.60	2.190

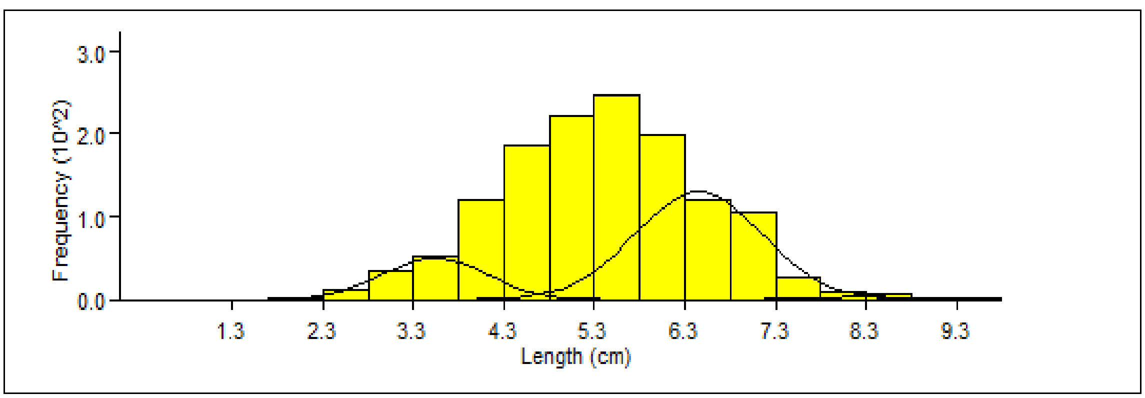

Figure (3): Age groups determination by length frequency distribution for the population of *A. membranaceus* from the Gulf of Suez during 2017/2018.

Determination of growth parameters (L_∞, K and t_0)

A prime estimate of the von bertalanffy growth parameters (L_∞ and K) was obtained by applying **Powell-Wetherall (1986)** method. The length frequency samples of *A. aegina* and *A. membranaceus*, were pooled and used as input parameters in the FISAT software **(Gayanilo *et al.*, 2005)** for the estimation of L_∞ and Z/K using the Wetherall plots. The used cut-off lengths were 6.3 and 8.4 cm for *A. aegina* and *A. membranaceus* respectively. The data corresponding to class-mid length of 6.3 and 8.4 cm onwards were only used in the regression, as they represent the fully recruited part to the fishery (Figures 4 & 5). The alignment of the points on the straight line was quite satisfactory with very high coefficient of correlation (r^2 = 0.99) for *A. aegina* and (r^2 = 0.87) for *A. membranaceus*. The following estimates were obtained L_∞ = 10.73 and 10.46 cm DML, and Z/K = 4.474 and 5.136 for *A. aegina* and *A. membranaceus*, respectively.

