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Original Article

Population structure of the European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758) in Lake Manzala, Egypt

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Abstract: The present study is to identify the population and stock characteristics of *Engraulis encrasicolus* in the Mediterranean lagoon "Lake Manzala" of Egypt. A total of 1536 specimens were collected seasonally by a local trammel net (El-Balla), from 2019 to 2021. The length ranged from 4.2 to 12.1 cm, where the dominance was of medium sizes. Two age groups were observed with a short longevity (t_{max} = 3.16 y). Parameters of Von Bertalanffy, L_∞, and K, were estimated as 12.52 cm and 0.95 y^{-1}, respectively. The growth performance index (Ø) was estimated as 2.17, expressing liner growth and environmental suitability. The calculated length at first maturity (L_m) = 8.1 cm, compared to 6.9 cm of length at first capture (L_c), expressing high fishing effort. Mortality indices include: total mortality (Z) = 3.71 y^{-1}, and natural mortality (M) = 1.46 y^{-1}. According to biological reference points, F_{opt} = 0.73 y^{-1} and F_{limit} = 0.97 y^{-1}, the fishing mortality (F = 2.25 y^{-1}) indicated overfishing of the anchovy stock in Lake Manzala. The current exploitation rate, E = 0.61 expressed the occurrence of overexploitation. Based on the results, reducing fishing efforts is vital to maintaining stock stability.

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Introduction

The European anchovy, *Engraulis encrasicolus*, is a small pelagic species that is a staple of the pelagic marine ecosystem, being the main prey for many other species and playing a major role in the marine food chain (Palomera et al., 2007). European anchovy belongs to the family Engraulidae, which endemic along the coasts of the eastern Atlantic and the Mediterranean Sea (Whitehead et al., 1988). It is characterized by a rapid growth rate and a short life, as it reaches a length of 15 cm and may reach 20 cm in the Northeast of the Atlantic Ocean during three lifespans (FAO, 1988). The global capture of Anchovies exceeds 6.2 million MT, including 533 thousand MT of European anchovy (FAO, 2018). There is an increasing demand for anchovies, whether canned or salted, which have high nutritional and economic value, especially in the Mediterranean countries (Palomera et al., 2007; Giannoulaki et al., 2008). In Egypt, the annual capture (anchovy and small sizes of *Sardinella* spp.) was about 8216 MT (GAFRD, 2020); where there are many local factories for salting, canning, and fish feeding raw materials (fish oil and fish meal).

Lake Manzala is one of Egypt's northern lakes, located east of the Nile Delta with a total area of 120 thousand acres and sprawling borders that penetrate three governorates (Damietta, Dakahlia, and Port Said). It is classified as a wetland with a depth of 0.7-1.5 m (Barakat et al., 2012). The lake receives about 7,500 million cubic meters annually of wastewater from 5 drains, extending along the southern and southwestern edges (Ayache et al., 2009). The lake was subject to a massive development plan under presidential directives that had a profound impact on improving the aquatic environment and fish production. The impact extended to the fish diversity and the existence of marine species. Anchovy is a flourishing species that settled recently in the northern sector of Lake Manzala, although they are caught as bycatch and sold fresh to feed farmed marine species (*Argyrosomus regius* and *Sparus aurata*). There were

