Blue Economy

Volume 2 | Issue 1 Article 7

2024

Egyptian sole Solea aegyptiaca Chabanaud 1927 as an eligible ecological indicator for Lake Qarun, Egypt

Usama Khalifa
National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt

Adel Ali. Abdelmageed
National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt, adel_abdelmageed@yahoo.co.nz

ISSN: 2805-2986 – e-ISSN: 2805-2994

RESEARCH ARTICLE

Egyptian Sole *Solea aegyptiaca* Chabanaud 1927 as an Eligible Ecological Indicator for Lake Qarun, Egypt

Usama Khalifa, Adel A. Abdelmageed*

National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt

Abstract

During the last century, Lake Qarun witnessed successive ecological changes and diverse exploitation patterns. Recently, by 2015, a vigorous invasion and spreading of an exotic crustacean isopod resulted in a massive mortality of lake fishes. For crisis management, administrative bodies adopted two low risk approaches; dredge the area near the entrance of main drainage and stop the regular annual lake stocking with fish fries, to improve water quality and interfere with the parasite life cycle. By 2021, proposing an effective plan for rehabilitation and restoration of the lake Qarun ecosystem was an urgent demand. Thus, determining the present status of fish stocks that still survive in the lake was a priority, through designing a comprehensive fishing survey, from September 2021 to September 2022. Surveys' results revealed that Egyptian sole, anchovy, and small shrimps are the aftermath survivors. Considering the economic importance of Egyptian soles, its current population characteristics studied in detail (length-frequency distribution, length-weight relationship, sex-ratio, age determination, age-length-key). Size-frequency distribution compared between the three different sectors of the lake. Screening the history of Egyptian soles population in Lake Qarun indicated that soles was the only commercially important fish species that withstand all consequences of ecological changes in the lake, since its appearance in the catch by 1948. To discuss the eligibility of Egyptian soles as an ecological indicator for Lake Qarun, recent size-frequency results compared with previous studies concerned species in Lake Qarun, through applying a simple reliable nonparametric statistical test. The comparison indicated that Egyptian soles is eligible as an ecological indicator for Lake Qarun ecosystem, and it should be highly considered in any fisheries development plan. Moreover, the high incidence of anomalies and malformation among the sole population in the lake compared to the rare incidence for wild population in other localities proposed its eligibility as an environmental quality indicator for the different lake fishing sectors. A well-designed stock enhancement program is recommended to support the existing Egyptian sole population in Lake Qarun. Concerning prevalence of cymothoid isopod parasite, present study revealed a sharp decline in its morbidity among sole fish compared to the single study carried out from 2014 to 2016.

Keywords: Lake Qarun, Egyptian sole, *Solea aegyptiaca*, Biological parameters, Anomalies & malformation, Ecological indicator

1. Introduction

Lake Qarun is in the lowest point of El-Fayoum depression; on the fringe of the Western Desert, about 90 km south of Cairo. It represented the remains of the oldest ancient Egyptian Lake "Moeris", which was used as an artificial regulator of the Nile floods by the monarchs of the XII dynasty. For centuries, the lake represented a freshwater reservoir for the extra Nile flood reach the depression at the most distant end of the Nile tributaries during flooding time. Thereafter, the lake completely detached from the river. The surrounding population used collected water for their domestic needs as well as agriculture. In addition, floodwater used to carry huge quantities of freshwater fishes to the reservoir. Thus, residents around the lake used to exploit it as fisheries resource. By the beginning of

Received 5 February 2024; revised 26 March 2024; accepted 27 March 2024.
Available online 8 June 2024

* Corresponding author.
E-mail address: adel_abdelmageed@yahoo.co.nz (A.A. Abdelmageed).

https://doi.org/10.57241/2805-2994.1019

the 19th century, the huge hydrological projects in the country change the exploitation pattern of the lake to a reservoir for agricultural drainage water. As a result, the salinity of the lake tends to increased gradually. Consequently, the ecosystem was not in favor of freshwater fish and most of the freshwater fishes disappeared (Faouzi, 1935). The Nile perch, *Lates niloticus*, and tilapias production markedly plummet. The former dropped from 63 tons in 1921 to about 30 kilograme during 1935, While the later leaned from 5 thousand tons to 475 tons, between 1927 and 1930 (Faouzi, *op. cit*).

The salinity of the lake has strongly increased over the twentieth century. In 1906, it was 10.5 g l−1, but already reached 18 g l−1 in 1919−1925. Naguib (1958) mentioned 17.8−25.5 g l−1 in 1953−1955. Salinity increased further, to 30.9‰, 38.7‰ and 42.8‰ in the 1971, 1995 and 1999−2000, respectively (Meshal, 1973; Anonymous, 1997; Ali, 2002). The water salinity was in order of 33.25 ‰. Soliman (1989) predicted a further increase in salinity in the twenty-first century. The annual salt gain via the main drains is 690.89 × 106 kg (Abd Ellah, 1999). Recently, the level of lake salinity reached 38‰ (Abdelmageed et al., 2022).

To accommodate the changes in the lake, the necessity arose to stock the lake with species tolerant high salinity, to compensate for the loss of the freshwater fishes. The Alexandria Institute of Hydrobiology started in 1928 a program to introduce fish of marine origin; grey mullets (*Mugil cephlus*), from Mediterranean into the lake (Faouzi, 1935; Wimpenny and Faouzi, 1935; El-Zarka, 1963, 1968; El-Zarka and Kamel, 1965; Ishak, 1980; Ishak et al., 1982). Following up the experiment results indicated that gray mullets could not spawn naturally in the lake. Thereafter, different mullet species; *Chelon ramada, Liza saliens* and *Chelon labrosus*, have been introduced hoping one of them will reproduce naturally in the lake. Some early studies concluded that *C. ramada* successfully spawned in the lake (Wimpenny & Faouzi, 1935), but the outcomes were disappointing. Accordingly, progressive annual supply of mullets' fry continues till it reached about 27 million in 2010 (Alrouby and Abdul-Tawab, 2019). During 1935, 103 Egyptian soles introduced to the lake. The first experimental sole fishing was during 1938 resulted in catching 38 kg. This encouraged additional transplanting of small fries, 7−10 cm, during 1943, 1945 and 1948. By the end of 1948, a total of 1603 young fishes were transplanted (El-Zarka, 1963). Accordingly, lake fisheries depend upon naturally reproduced species and regularly transplanted fries and fingerlings. Naturally reproduced species include Tilapias (*Captadon zillii, Oreochromis niloticus and O. aureus*) and Egyptian soles (*Solea aegyptiaca*). Transplanted fish species comprised mullets (*Mugil cephlaus, Liza saliens, Chelon ramada and C. labrosus*), sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*). Lake catch composition, to large extent, depends upon the stocking regime of the lake for the present and preceding years. Lake Qarun declared as a protected area in 1989 (Prime Ministerial Decree 943 for 1989).

The progressive increase of salinity may be the main problem in the lake due to its direct effects on biological productivity, fish production and all biota in the lake. Besides, the lake suffers from a serious water pollution problem due to receiving huge quantities of domestic and industrial waste via the two drains. In addition, a clear sustainable wastewater management aimed at reducing agrochemical contamination of the received drainage water. By 2015, the misery of lake Qarun ecosystem increased by the sudden appearance, prevalence, and vigorous attack of an exotic cymothoid isopods crustacean. The invasion resulted in a massive mortality of lake fishes (Abdel-Latif, 2016; Younes et al., 2016; Mahmoud et al., 2017; Shaheen et al., 2017; Abdelkhalek et al., 2018). Administrative bodies preferred the lowest-risk approaches in crisis management. The first approach was a project supervised by General Authority of Fish Resource Development (GAFRD) to dredge the Lake bottom near the entrance of the main water source; Al-Bats drain. The project aimed at removing the accumulated organic matter in the area to improve the water quality. The second, and the most serious approach, was a complete stop of annual supply with transplanting fish fries. The main intention was to interfere with the parasite life cycle by reducing the number of infected fishes. The applied approaches led to a severe decline in fisheries production without further intervention to restore the lake ecosystem.