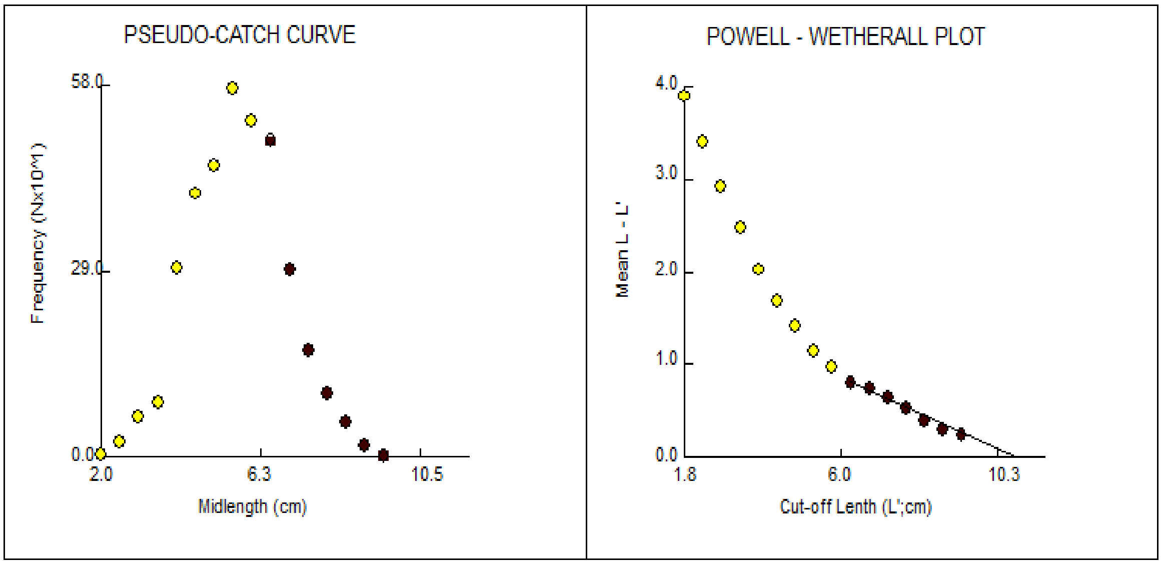

Figure (4): Initial estimation of L_∞ and Z/K using Powell–Wertherall plot for *A. aegina* from the Gulf of Suez during 2017/2018.

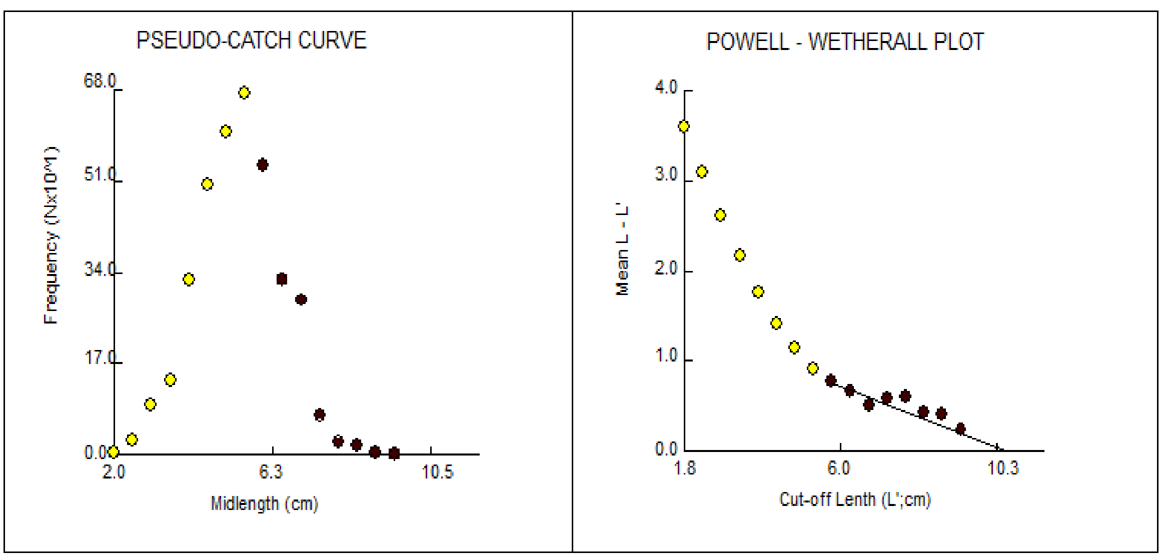

Figure (5): Initial estimation of L_∞ and Z/K using Powell–Wertherall plot for *A. membranaceus* from the Gulf of Suez during 2017/2018.

The von Bertalanffy growth model parameters (L_∞, K and t_0) were calculated by three methods **(Ford, 1933 - Walford, 1946; Gulland & Holt, 1959; Chapman, 1961)** for *A. aegina* and *A. membranaceus* and the results were illustrated in Tables (3 & 4).

Table (3): The parameters of von Bertalanffy growth model of *A. aegina* from the Gulf of Suez during 2017/2018.

Content	Ford-Walford	Gulland	Chapman
L_∞	11.76	11.76	11.76
K	0.39	0.38	0.39
t_0	0.11	0.07	0.11

Table (4): The parameters of von Bertalanffy growth model of *A. membranaceus* from the Gulf of Suez during 2017/2018.