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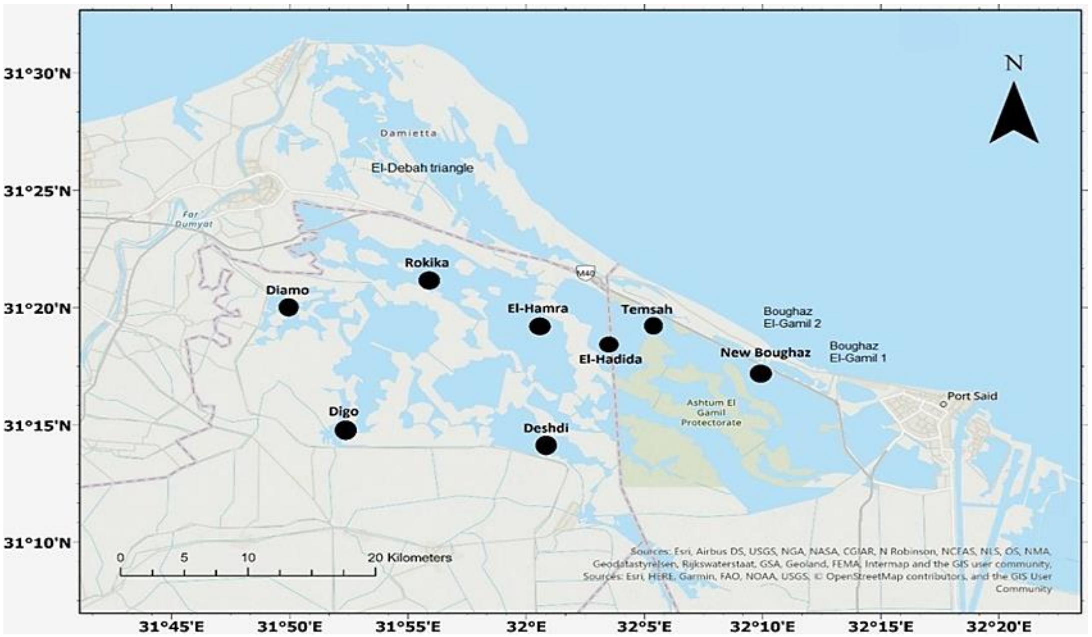

Figure 1. Map shows sampling sites in Lake Manzala on the Mediterranean coast of Egypt.

few studies conducted on this species in Egypt (Sharaf et al., 2009; El-Beltagy et al., 2022) except in Lake Manzala, where anchovy has not been studied before. Hence, the current study took precedence in identifying the population characteristics of European anchovy in Lake Manzala, providing the basic data for the development and optimal management of its catch.

Materials and Methods

Study area: Lake Manzala is characterized by the dense presence of fish farms along the shores of the Lake, as well as in the northern sector in the El-Dibeh triangle area. Marine water sources in the lake were derived from the north; Boughaz Al-Gamil 1 and Al-Gamil 2; and wastewater from the south and southwest drains. There are two sources of Nile water, Ananiya, and Rutma channels, from the west and northwest, respectively (Beheary et al., 2019; Al-Agroudy and Elmorsi, 2022). Samples were collected from different sites of the lake (Fig. 1).

Sampling: Sampling of European anchovy (Fig. 2) was carried out seasonally from different sites, where 1536 individuals were collected using El-Balla, a local type of trammel net, from 2019 to 2021. Length was measured to the nearest 0.1 cm and weighed to the nearest 0.1 g.

Data analysis

Figure 2. European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758).

Age and growth: The length frequency distributions were determined at 1.0 cm length intervals. Bhattacharya (1967) method was applied to the pooled size distributions to identify the different cohorts and split the length distributions into normal components. The parameters of the Von Bertalanffy growth equation L_∞ and k were estimated by applying the method of Wetherall (1986). The resultant growth estimates were then used as seed values in the ELEFAN I program (Pauly, 1984) for the estimation of the best combination of L_∞ and k. The growth in length equation of Von Bertalanffy was: $L_t = L_\infty [1- e^{-k (t - to)}]$, where L_t is the total length at age t, L_∞ is the asymptotic length, K is the growth coefficient, and t_0 is the hypothetical age at zero length. The longevity (t_{max}) was calculated according to Pauly (1980) using the formula of t_{max}= 3/K, where K is the growth coefficient. The growth performance index (Ø) was

Table 1. Mean length at age estimated from length frequency distribution (Bhattacharya, 1967).

Age group	Mean (L)	Population	Frequency	S.D.	S.I.
I	7.45	1193	77.7	1.12	n.a
II	9.63	343	22.3	0.86	1.93

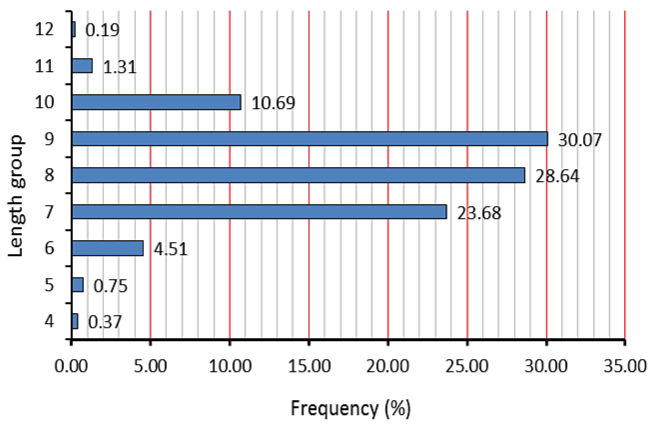

Figure 3. Length frequency distribution of *Engraulis encrasicolus* from Lake Manzala.