Several studies strictly concerned with sole fish biology, fisheries, and population structure of soles in Lake Qarun. On the other hand, some studies interested in certain aspect of Egyptian sole in the lake, like taxonomical characteristics (Abdel-Missih, 1995) or reproductive biology (El-Husseiny, 2001), but delineated the biological characteristics of the sole population. El-Zarka (1963) briefly described the transplantation of soles to lake Qarun and its production characteristics from 1938 up to 1960. The reproductive cycle of sole in lake Qarun draw the attention of Boulos and Ashour (1973). Kirollus (1977) studied the sole fisheries for about 10 years. Bishai and Kirollus (1988) studied the selectivity of five experimental sets of cotton and nylon nets. Abd El-Khalek (2008) studies condition factor, hepatosomatic index, biochemical parameters and electrophoretic separation of eye and muscle esterase isoenzyme for Egyptian sole. Shalloof (2009) studied fisheries biology of *S. vulgaris* in Lake Qarun. She noticed a decline in the coefficient of allometry (b) and absence of older age. Zaghloul et al. (2011) linked findings of the histological and histopathological studies of gills, liver and kidneys sections for Egyptian soles collected from lake Qarun during summer with the results of residual heavy metals in water. In addition, they found significant differences in values of growth indices, flesh quality, blood parameters and plasma constituents of *S. aegyptiaca* collected from Lake Qarun compared to that collected along Egyptian Mediterranean coast. El-Serafy et al. (2014) gave a detailed synopsis about fishing gear, catch composition, effort and catch per unit effort for lake Qarun fisheries. El-Far (2014) assessed lake Qarun fisheries with a special interest to sole fisheries. He calculated length-weight relationship and growth parameters for separate and combined sexes. The maximum determined age was 3 years for males and 4 years for females, respectively. Desouky (2016) studied the population dynamics of Egyptian soles in Lake Qarun. He collected 537 sole fishing during 2015. He determined the age of fishes between one and four years. Total mortality rate; based on cumulated catch curve, was determined at 1.1 $year^{-1}$. Mehanna (2020) studied the impact of the isopod parasites on the fishery resources of lake Qarun. Among her fish samples; from 2014 to 2016, eighty three percent infected with the cymothoid copepod.

It is obvious that studies are sporadic, and in common, they confined their research intention just for determining the population characteristic at certain period. They used to attribute changes or deterioration of biological parameters of sole population to ecosystem pollution and/or exploitation pressure. Their conclusions extend our intension to discuss the eligibility of the sole population to represent a simple and meaningful indicator for screening the ecosystem ecological changes as well as anthropogenic activities. Especially with the growing concern about the need to define, test and elect an indicator to guide rational sustainable management of aquatic ecosystem (e.g., Zangaro et al., 2021; Pinna et al., 2023). Accordingly, the present study aimed at proposing an effective plan for rehabilitation and restoration of the lake Qarun ecosystem and its fisheries resource, and try to elect an eligible ecological indicator help in tracking ecosystem status and highly contributed in rational sustainable management decision. For proposing an effective plan for rehabilitation and restoration of the lake Qarun ecosystem and its fisheries resource, the priority was determining the status of fish stocks that still survive in the lake. A fishing survey designed to accomplish the task. The survey extended throughout five experimental fishing trips from September 2021 to September 2022. For electing an eligible ecological indicator, Survey results with special reference to Egyptian soles analyzed and discussed in the light of previous studies results. Changes in the fish body size considered and the differences examined through applying simple qualified non-parametric statistical analysis tool.

2. Materials and methods

Fish population status as well as isopod parasite prevalence rate in Lake Qarun studied for a year extended from September 2021 to September 2022. In the normal conditions, fish samples used to be collected from the commercial catch. Since fishing activities in the lake were irregular and sometimes rare due to the sever decline in catch, experimental fishing has been designated to collect fish samples. Experimental fishing carried out using the commonly used trammel nets as well as non-selective beach-sein nets. Beach-sein nets applied where the topography of the area is suitable; gentle slope, free of any plant debris or obstacles and extended soft bottom. In addition, merged brushwood bundles have been used as Fish Aggregating Devices (FADs) in certain areas; where batches of emergent hydrophytes are present (Fig. 1). It is worth mentioning that FADs do not target sole fish.

To avoid bias, a single set of trammel nets used. Its length reached about 2000 m, and the height is 1.5 m the set is composed of 40 connected panels. Each panel composed of three layers of Monofilament nylon nets. The mesh size of the outer layers varied between 65 and 85 mm, while the mesh size of the inner layer varied between 22 and 28 mm. The net used to set in the water before suns set and hauled in the next morning. Also, a single set beach-sein was used, its length was 300 m. The net consists of three parts of Knotted-twisted multifilament, two wings and middle bag (code end). The mesh size of the wings was 10 mm, while the mish size of the code end (bag) was 8 mm. The net operated from the shoreline. A wing end fixed on the shore and other wing pulled offshore to the maximum stretch of the net. Then, the fishermen drag the wing in circle manner to return back to the shore. From the shore, the fishermen pulled the two wings concomitantly, until the bag reached near shore, they closed the bag and drag it out of water to collect the trapped fish.

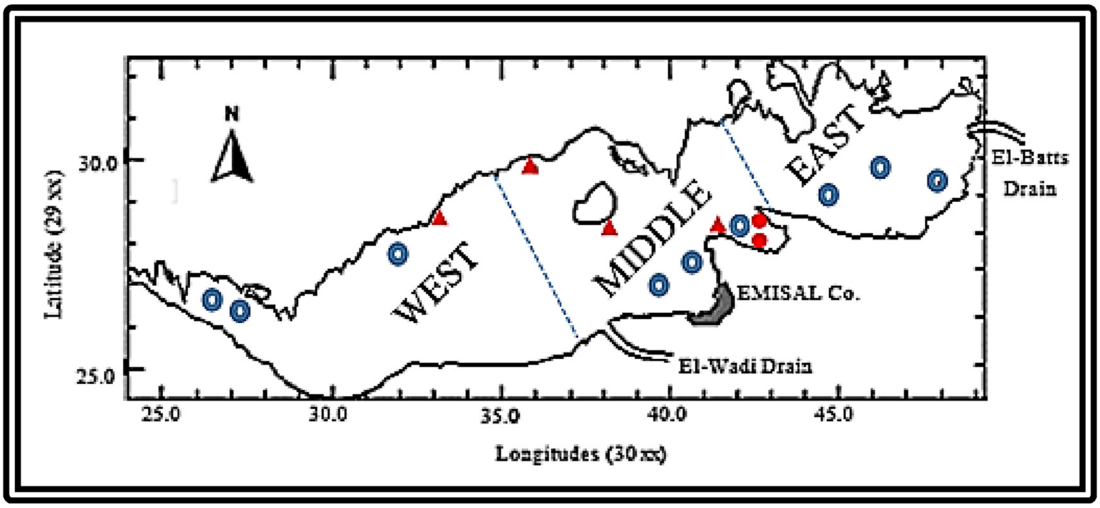

Fig. 1 Map of Lake Qarun showing the location of using different fishing gears, where red triangle (▲) indicates the places of using beach-seine nets, red circle (●) points to places where FADs have been used, and blue hollow circle (◎) shows the places where trammel nets have been used. Dotted lines show the separation between the different sectors.