Content	Ford-Walford	Gulland	Chapman
L_∞	11.47	11.48	11.47
K	0.45	0.44	0.45
t_0	0.33	0.29	0.33

Estimation of growth performance index (Ø)

The growth performance index was calculated using the parameters of von Bertalanffy growth equation; L_∞= 11.76 cm DML, and K= 0.39 year^{-1} for *A. aegina*, also, L_∞= 11.47 cm DML, and K= 0.45 year^{-1} for *A. membranaceus*. The obtained results are:

$Ø = \text{Log}_{10}\ 0.39 + 2\ \text{Log}_{10}\ 11.76$ Ø = 1.73 For *A. aegina*

$Ø = \text{Log}_{10}\ 0.45 + 2\ \text{Log}_{10}\ 11.47$ Ø = 1.77 For *A. membranaceus*

Mortalities

The total mortality coefficient (Z) was estimated as in Figures (6 & 7) which indicated that "Z" of *A. aegina* and *A. membranaceus* was 2.87 and 2.70 year^{-1} respectively. While the natural mortality coefficient (M) was calculated as a mean annual temperature of 24°C, and the estimated values were M = 1.17 and 1.29 year^{-1} for *A. aegina* and *A. membranaceus*, respectively.

When adopting the estimated values of the total and natural mortality coefficients, it follows that the instantaneous fishing mortality coefficient "F" is 1.70 and 1.41 year^{-1} for *A. aegina* and *A. membranaceus*, respectively. Using the obtained results of total and fishing mortality coefficients, it lead to the following exploitation rate: E = 0.59 and 0.52 year^{-1} for *A. aegina* and *A. membranaceus*, respectively.

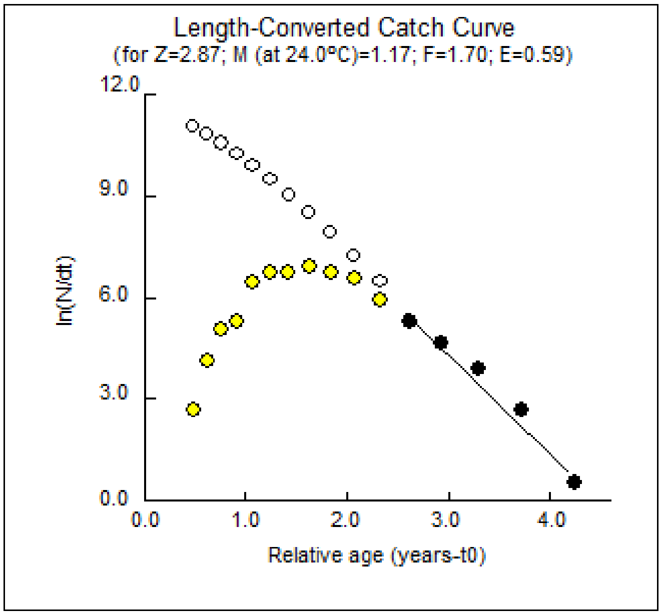

Figure (6): Length converted catch curve showed total mortality (Z), fishing mortality (F), natural mortality (M) and Exploitation rate (E) of *A. aegina*.

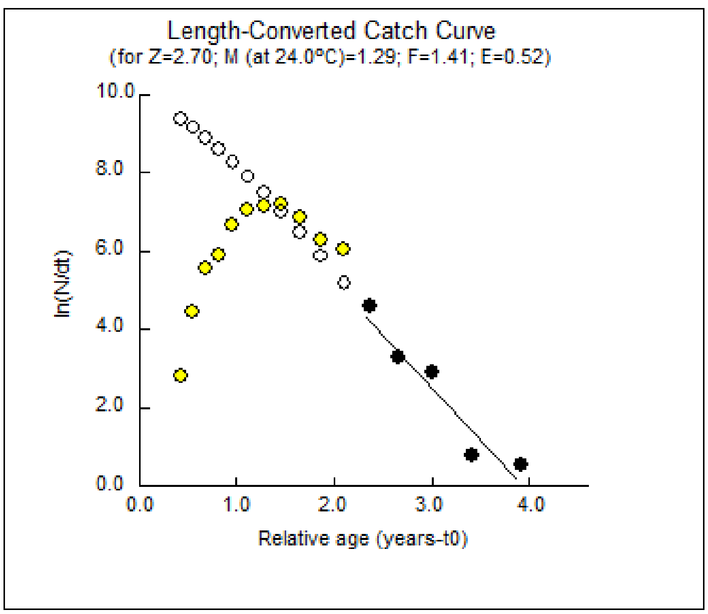

Figure (7): Length converted catch curve showed total mortality (Z), fishing mortality (F), natural mortality (M) and Exploitation rate (E) of *A. membranaceus*.