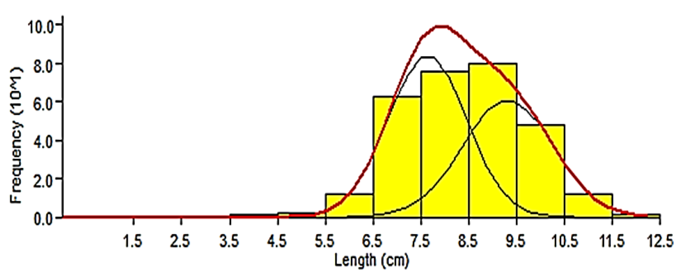

Figure 4. Bhattacharya plot for the decomposition of the length frequency distribution of *Engraulis encrasicolus* from Lake Manzala.

calculated according to Pauly (1983) as follows: Ø =log K + 2*log L_∞, where L_∞ is the asymptotic length and K is the growth coefficient.

Population structure: The instantaneous rate of total mortality (Z) was estimated by the length-converted catch curve method described by Pauly (1983). The natural mortality rate (M) was estimated after King (1995) method using the formula of M = –ln [0.01] / t_{max}, where t_{max} is the time required for a fish to reach 95% of the species $L\infty$, or the maximum age. The instantaneous rate of fishing mortality (F) was extracted from the formula of F = Z-M (Pauly, 1983).

Length at first sexual maturity (L_m) was calculated according to Froese and Binohlan (2000) as follows: Log L_m= 0.8979*Log L_∞ - 0.0782. The selectivity curve was generated by fitting a logistic function to the plot of the probability of capture against size, from which values of the parameters L_{50} (L_c), L_{75}, and the size at which fish were fully recruited to the fishery (L_{100}) were obtained using FiSAT program (Gayanilo et al., 1995).

The effect of fishing was explained using the relative yield per recruit model (Beverton and Holt, 1957, 1966). The biological reference point, fishing mortality rate with the target (F_{opt}), and fishing mortality limit (F_{limit}) were calculated using the two formulas described by Patterson (1992), as follows: F_{opt} = 0.5 M and F_{limit} = 2 / 3 M.

The length that generates optimum yield per recruit (L_{opt}) was estimated according to Beverton (1992), as follows: $L_{opt} = L_\infty * [3 / (3 + M/K)]$.

The exploitation ratio (E) was calculated as equal to the fraction of death caused by fishing, as follows: E = F/Z (Gulland, 1971). The optimum exploitation ratio (E_{opt}) was calculated according to Gulland (1971). The maximum exploitation rate (E_{max}) associated with the relative maximum yield per recruit was estimated, along with $E_{0.1}$, the rate at which the marginal increase of Y/R is 1/10 of its value at E = 0.

Results

Length frequency distribution: According to length, the frequency distribution of European anchovy in Lake Manzala was obtained (Fig. 3). The range of 4.2-12.1 cm was observed for the catch of European anchovy, where medium sizes were dominant. Length groups 9, 8, and 7 represented 30.07, 28.64, and 23.68% of the population, respectively.

Age and growth: The population of *E. encrasicolus* in Lake Manzala consisted of 2 age groups; I^+ and II^+; which shared 77.7 and 22.3% of the population, and 7.45 and 9.63 cm for the mean length, respectively (Table 1, Fig. 4). The maximum age (t_{max}) was obtained as 3.16 years.

The length frequency distribution was used as the input parameter for the estimation of L_∞ and Z / K using the Wetherall plot. The data corresponding to the class-mid length of 8.5 cm and onwards were only

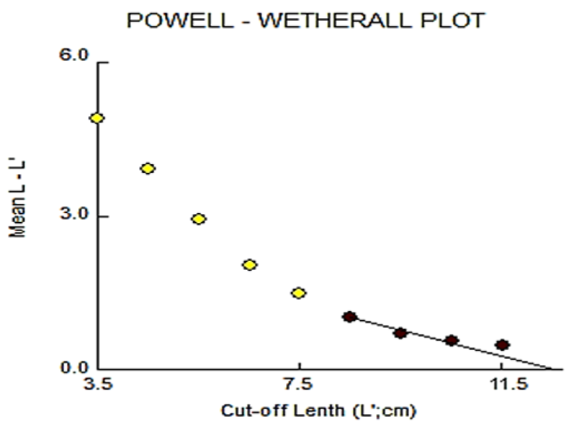

Figure 5. Wetherall plot for estimation of the theoretical growth length (L_∞).