Table 1. Lake Qarun fishing ground profile.

Items	East	Middle	West
Sources of pollution	Highly influenced by the discharge of El-Bats Drain	Influenced by El-Wadi Drain, inhabited villages, cultivated land, some resorts, and inland fish farms	No pollution in this sector but salinity is higher than in the other parts of the lake
Transparency	Water is highly turbid	More turbid in the south and clear in the north	Usually clear; the least turbid sector
Bottom nature	Muddy with a huge amount of plant debris and broken branches, and dead molluscs	Muddy with varying densities of debris and dead molluscs	In general, the sector is relatively shallow. The bottom is mostly sandy
Fishing gear and techniques	Operating trammel nets	Fish aggregating devices, trammel nets, beach seine, and beach seiners on the sandy bottoms only	Beach seining
Biota	Noticeable densities of small crabs, amphipods, and abundant clumps of barnacles	Pronounced densities of small crabs, amphipods, clumps of barnacles, and sporadic patches of emergent macrophytes	Abundant densities of small crabs, amphipods, and empty mollusk shells

During the survey, the lake divided into 3 different sectors; east, middle, and west according to the difference of the fishing ground. The profile of the three sectors summarized in Table 1. In general, almost all human activities confined to the southern banks of the lake, while the northern part is uninhabited desert.

Collected fish measured to the nearest millimeter and weighted to the nearest gram. The sex for each individual fish identified and recorded. The sexes easily identified by naked eye, as they are completely different in shape and size. Ovaries are two-cylinder lobes located inside the body cavity. The right ovary, on the eyed side, is usually longer than the left one. Ovary size and color differ according to the maturity stage. Testes are whitish creamy triangle small mass, located inside the body cavity, gust behind the genital opening on the eyed side. The length-weight relationship ($W = a L^b$) is calculated. The relation parameter (a & b) calculated by adopting the ordinary least-square approach. Length-frequency distribution constructed for each gear and the different sectors. For comparing the results, two statistical tests employed. The first is the independent sample t-test to compare the mean length, assuming difference in standard deviation. The second test was nonparametric two-sample Kolmogorov—Smirnov test to compare the distribution of the catch by the two gears. Otolith removed from each fish for age determination. Each pair of otoliths cleaned, dried, and stored in an envelope labeled with all information concerned the

Table 2. Statistical analysis comparison of Solea aegyptiaca*, catch between trammel nets and beach-seine catch and between the catch of trammel nets from the different sectors of Lake Qarun during the period from September 2021 to September 2022.*

Items	No	Mean	SD	Independent sample *t* test				Two sample Kolmogorov–Smirnov test			
				Cal. t	Critical *t*	*P* value	Conclusion	D-stat	D-critical	*P* value	Conclusion
Trammel net	725	14.820	1.528	8.442	1.962	<0.0001	Highly significant difference	0.332	0.1058	<0.0001	Highly significant difference
Beach seine	208	13.721	2.035								
Middle sector	620	14.765	1.440	0.896	1.963	0.3701	Nonsignificant difference	0.046	0.2401	0.9999	Nonsignificant difference
East sector	32	14.531	1.310								
Middle sector	620	14.765	1.440	3.467	1.963	0.0006	Highly significant difference	0.174	0.1653	0.0370	Significant difference
West sector	73	15.418	2.098								
East sector	32	14.531	1.310	2.205	1.983	0.0297	Highly significant difference	0.221	0.2794	0.2259	Nonsignificant difference
West sector	73	15.418	2.098								

fish and time of collection. For age determination, otolith examined under binocular stereomicroscope using transmitted light.

3. Results

3.1. Length-frequency distribution of the collected S. aegyptiaca

As *S. aegyptiaca*, was the only abundant commercial species in the lake, length composition of the sole catch from the different sectors and by different fishing gears and techniques have been done. Table 2 summarized the statistical analysis to compare sole catch of trammel nets and beach seine and to compare the catch of trammel nets from the different sectors. The fish length varied between 5 and 24 cm, with an average of 14.58 cm and a standard deviation of 1.72 cm. More than half of the soles caught in lengths between 15 and 16 cm; 55.73%. Up to length of 16 cm, caught sole fish represented about 86.17%, while 98.07 % of the caught fish do not exceed 18 cm in total length (Fig. 2).

The length frequency distribution of soles caught by trammel nets and beach-seine compared to show the effect of gear selectivity on the length frequency of the catch. The average length of fish caught by trammel nets is slightly greater than that caught by beach-seine. It was 14.82 cm for the former, while it was 13.72 cm for the later, with a standard deviation of 1.53 and 2.04, respectively. The percentage of fish caught 15 cm in length or less by trammel and beach-seine nets were 84.41% and 92.30%, respectively. The noticeable difference in the percentage

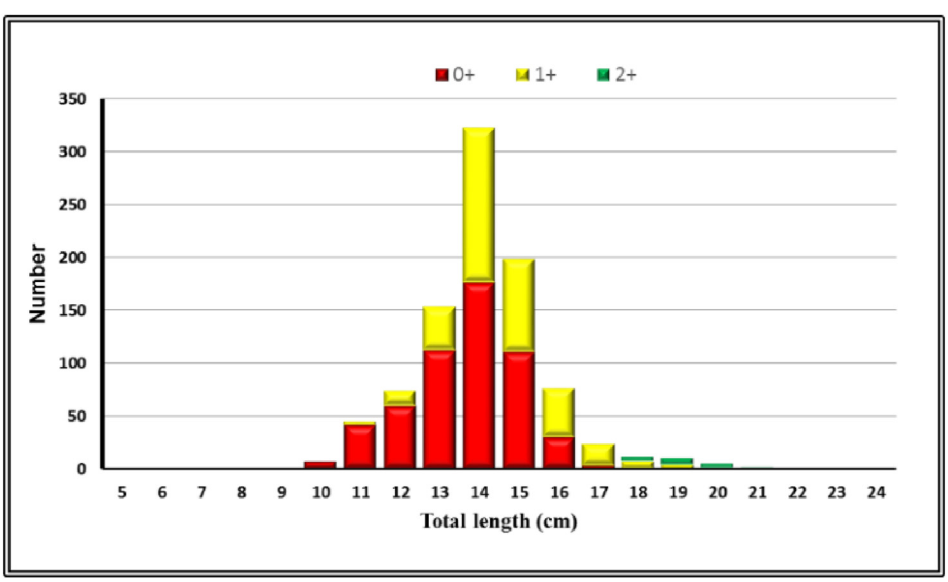

Fig. 2. Length–frequency distribution and age composition of S. aegyptiaca *caught from Lake Qarun during the experimental fishing trips from September 2021 to September 2022.*