Length and age at recruitment (L_r & t_r)

Length at recruitment (L_r) of *A. aegina* and *A. membranaceus* was 1.9 and 2.4 cm DML, that corresponding to age (t_r) of 0.56 and 0.85 year, respectively.

Length and age at first capture (L_c & t_c)

For *A. aegina*, the probability of capture is given in Figure (8), where 25% of the population were caught at 5.67 cm, 50% at 6.28 cm (the length at first capture, L_c) and 75% at 6.90 cm DML. For *A. membranaceus*, the probability of capture is given in Figure (9), where 25% of all Octopuses were caught at 3.78 cm, 50% at 4.05 cm (the length at first capture, L_c) and 75% at 4.31 cm DML.

The age at the first capture (t_c) of *A. aegina* was found to be 2.07 years, while the t_c of *A. membranaceus* was found to be 1.46 years.

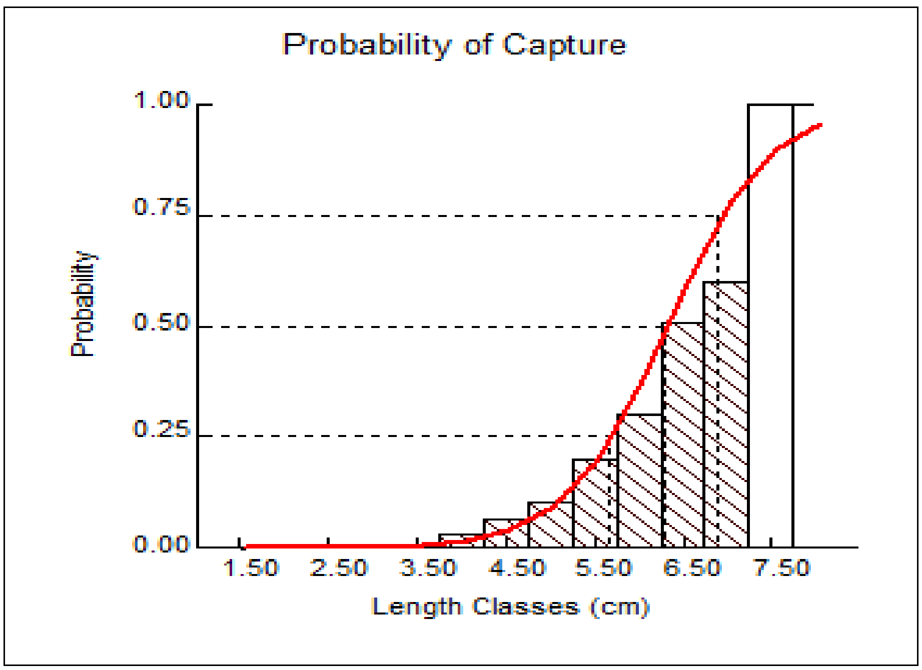

Figure (8): Analysis of probability of capture and L_c value for *A. aegina* from the Gulf of Suez.