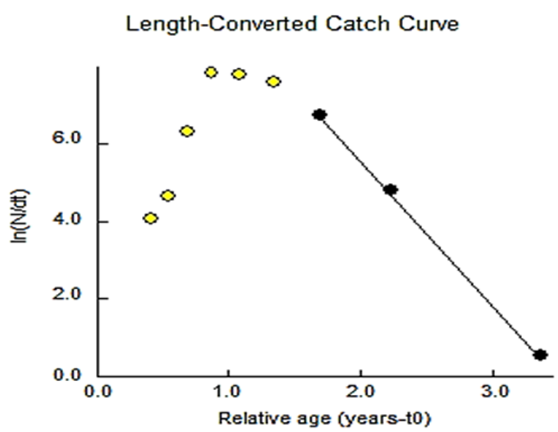

Figure 6. Length converted catch curve for estimation of total mortality coefficient (Z).

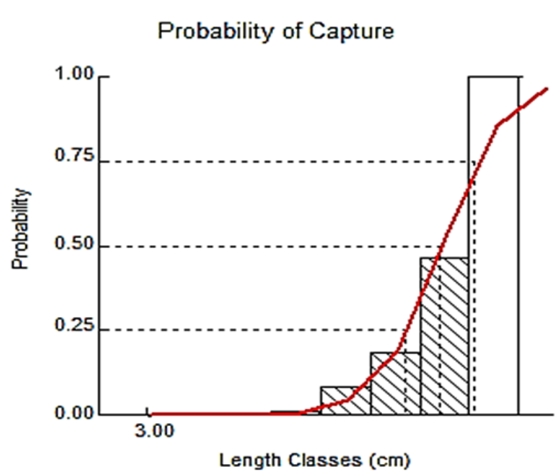

Figure 7. probability of capture plot *Engraulis encrasicolus* from Lake Manzala.

used in the regression, as they represent the fully recruited fishes (Fig. 5). The alignment of the points on the straight line was quite satisfactory with a very high coefficient of correlation (0.981). The following estimates are obtained: $L_\infty = 12.52$cm and $Z / K = 3.93$. The von Bertalanffy growth equation for the growth in length was described as $L_t = 12.52\ (1- e^{-0.95\ (t\ +0.162)})$. Von Bertalanffy growth parameters were found to be 12.52 cm, 0.95 y^{-1}, and -0.162 for L_∞, K, and to, respectively. The growth performance index (Φ) was calculated as 2.17.

Demographic aspects

Mortality: The length converted catch curve (Fig. 6) was applied for *E. encrasicolus* and the mortality coefficients were estimated as follows: total mortality (Z) was 3.71 y^{-1}, as well as 1.46 y^{-1}, 2.25 y^{-1} and 1.536 y^{-1} for natural mortality (M), fishing mortality (F) and M/K ratio, respectively. Biological reference points were estimated as $F_{opt} = 0.73\ y^{-1}$ and $F_{limit} = 0.97\ y^{-1}$.

Length at first capture (L_C) and length at first maturity (L_m): It was found that 50% of the population of European anchovy in Lake Manzala was captured at a length of 6.9 cm. Values of the sizes where the probability of capture was 25% (L_{25}) and 75% (L_{75}) were found to be 5.5 and 9.9 cm, respectively (Fig. 7). The length that generates optimum yield per recruit (L_{opt}) was calculated as 8.29 cm. 50% of the population obtained the first sexual maturity (L_m) with an estimated length of 8.1 cm. The isopleth ratio ($Lc/L\infty$) was equal to 0.56.

Fishery assessment: Prediction of the yield and future state of *E. encrasicolus* stock in Lake Manzala was studied by applying the analytical relative yield per recruit model. The fixed parameters used in the estimation were M/K ratio = 1.536, and L_C/L_∞ ratio = 0.56. The results showed the relative yield per recruit (Y/R), where the optimum Y/R takes place at an exploitation rate of $E_{0.5}$= 0.39. The current (calculated) exploitation rate (E) was estimated at 0.61 (Fig. 8).