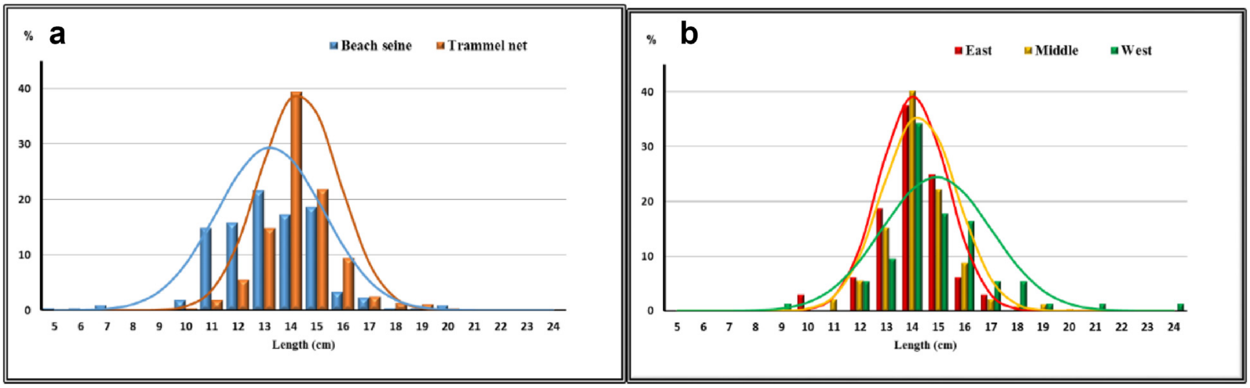

Fig. 3. Length–frequency distribution of S. aegyptiaca *caught from Lake Qarun during the experimental fishing trips from Sept. 2021 to Sept. 2022, with an overlapped normal distribution curve: (a) by trammel nets and beach seine, (b) from different sectors.*

attributed to the fact that small fish more vulnerable to beach-seine (Fig. 3).

By employing the independent sample t-test to compare the mean length, assuming difference in standard deviation and the second test was two-sample Kolmogorov–Smirnov test to compare the distribution of the catch by the two gears; results t = 8.442, P-value <0.0001 indicated a highly significant difference between the mean length of the fish caught by the two gears. Regarding the distribution of the catch by the two gears, Kolmogorov–Smirnov test results showed that the two distribution is significantly differ (D-sat = 0.332, P-value <0.0001).

The average length of fish caught by trammel nets from the east, middle and west sectors was comparable, 14.53, 14.76 and 15.42 cm, respectively. The length range of fish caught from the east sector varied between 10 and 17 cm. For the middle sector, length of caught soles ranged between 10 and 20 cm, while it ranged between 9 and 24 cm in the west sector. Rather the comparable average length of the caught soles from the different sectors, statistical analysis showed diverse results. Independent sample t-test showed a highly significant difference in mean length of fish caught from west sector and those caught from both middle and east sectors (t = 3.47; P-value = 0.001, t = 2.21; P-value = 0.0297). On the other hand, the test doesn't reflect any difference between the average length of sole fish caught from east and middle sectors (t = 0.897; P-value = 0.37).

The length frequency distribution of fish caught from the three sectors statistically compared using two-sample Kolmogorov–Smirnov test for each two in sequence. The results showed non-significant between the length frequency distribution of soles caught from east and middle sectors (D-sat = 0.047, P-value = 0.999), and the fish caught from east and west sectors (D-sat = 0.221, P-value = 0.226). On the other hand, Kolmogorov–Smirnov test results indicated a significant difference between the length frequency distribution of soles caught from middle and west sectors (D-sat = 0.175, P-value = 0.037). The results may be attributed to the limited number of sole fish caught from both east and west sectors.

3.2. Length-weight relationship of the collected S. aegyptiaca

An important tool for extracting information about fish growth pattern is the length-weight relationship. For *S. aegyptiaca*, calculated parameters for length-weight relationship were a = 0.0037 and b = 3.298, with a correlation coefficient of 0.98 (Fig. 4). The slop value (b) was slightly greater than 3. The 95% confidence interval of the calculated slope ranged between 3.185 and 3.412. Statistical t-test for the difference of the calculated slope and the value 3 showed a highly significant difference ($t_{cal.} = 5.184$, $t_{critical} = 1.978$, P-value <0.00001). The results indicated that the fish become heavier with increase in length.

3.3. Sex ratio of the collected S. aegyptiaca

Sex ratio is one of the basic information necessary for analyzing fish reproduction and stock size assessment. Domination of certain sex on another indicated either segregation between sexes through the fishing ground, or due to high abundance and lower mortality rate for such sex. Fig. 5 illustrates the number of males to the number of females of soles among the different length class intervals.

The overall sex ratio for collected soles was one male to 0.57 females. In general, males outnumbered females and up to length 14 cm males dominating the catch. For the length 15 cm the number of males to females are comparable; about 1.08 females for each male. For the fishes longer

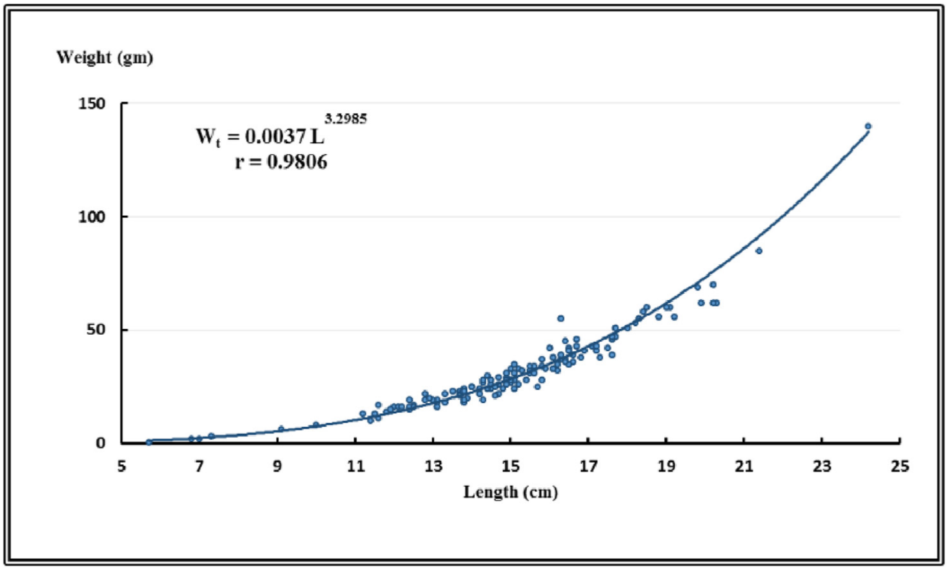

Fig. 4. Length–weight relationship of Solea aegyptiaca *collected from Lake Qarun from September 2021 to September 2022.*

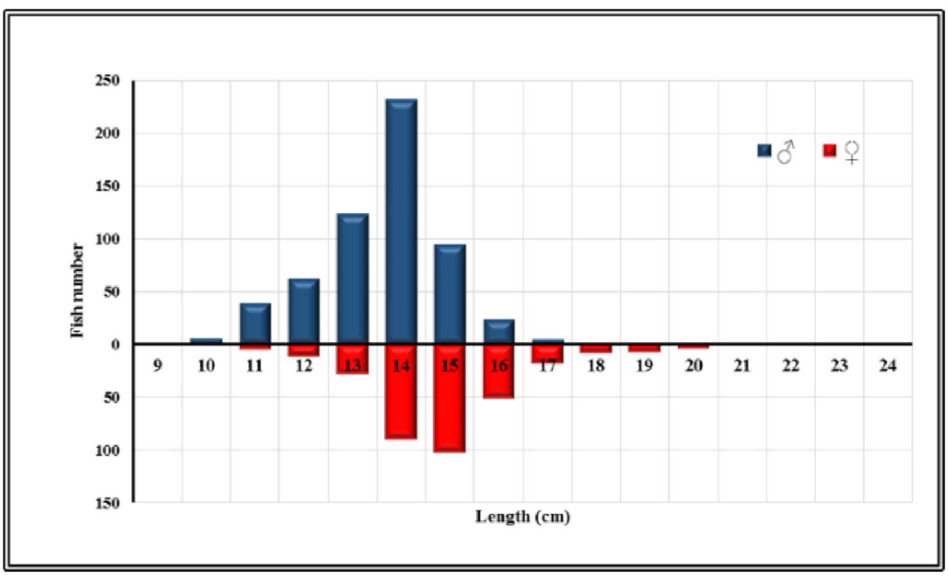

Fig. 5. Sex ratio of Solea aegyptiaca *collected from Lake Qarun during the period from September 2021 to September 2022.*

than 15 cm, females dominating, where the ratio reached 2.91 females to every male. Chi-square statistics indicated that the overall ration between males and female is significantly differ from the 1:1 ratio, $\chi^2 = 35.65$ and P-value <0.00001.