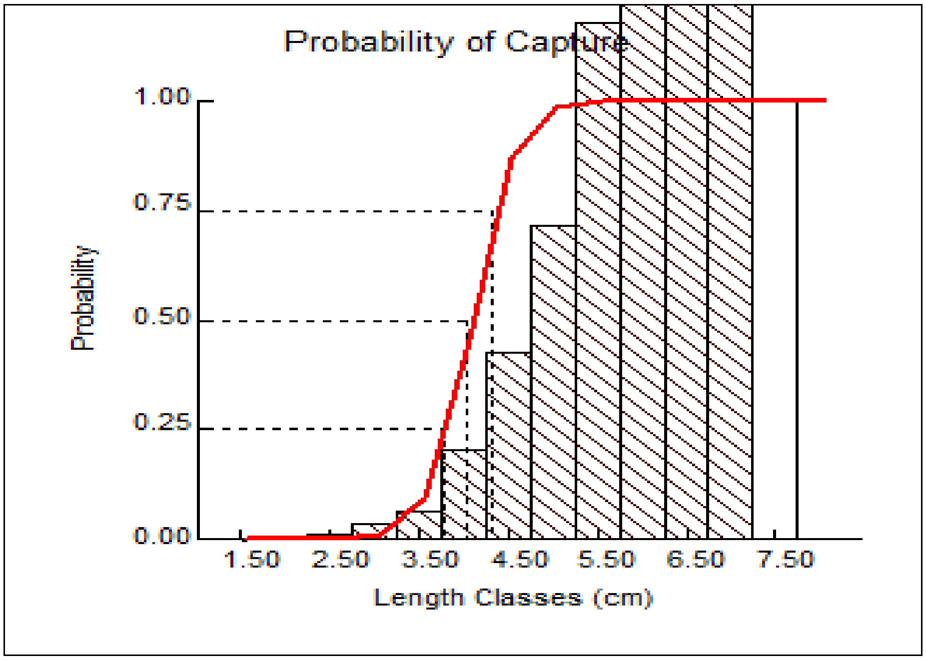

Figure (9): Analysis of probability of capture and L_c value for *A. membranaceus* from the Gulf of Suez.

DISCUSSION

The age groups of *A. aegina* and *A. membranaceus* were in agreement with **Ignatius *et al.* (2011)** who studied the age and growth of *Octopus aegina* from Mandapam Coastal Waters (Palk bay), Southeast Coast of India, and concluded the growth data obtained of *O. aegina* have a life span of about 3 years. But in India the growth was faster and the maximum recorded length was higher and they have grown up to 7.45 and 9.34 cm (ML) after first and second year, respectively. Other authors discussed the age and growth of another species. **El Ganainy & Riad (2008)** identified that two cohorts for males with mean lengths of 5.0 and 6.1 cm of *Octopus defilippi* from the Gulf of Suez. For females three cohorts could be separated with mean lengths of 5.53, 6.88 and 7.45 cm. The evolution of the population structure examined suggests a lifespan of about 2 years and a maximum age of about 3 years for combined sexes. While, **Hernandez-Lopez *et al.* (2001)** estimated a lifespan of 12-13 months for *O. vulgaris* in the Canary Island waters, by counting the number of concentric rings on the upper beaks of 275 Octopuses. **Katsanevakis & Verriopoulos (2006)** stated that the lifespan of the common Octopus *O. vulgaris* in the eastern Mediterranean would be between 12 and 15 months.

The L_∞ which indicates the maximum theoretical length of an animal under a given rate of growth was estimated at 11.76 and 11.47 cm DML of *A. aegina* and *A. membranaceus*, respectively. The maximum observed dorsal mantle length (DML_{max}) was 9.9 cm for *A. aegina* and 8.6 cm for *A. membranaceus*, which is near to the estimated value for L_∞. The K value of an animal reflects its growth rate and it's was 0.39 and 0.45 for *A. aegina* and *A. membranaceus*, respectively; also, the growth performance index (Ø) was calculated at 1.73 and 1.77 of *A. aegina* and *A. membranaceus*, respectively. These results are similar with **El Ganainy & Riad (2008)** that estimated von Bertalanffy growth parameters of L_∞, K and Ø at 9 cm, 0.94 and 1.88, respectively of *Octopus defilippi* in the Gulf of Suez. L_∞ and Z/K values were relatively in agreement with **Ignatius *et al.* (2011)**. They applied the data of *Octopus aegina* from Mandapam Coastal Waters (Palk bay), Southeast Coast of India, in Powell Wetherall plot and the initial estimate of growth parameter L_∞ obtained was 11.020 cm and Z/K as 5.49. Also, he estimated the L_∞ at 10.0 cm and K at 1.366.

The mortality rates estimated in this study is comparable with those estimated by **El Ganainy & Riad (2008)** who stated that, Z = 3.34 from Jones & van Zalinge plot, M = 1.43 and F = 1.91 of *O. defilippi* from the Gulf of Suez. The results is lower than that reported for *O. aegina* from Mandapam Coastal Waters (Palk bay), Southeast Coast of India, by **Ignatius *et al.* (2011)**. They estimated Z = 5.68 from length converted catch. M = 3.02 and F = 2.66. While it was much lower than that reported by **Arreguin-Sanchez *et al.* (2000)** where Z from the catch curve was 8.77 and for the Jones & van Zalinge methods was 6.6, and M = 2.2 for *O. maya* in the Campeche Bank, Gulf of Mexico. F rates of *A. aegina* and *A. membranaceus* were larger than the rates of M. This indicated that the mortality in the Gulf of Suez largely was caused by fishing activities, and this was the same results that reported by **El Ganainy & Riad (2008)** for *O. defilippi* in the Gulf of Suez. Moreover, low M rate and high F may indicate the occurrence of overfishing, in which more young fish were caught than old fish **(Sparre & Venema, 1998)**.