Discussions

During the past few years, Lake Manzala has undergone massive development, represented by dredging, deepening, and establishing the largest plant globally to treat the wastewater of Bahr Al-Baqar drain, a huge and highly polluted drain, with a capacity

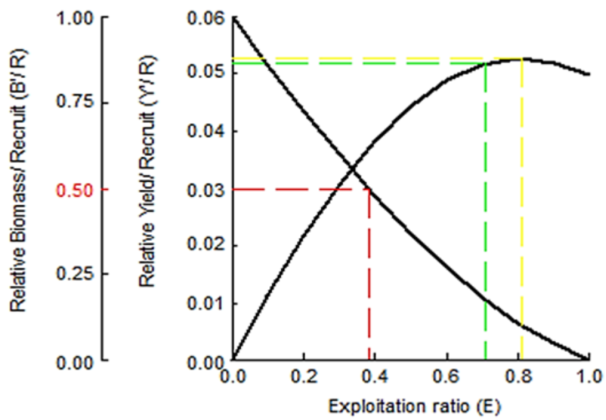

Figure 8. Relative yield per recruit plot of *Engraulis encrasicolus* from Lake Manzala

of 5.6 million m^3/day (ESIA, 2021). This led to significant changes in the water quality (Al-Agroudy and Elmorsi, 2022) and the settlement of many marine species in the lake, although their penetration depends on the adaptation to water salinity, which decreases by heading south. *Engraulis encrasicolus* is a marine species, that penetrated and flourished recently in Lake Manzala, expressing biological evidence of the efficient development and management.

European anchovy in Lake Manzala was represented by lengths ranging from 4.1 to 12.1 cm. The frequency distribution indicated that individuals belonging to medium sizes (8 and 9 cm) were predominated, representing 30.5 and 29% of the population, respectively. According to the maximum length, the reduction in predominated sizes was a common observation, although the size of anchovies in Lake Manzala corresponds to their size in other regions. The range of 6.8 to 11.2 cm was obtained for the same species in the Adriatic Sea, where the most frequent length classes were 8 and 9 cm (Manzo et al., 2013). Close results for anchovy in the Black Sea were observed (Erkoyuncu and Ozdamar, 1989; Karacam and Düzgünes, 1990). The existence of almost similar results does not preclude differences in other studies, where the range of 5.3 to 14.9 cm was reported by Samsun et al. (2006) in the Turkish water of the Black Sea. An extreme range of 3.4 to 9.8 cm, was recorded for the same species in Lake Temsah, Egypt (Sharaf et al., 2009). Generally, European anchovy in tropical water was found to be smaller than those in the north (FAO, 1988).

Concerning age and growth, 2 age groups were observed with the highest percentage (77.7%) for the first age group. The short longevity was obtained with 3.15y for (t_{max}). The majority of the Mediterranean Anchovy indicated four years of lifespan on the Algerian coast (Benchikh et al., 2018), the Tunisian coast (Khemiri et al., 2007) and the Adriatic (Sinovčić, 2000). Furthermore, extreme results showed longevity ranging from two (Fage, 1911) to five years (Hemida, 1987; Bellido et al., 2000). The variation may be due to factors led by environmental variables in Lake Manzala; depth, salinity, and availability of suitable food items, which may be appropriate for specific age groups but hinder others. The estimated method may reflect on results accuracy (Benchikh et al., 2018).

Values of L_∞ and K, Von Bertalanffy parameters, reflected the pattern of short longevity and rapid growth. The same observation was reported in the Mediterranean (Erkoyuncu and Ozdamar, 1989; Bacha et al., 2010) and Atlantic (Amponsah et al., 2016; Benchikh et al., 2018). The high value of the growth performance index (2.17) confirmed the accelerated linear growth. For the same species, closed results were reported in the Mediterranean and Atlantic regions (Bellido et al., 2000; Bacha et al., 2010; Benchikh et al., 2018). A lower value (1.90) was reported in the Turkish sector of the Black Sea (Samsun et al., 2006). The deviation of (Ǿ) values is directly related to environmental variables and is an explicit indicator of environmental suitability (Devaraj, 1981).