3.4. Age determination of the collected S. aegyptiaca

The otolith used for age determination of the collected samples. The otolith of sole irregular round, with one blunt edge and another broad edge. There is a small notch in the middle of the border edge. For age determination, otolith examined with transmitted light; light that has passed through the otolith. The otolith nucleus appeared as an opaque dense area in the middle. The annuli appeared as thin opaque circle separated from the nucleus by translucent area. Both opaque circle and the translucent area represent a complete cycle of fast and slow growth, respectively. Determined age varied between 0^+ and 2^+ (Fig. 6).

Fig. 6. Otoliths of S. aegyptiaca*, collected from Lake Qarun during the period from Sept. 2021 to Sept. 2022. Age varied between* 0^{+} *and* 2^{+}*.*

3.5. *Age length key and age-composition of the collected* S. aegytiaca

Based on the age determination, age length key for the sole have been constructed. *S. aegyptiaca* caught before complete their first year of life dominating the catch, where they represented about 58.6% (Fig. 2). Fishes caught after complete the first year of life represented 39.7% of the total catch. Two years old fish represented less than 2% of the total fish caught; exactly 1.7%. From the age length key, the average observed length for fishes completes their first year of life calculated at 15.095 cm, with a standard deviation of 1.396. The mean observed length for fishes complete their second year of life was 20 cm, with a standard deviation of 1.715. From the constructed age-length key, the average age of soles in Lake Qarun was 0.931 year with a standard deviation of 0.528. From the obtained results, the age of 95% of sole found in the lake varied between 0.896 and 0.964 year.

3.6. *Parsitic cymothoid isopod prevalence among sole fishes*

Throughout the survey expedition, number of infected fishes with parasitic cymothoid isopods detected, examined, and recorded (Fig. 7). The prevalence percentage of isopod parasite recorded among the collected sole fish from different sectors and with different gears are summarized in Table 3(a & b). The overall prevalence percentage of detected fish with cymothoid parasite is 1.179%. In the middle sector, sole length ranged between 10 and 24.9 cm, the prevalence rate of cymothoid parasite infected sole fish caught by trammel nets varied between zero and 16.667%. The highest prevalence was recorded among fish caught during February 2022. For soles caught by beach-sein, sole length ranged between 5 and 24.9 cm, the prevalence rate of isopod parasite varied between zero and 4.760%. The later prevalence was among soles caught during December 2021.

In the east sector, one sample of size 32 fish caught during September 2021. No isopod parasite detected on any fish. In the west sector, sole length ranged between 9 and 24.9 cm, the prevalence rate of parasite was relatively higher, varied between zero and 25%. The higher rate attributed to the small number of fishes caught from this sector; i.e., one fish with isopod parasite represent 25% out of four fish caught. As, Cymothoid isopod is protandrous hermaphrodite where females are derived from sex-changed males. Thus, it could be concluded that cymothoid isopod females usually found near the operculum.

3.7. *Anomalies and deformities of* S. aegyptiaca

During the present survey, the most pronounced observation among caught Egyptian sole is the

Fig. 7. Cymothoid isopods on Solea aegyptiaca*. Big females are usually found underneath the operculum while the small size males are found on the body.*

Table 3. Cymothoid isopod prevalence rate among Solea aegyptiaca *collected from Lake Qarun during 2021 and 2022.*

a Collected from the middle sector by trammel nets and beach seine										
Net	Trammel nets						Beach seine			
Year	2021	2022	2021	2022						
Date	14/09	6/12	15/2	29/5	22/9	23/9	15/9	07/12	29/5	22/9
No.	501	30	6	8	13	59	144	21	11	32
Weight (g)	14664	871	142	308	386	1447	3228	568	240	794
Isopod prevalence %	0.199	0	16.66	0	0	1.69	0.69	4.76	0	3.12
b Collected from the western sector by trammel nets.										
Date			14/02/2022		29/05/2022		22/09/2022			
No.			49		4		20			
Weight (g)			1652		123		574			
Isopod prevalence %			8.16		25		0			

Fig. 8. Some anomalies and disorders of Solea aegyptiaca*, recorded in Lake Qarun.*

high rate of anomalies and disorders. The anomalies ranged between malpigmination, complete absence of caudal fin and absence of either both eyes or one of them, and malformed forked snout (Fig. 8). The three types of malpigmination have been noticed and recorded as seen in Fig. 8 which includes: hypomelanosis (pseudoalbinism), characterized as a full or partial lack of pigmentation on the ocular side; hypermelanosis, characterized as abnormal pigmentation on the blind side; and ambicoloration, which means the pigmentation on both sides of the fish. Among the collected sole fish, the ratio of anomalies and deformities reached about 1.5% of the total collected fish. This ration is relatively high considering the limited number of collected fish. Such deformities may happen due to genetic problem, prevalence of unfavorable conditions during embryonic developmental stages and/or physical and chemical stressors within the environment.

4. Discussion

The proverb "The greatest oak was once a little nut" clearly abstract the story of sole fish in Lake Qarun. The first introduction of soles to the lake was during 1938, when 103 young fish, ranging in length from 7 to 10 cm, collected from the coastal areas of the Mediterranean Sea at Maadia district and from Lake Idku, and released to the lake. During years 1943, 1945 and 1948 transplanted sole fish completed 1603 fish (El-Zarka, 1963). The first experimental fishing for soles during 1938 resulted in catching 38 kg. The presence of soles proved the successfully acclimatization and the fish naturally reproduced and its population flourished in the lake. At that time, local fishers were not familiar with soles. By the time, local fishers noticed the existence of soles, and they were cleaver enough to modify trammel nets, which originally designated to catch *Tilapias* and start to exploit the newcomer population. El-Zarka (1963) briefly described the introduction process. Within 7 years, by 1949, sole fisheries production reached about 230 tons. During the following ten years, to 1960, the sole fisheries production fluctuated with a peak of about 271. The increase of the annual catch was not only due to in-lake production but also to improved skills of fishermen to catch soles. From 1961 to 1966, sole fisheries constituted about 33% of total yield (El-Zarka, 1968). For the period from 1962 to 1975, Kirollus (1977) found that lake Qarun sole fisheries production contributed between 24.63 and 59.11% of the total Lake fisheries production. Lake Qarun fisheries production at this period contributed between 31.56 and 89.20% of the total country sole fisheries production. Ishak (1980) mentioned that additional stocking with young fishes collected from Lake Menzalah-Mediterranean Sea connection were made in 1977, with the objective of renewing the stock of soles in Lake Qarun. The number of introduced young were very limited; about two hundred.