In the present study, the exploitation rate (E) of *A. aegina* and *A. membranaceus* were in agreement with **El Ganainy & Riad (2008)** who illustrated that, E = 0.57 $year^{-1}$ for *O. defilippi* in the Gulf of Suez. Also, **Arreguin-Sanchez *et al.* (2000)** estimated E was 0.75 $year^{-1}$ of *O. maya* in the Campeche Bank, Gulf of Mexico. While, **Ignatius *et al.* (2011)** evaluated E for *O. aegina* and showed that is available for exploitation in the shallow coastal areas and adjacent deeper waters from Mandapam Coastal Waters (Palk bay), Southeast Coast of India, where, E was 0.47 $year^{-1}$.

It must be noted that F and E are fishery dependent parameters and they are functions of the fishery characteristics, in particular the exerted fishing effort and the mesh size of the fishing gears applied in each case . Thus, each estimate depends on the mesh size and fishing effort used in the particular fishery **(El Ganainy & Yassien, 2012)**. The Octopus species were discarded species till 1990's **(El Ganainy *et al.*, 2005)**, but at the last years they have a relatively high abundance and commercial importance, so, changed from non-commercial to commercial species and start to record as a target species in the Gulf of Suez.

Gulland (1971) suggested that the optimum exploitation rate for any exploited fish stock is about 0.5, at F_{opt}= M, while **Pauly (1987)** proposed a lower optimum F that equals to 0.4 M. In the present study, F was higher than the F_{opt} given by both **Gulland (1971)** and **Pauly (1987)** for *A. aegina* and *A. membranaceus*, indicating that the stock of these species in the Gulf of Suez is exposed to high fishing pressure and overexploitation (> 0.5).

The length at first capture (L_c) is defined as the length at which the fish is vulnerable to fishing **(Pauly, 1984)**. This parameter along with the length at first sexual maturity (L_m), as well as their corresponding ages, consider as indicators for stock status. L_c was estimated at 6.28 and 4.05 cm DML for *A. aegina* and *A. membranaceus*, respectively. In this study, L_c of *A. aegina* was considerably smaller compared with **(Ahmed *et al.*, 2023)** recorded L_m 6.4 and 7.0 cm DML for males and females, respectively. But, L_c of *A. membranaceus* was considerably similar with **(Ahmed *et al.*, 2023)** recorded L_m 3.7 and 3.9 cm DML for males and females, respectively. This means that, the present L_c were not the optimum L_c for *A. aegina*, it must be raised to be around 8 cm DML, in order to give a chance for the species to spawn at least once in its spawning activity or during its life span, this can be achieved by controlling gear characteristics that targeting Octopuses in the Gulf of Suez. Also, L_c for *A. membranaceus*, it prefers raised to be around 5 cm DML. These results are more or less similar with that of **El Ganainy & Riad (2008)**, they illustrated that L_c = 4.2 cm is smaller than L_m = 6.0 cm for combined sexes of *Octopus defilippi* from the Gulf of Suez. Also, they mentioned that L_c for this population should be increased to obtain the maximum possible yield and to maintain the sustainability of the species.

The results of current study are important as they support the contention that Octopus species have a low resilience to exploitation and their populations may be particularly vulnerable to overfishing. So, reducing the exploitation rate can be done through output control management, such as determination of total allowable catch, as well as input control management, such as reduce the fishing effort to maintain the sustainability of the stock. Efforts should be more intensive to control the size of *A. aegina* and *A. membranaceus* captured and the number of fishing fleets allowed to catch it in the Gulf of Suez. Uncontrolled exploitation can lead to structural changes in the Octopus stock, and therefore, reduction of Octopus biomass. Also, the small size protection of Octopus is might the key factor for the sustainability of *A. aegina* and *A. membranaceus* resources.

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