Based on the results of the current study, the length at first sexual maturity (L_m) was estimated as 8.1 cm, which was varied from those found in other regions. It showed a wide range of variance, 7.2 cm in Egypt's Lake Timsah, and 11.3 cm in the Mediterranean coasts in Italy and Algeria (Table 2). Regional variations in ecological variables tightly control size and age at sexual maturity (Ferreri et al., 2021). A length of 6.9 cm was the calculated as length at first capture, which is less than the L_m value. The same pattern was shown

Table 2. Length at first maturity of *Engraulis encrasicolus* in different Mediterranean regions.

Country	L_{min} (cm)	L_{max} (cm)	L_m(cm)	References
Spain	9.5	14.0	10.3	Giraldez and Abad (1995)
Spain	9.0	18.0	11.2	Millan (1999)
Algeria	6.8	17.8	11.3	Bouaziz and Bennoui (2004)
Italy	9.0	19.0	11.3	Basilone et al. (2006)
Egypt	3.4	9.8	7.2 (M) 7.5(F)	Sharaf et al., (2009)
Egypt	4.2	12.1	8.1	The present study

Where; L_{max} = Maximum length, L_{min} = Minimum length and L_m =Length at first sexual maturity

when compared to the value of L_{opt} (8.29 cm), which achieves the maximum sustainable yield showing the risk of overexploitation. To maintain the sustainability of fish stocks, they must be given the opportunity to reproduce before being caught (Beverton and Holt, 1957). The resulting ratio of (L_C/L_∞) indicated the exposure to overfishing (Pauly and Soriano, 1986).

Mortality coefficients were estimated, where total mortality (Z) = 3.71 y^{-1} and natural mortality (M) = 1.46 y^{-1}, which is consistent with the finding of Amponsah et al. (2016) in the Atlantic coast of Ghana (Z = 3.4 y^{-1} and M = 1.59 y^{-1}). Clear differences have been reported in the Turkish coasts, where Z = 1.6 y^{-1} and M = 0.46 y^{-1} (Samsun et al., 2006). A similar pattern was observed on Algerian coasts, where the estimated values of 2.31 y^{-1} and 0.56 y^{-1} were reported for Z and M, respectively (Benchikh et al., 2018). The present high value of natural mortality, compared to other regions, may be attributed to the flourishing of natural predators (European seabass) and competitors (*Sardinella* spp.) along with the spread of European anchovy in Lake Manzala. The effect of drainage water from the southern edge cannot be ruled out, due to the influence of the northbound water stream on the water quality. Variables that affect natural mortality were explained by El-Betar et al. (2022) in Lake Bardawil, Egypt. A value of 1.536 was observed for the M/K ratio, which is located within the range of Beverton and Holt (1956). Compared to biological reference points, F_{opt} = 0.73 y^{-1} and F_{limit} = 0.97 y^{-1}, the highest value of fishing mortality (2.25 y^{-1}) shows the extent of overfishing.

The relative yield per recruit (Y'/ R) increases with the increase in exploitation rate and the optimum Y/ R takes place at an exploitation rate of $E_{0.5}$ = 0.39. The higher rate of the current exploitation (E = 0.61) vs. the optimum index ($E_{0.5}$ = 0.39), which maintains 50% of the stock for spawning, confirmed the occurrence of overexploitation. Exceeding the limit of 0.5 for the current exploitation rate shows overexploitation (Beverton and Holt, 1966). These results indicate that, to achieve the optimum yield per recruit, the current exploitation level of the European anchovy stock in Lake Manzala should be reduced to 0.39 (36.06%) and the fishery needs some management regulations.

Generally, the features of European anchovy in Lake Manzala were characterized by exceeding the value of the current fishing mortality for biological reference points, degradation of L_c against L_m, in addition to the conclusive high value of (E_{cur}), expressing the stock's giving up to overexploitation.

Conclusion

The present investigation is a pioneer in the study of European anchovy in Lake Manzala, Egypt. The common observation was the dominance of anchovy's small sizes and the limitation of age groups in Lake Manzala. Compared to L_m value, the length at first capture suggests the probability of overexploitation. It is supported by exceeding (F) value for biological reference points. The current exploitation value definitively confirms the biological indicators of overexploitation. Reducing current exploitation rates is essential for development and stock preservation.

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