Egyptian sole fisheries production in lake Qarun, since its first appearance in the catch by 1939−2018, is depicted in Fig. 9. The catch statistics indicated that less than two thousands of transplanted young soles supported the production of about 32 thousand tons; exactly 31595.3165 tons, during the whole period. Meticulous examination of the figure

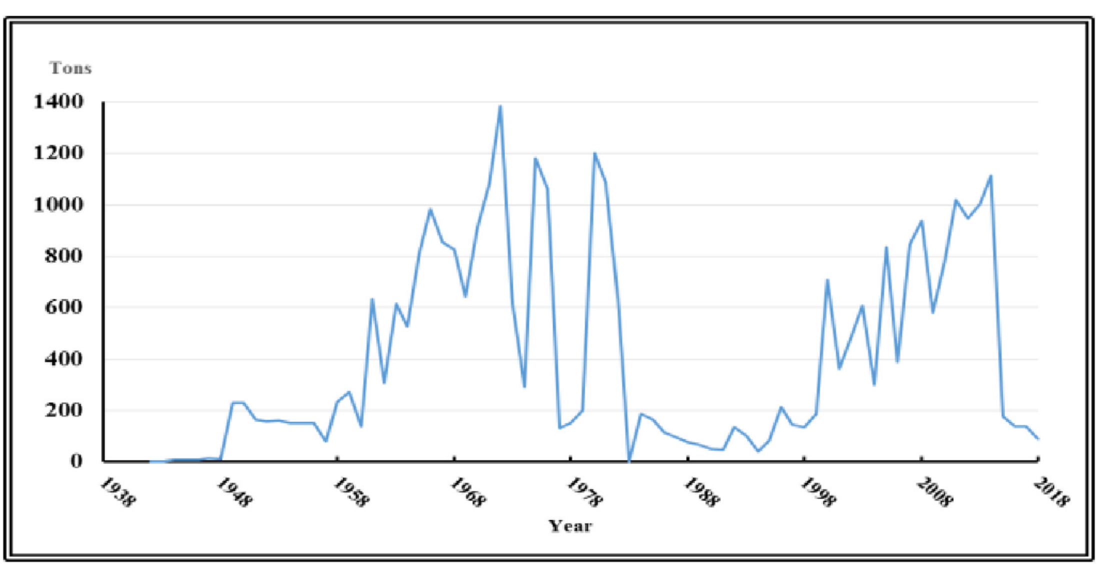

Fig. 9. Lake Qarun annual Egyptian sole fishery production from 1938 to 2018.

indicated that an introduced (non-native) fish species succeeded to establish self-sustained population. Since 1938 to 1972, it production fluctuated in progressive increasing trend to reach about 1384 tons. Thus, during the period, the population found the suitable ecological niche without any competition or overcrowded. Thereafter, the decline fluctuation trend of the resident fish population, till the plummet 1983, accompanied with increased salinity, water quality deterioration and irrational fisheries management decisions. As an instant, the evident plummet in the catch of soles during the early 80's was concomitant with and followed the implementation of an ambitious plan to supplement the lake with fries and seeds of marine fishes and shrimps. Abdel Razek (1991, 1995) mentioned that three million of shrimp seeds of four shrimp species; *Penaeus kerathurus*, *P. japonicas*, *Metapenaeus monoceros*, and *M. stebbingi* were transplanted into the lake in 1977. Introducing shrimps heavily affected the deteriorated sole production, because local fishermen had to use narrow mesh size nets and beach-seine to catch shrimps. The new practice led to catching huge number of fries and fingerlings of the naturally reproduced soles; "Ripple effect".

Despite the deterioration in lake water quality, progressive increase in salinity, pollution, and mismanagement practices for fish exploitation, introduced sole population persist and survive in the lake. Throughout the last 25 years; from 1994 to 2018, Lake Qarun resident sole fisheries produced a sum of 12255 tons. Its contribution in the total fisheries production varied between 10.15 and 38.92%, during 1994 and 2000 respectively, with an average of 20.27%. Accordingly, Egyptian soles throughout the period was a crucial part of Lake Qarun ecosystem; affected, effected, and could not eradicated. Thus, its production satisfies the requirements of an "indicator" which not only reflects the changes in exploitation starategies but also the ecological status of Lake Qarun.

Intentional introduction of non-native species is very common practice all over the world, especially for freshwater ecosystem. The main reason usually is to meet the increasing need for protein source. In some cases, fish introduction fulfill recreation, hobbies as well as other economic reason (Tarkan et al., 2015; Syafei and Sudinno, 2018; Kiruba-sankar et al., 2018; Andriyono and Fitrani, 2021). Kiruba-sankar et al. (2018) considered the non-native species as invasive **iff** (if and only if) it causes some negative impacts on the ecosystem. Earlier, Gozlan (2008) discussed the negative and positive impacts of introducing non-native freshwater fish. He pointed out to the importance of distinguishing between man-made lakes or reservoirs and natural lake as the impact of introduced non-native species is completely different.

For wrapping up, Egyptian sole, *S. aegyptiaca*, is a native Egyptian fish along the Mediterranean coast that introduced (trans-located) to the newly developed saline ecosystem (Lake Qarun) by 1935. Up to 1948, total of 1603 young fishes were transplanted to the lake. With the further increase in salinity of the lake, the species found its suitable ecological niche without any competition or overcrowding. Resident soles established a self-sustained population that represented a crucial part of the ecosystem and contributed a considerable share in lake fisheries production. Following up soles production throughout the period indicated that the population affected with and effected the exploitation pattern of lake fisheries. The dramatic disaster of cymothoid copepod invasion affected the Egyptian sole population in the lake to some extent, but it hasn't been eliminated or eradicated.

Concerning the proper identification of the sole species in Lake Qarun, all previous studies defined soles in Lake Qarun as *S. vulgaris*. It is worth mentioning that the first precise identification of the species as *S. aegyptiaca* have been carried out by the first author during 1992 (Lake Qarun Ecosystem project, US aid, unpublished data). The identification based on morphometric and meristic characteristics. The later includes counts of fin rays, lateral line scales, and vertabera). The vertebral counts ranged between 40 and 44, which confined to the *S. aegyptiaca* (where number of vertebra for *S. vulgaris* varied between 46 and 52). The aforementioned report included the full results of the meristic study, supplemented with x-ray images for fishes of various size. The identification of *S. aegyptiaca* in Lake Qarun inspired other studies for identifying and separating the species in other localities (i.e. Abdel-Missih, 1995; Ali, 1995). Here, we should point out that the Egyptian soles was formerly identified as a variety of *S. vulgaries* (i.e., *S. vulgaris* var. *aegyptiaca*). Subsequently, the species recorded as *Solea vulgaris aegyptiaca,* Chabanaud (1927). Finally, The species defined as *Solea aegyptiaca*, Chabanaud (1927) (Quignard et al., 1984; Quéro et al., 1986; Fischer et al., 1987; Wheeler, 1988; Ben-Tuvia, 1990; Borsa and Quignard, 2001; Bariche and Fricke, 2020). Despit the facts, Abdel-Missih (1995) stated that the two sole fish species; *Solea vulgaris* and *S. aegyptiaca*, lived *simultaneously* in Lake Qarun. She added that *S. vulgaris* seems to disappear due to drastic changes of environmental conditions of the lake including water salinity increase. Her postulate based on a

Table 4. Comparing length (cm) — frequency characteristics of sole fish in Lake Qarun in the present study with the previous studies.

References	El-Zarka (1963)	El-Zarka (1963)	Kirollus (1977)	Abd El-Gawad and Ragheb (1996)	El-Husseiny (2001)	El-Far (2014)	Present study
Time of collection	1958	1960	1967	1993—1994	1991—1994	2010—2011	2021—2022
Min	10.25	9.25	10.50	14.5	12.50	11.50	5.50
1st Quartile	16.78	16.23	16.20	18.42857	17.54	15.32	13.67
2nd Quartile	18.50	18.34	16.88	20.16	18.61	16.39	14.57
3rd Quartile	19.91	20.26	18.01	21.54839	19.74	17.59	15.47
Max	33.25	31.25	33.50	26.5	25.50	25.50	24.50
Interquartile range	3.1285	4.0357	1.8103	3.1198	2.2073	2.2709	1.8052
Range	23.00	22.00	23.00	12.00	13.00	14.00	19.00

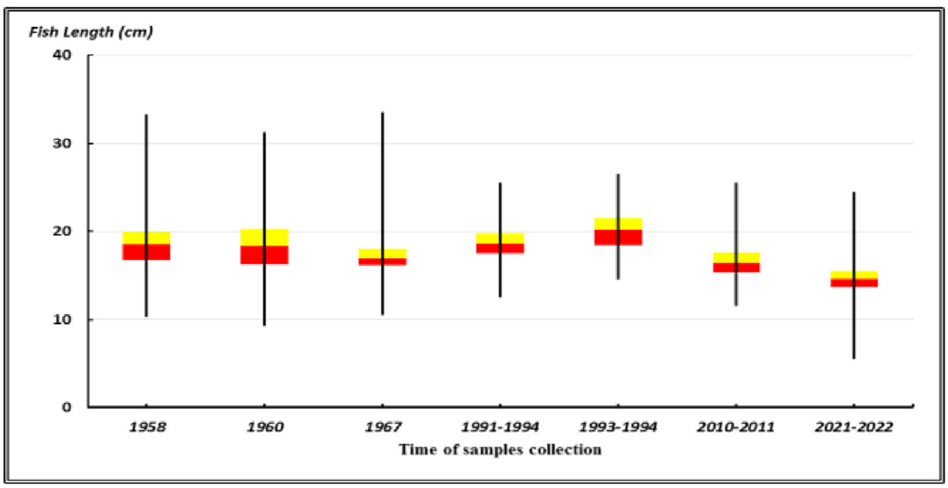

Fig. 10. Box-plot for length—frequency distribution of sole samples collected from Lake Qarun in different sampling periods.

misleading assumption that the two species were present since the first introduction, rather than the fact that from the early beginning the Egyptian soles in Lake Qarun misidentified as Dover sole, *S. vulgaris*.

The length frequency distribution characteristics of soles collected during the present study compared with previous studies summarized in Table 4 and depicted in Fig. 10. The comparison encompassed the calculation of 1st and 3rd quartiles as well as median and interquartile range (IQR). From the figure, it is obvious that up to 1977 fishes of length greater than 30 cm observed. On the other hand, since the beginning of 90's, the maximum observed length didn't exceed 27 cm. The minimum observed sole length in the commercial catch for all the previous studies was comparable ranged between 9 and 12 cm. The results are associated with the selectivity of the commonly used trammel nets. Abdel-Missih (1995) during her taxonomic studies collected 906 sole fishes from the lake Qarun varied in length between 4.5 and 25 cm. In the present survey, the sole fingerlings obtained among the catch of the non-selective beach-seine. Thus, it is believed that Abdel-Missih (1995) collected fishes caught by trammel and beach-seine. In general, the comparison indicated that after the introduced soles built up the self-sustained population, from 40's to 70's, it was subjected to growth-overfishing, which led to a complete disappearance of bigger fishes. Thereafter, sole population endure and survive despite the drastic and successive changes in lake ecosystem.

Calculated length-weight relationship parameters for collected Egyptian soles from lake Qarun, during 2021—2022, were $a = 0.0037$ and $b = 3.298$. Statistical t-test indicated that the slope differs significantly from the cube value; i.e., 3. Table 4 summarized previous studies concerning the length-weight parameters of Egyptian soles from different Egyptian water bodies including Lake Qarun, and a sympatric similar species; *Solea solea*, from Egypt and other localities. Meticulous revision of the results indicated that the b value for all previous studies concerning soles in Lake Qarun is less Than 3. The only comparable results were that of Gabr (2015) for the Egyptian soles in Bardawil Lagoon. For the sympatric similar common sole, *Solea solea*, most studies calculated the b value greater than 3. However, other studies concerning the same species and sometimes for the same area calculated the b parameter less than 3 (i.e., Demirel and Dalkara, 2012; Kahraman et al., 2021). Accordingly, it is erroneous and misrepresent conclusion that fish exhibit isometric growth if the value of b is less or greater than 3 and allometric growth if the value of b is less or greater than 3. Illogic to consider that the species change their growth pattern, but the logic that changing environmental condition, stock size and food availability affect the weight gain pattern of the species; more slim or fleshier (Ama-Abasi, 2008; Nehemia et al., 2012). Thus, it is better to consider the b parameter just as a mathematical parameter that fit the data with the power equation. If the b value is less than 3, fishes become leaner as growing in length. If the b value is greater than 3, fishes become plumper as growing in length. Accordingly, we could assume that obtained results indicated that Egyptian soles in lake Qarun during the present study fleshier than the fishes of the same species during previous years. This for a large extent explained by the decline in stock size as well as the abundance of benthic fauna in the lake, especially *Gammurus*. In addition, rich zooplankton population offer a plenty food supply for the very few inhabiting fish species. El-Zarka (1963) pointed out to lake rich of Gammurus, which provide an essential food for soles. Thus, he found that soles condition in lake Qarun is better than that along the Mediterranean coast. During the survey, we noticed the abundance of *Gammurus* spp. that appeared by the naked eye attached to the trammel nets when pulling it out of the water.

Otoliths have been used for age determination of Egyptian soles from Lake Qarun. Validity of otoliths for age determination approved for Egyptian soles and its relatives in many localities as shown in Table 6. During the present survey, the maximum determined age was 2^+ years, which is relatively younger than that determined for the same population during preceding periods from 1970 to 1990, when the maximum age was five and six years respectively (Kirollus, 1977; Abdel-Missih, 1995). From the beginning of millennium on, maximum determining age of the stock was 4 years (Desouky, 2016). Shalloof (2009) pointed out to the disappearance of the older fishes among the sole population in the lake, when the maximum determined age for the collected sample were 2^+. The present results for large extent agreed with that of Shalloof (2009). She found the most abundant age group in the lake was age group 1^+.

Considering the length at age, the present survey results were comparable with that obtained by previous studies. For the period from 1960's and 1990's, sole population in the lake was in equilibrium with considerable abundance of old fish and subsequently abundant recruit. The recruit abundance increases the grazing pressure on zooplankton, thus length at the end of the first year was relatively low. Overfishing of the stock at that time led to complete disappearance of older fish. With the decline in stock size, the length at younger age increased due to decline in recruitment magnitude and decrease in competition over the available food resources. Accordingly, length at the end of the first year of life increase compared to the previous studies (Table 5). For the same species along the Egyptian Mediterranean coast and Bardawil lagoon, length at end of each year of life varied compared with the population in Qarun Lake.

For the sympatric similar species, *Solea solea*, length at the end of each year of life is comparable for the same author in different localities and incomparable between authors (Table 6). The results increase the suspicious of errors in age determination between authors, as annulus recognition and identification for large extent based on acquired skill and researcher's experience.

The present survey revealed a relative low prevalence of cymotoid isopode parasite among collected sole fish. The prevalence varied among the three fishing sectors and with the use of different fishing gears. For trammel net catch, no infection detected among the fish collected from the eastern sector. The highest percentage of parasitic prevalence in middle sector was 16.66%, which represented one fish among 6 collected fish. The same was found in the western sector, where one infected fish was found among 4 fish. For the beach-seine net catch in the middle sector, the highest percentage for infected fish was 4.76%. A single study has been carried out between 2014 and 2016 concerned with the prevalence of cymothoid parasite among sole fishes (Mehanna, 2020). She recorded 83% of 537 collected sole fishes infected by the isopod external parasite. Accordingly, it could be concluded that there is a sharp decline in the prevalence of external isopod parasite during the present years compared to its prevalence during the period from 2014 to 2016.

One the most pronounced observation during the present survey was the relatively high rate of anomalies and disorders among sole fishes in Lake Qarun. Malpigmination is a common problem among reared flat fish species (Venizelos and Benetti, 1999; Bolker and Hill, 2000; Aritaki and Seikai, 2004). The authors attributed malpigmination to aquaculture conditions. Those conditions include temperature, light intensity, feeding type and quality during larval stages, stocking density, hormones and genes involved in body colouration, neurological aspects and water quality conditions. For wild flat fish few incidences of malpigmentation is very rare. Goucha (1981) pointed out

Table 5. Length–weight relationship parameters of previous studies concerning Egyptian sole, Solea aegyptiaca; from Lake Qarun and other Egyptian coastal areas, and for sympatric similar species Solea solea; from Egypt and other countries within the Mediterranean.

Species	Sex	a	b	Location	Source
Solea aegyptiaca	M	0.00004	2.6833	Lake Qarun	Kirollus, 1977
	F	0.00003	2.76690	Lake Qarun	Kirollus, 1977
	F + M	0.00003	2.74740	Lake Qarun	Kirollus, 1977
	F	0.008	2.974	Lake Qarun	Abdel-Missih, 1995
	M	0.0166	2.711	Lake Qarun	Abdel-Missih, 1995
	F + M	0.011	2.86	Lake Qarun	Abdel-Missih, 1995
	F	0.0123	2.844	Egyptian Mediterranean Coast	Abdel-Missih, 1995
	M	0.0122	2.811	Egyptian Mediterranean Coast	Abdel-Missih, 1995
	F + M	0.0121	2.863	Egyptian Mediterranean Coast	Abdel-Missih, 1995
	F + M	0.00860	3.0054	North Egyptian Mediterranean coast, Port Said	Mehanna, 2007
	F + M	0.0362	2.509	Lake Qarun, during summer	Shalloof, 2009
	F + M	0.0463	2.3967	Lake Qarun, during winter	Shalloof, 2009
	F + M	0.067	2.2949	Lake Qarun	Shalloof, 2009
	F + M	0.013	2.84	Lake Qarun	El-Far, 2014
	M	0.014	2.789	Lake Qarun	El-Far, 2014
	F	0.016	2.769	Lake Qarun	El-Far, 2014
	F + M	0.0052	3.179	Bardawil Lagoon, Egypt	Gabr, 2015
	F + M	0.01	2.932	Lake Qarun	Desouky, 2016
	F + M	0.0056	3.146	Egyptian Mediterranean Coast	Mehanna and Farouk, 2021
	F + M	0.0054	3.17	Bardawil Lagoon, Egypt	Fetouh and El-Far, 2023
	F + M	0.0037	3.298 (3.185–3.412)	Lake Qarun	Present work
Solea solea	F + M	0.00781	3.08	Arade estuary, southern Portugal	Veiga et al., 2009
	F + M		3.171	Sea of Marmara, Turkey	Bok et al., 2011
	F + M	0.006	3.11	Bardawil Lagoon, Egypt	Mehanna and Salem, 2012
	F + M	0.006	3.055	Sea of Marmara	Demi̧rel and Dalkara, 2012
	F	0.004	3.077	Sea of Marmara	Demi̧rel and Dalkara, 2012
	M	0.089	2.885	Sea of Marmara	Demi̧rel and Dalkara, 2012
	M	0.0055	3.171	Bardawil Lagoon, Egypt	El-Aiatt et al., 2019
	F	0.0047	3.2334	Bardawil Lagoon, Egypt	El-Aiatt et al., 2019
	F + M	0.0048	3.2215	Bardawil Lagoon, Egypt	El-Aiatt et al., 2019
	M	0.009	3.0104	Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020
	F	0.0059	3.1495	Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020
	F + M	0.00067	3.1056	Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020
	F + M	0.0079	3.064	Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	F	0.0072	3.101	Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	M	0.0054	3.024	Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	F + M	0.022	2.6838	Sea of Marmara, Turkey	Kahraman et al., 2021
	F	0.0349	2.5536	Sea of Marmara, Turkey	Kahraman et al., 2021
	M	0.0253	2.6235	Sea of Marmara, Turkey	Kahraman et al., 2021
	Unidentified	0.0201	2.7179	Sea of Marmara, Turkey	Kahraman et al., 2021
	F + M	0.0066	3.092	Egyptian Mediterranean coast	Mehanna and Farouk, 2021
	F + M	0.008	3.04	Bardawil Lagoon, Egypt	Fetouh and El-Far, 2023

to some aberrations in three soles species; *Solea vulgaris*, *S. aegyptiaca* and *S. senegalensis*, from the gulf of Tunis. Akyol and Şen (2012) recorded the first abnormal pigmentation in *Solea solea* from the Aegean Sea. Recently, Sanaye et al. (2019) reported ambicolouration of Malabar tongesole, *Cynoglossus macrostomus*, collected off Capora, cental west coast India. The authors listed up few incidences of reported ambicolouration of different flat fish species along Indian coast. Some of this incidence dated back to the early 1950. In general, authors attributed the malepigmintation to environmental condition impacts.

Dulčić and Soldo (2005) found about 10.1% of single collection of common soles (*Solea solea*) from Northern Adriatic by trammel nets, with entirely absent non-developed caudal fin. They reported that such a phenomenon for common soles and family *Soleidae* was not observed before. Recently, Cerim et al. (2022) caught two sole individuals only; one with lateral line anomalies and the other without caudal fin, from southern Aegean Sea. The fish without caudal fine was with large body size and in good condition. Thus, the author attributed that absence of caudal fin did not affect its swimming ability besides activities like feeding.

Table 6. Length at the age for Egyptian sole, Solea aegyptiaca*; studied in Lake Qarun and other Egyptian coastal areas, and for sympatric similar species* Solea solea*; from Egypt and other countries within the Mediterranean.*

Species	Sex	Alge									Location	Source
		I	II	III	IV	V	VI	VII	VIII	IX		
Solea aegyptiaca	F + M	12.56	17.15	20.97	26.03	31.57					Lake Qarun	Kirollus, 1977
	F	11.5	15.58	18.89	21.5	23.4	24.59				Lake Qarun	Abdel-Missih, 1995
	M	11.53	15.36	18.69	20.63	22.53	23.5				Lake Qarun	Abdel-Missih, 1995
	F + M	11.4	15.48	18.8	21.1	22.9	24.05				Lake Qarun	Abdel-Missih, 1995
	F	14.5	19.22	22.72	24.8	26.73	28.06				Egyptian Mediterranean Coast	Abdel-Missih, 1995
	M	14	18.7	22.4	24.75	26.3	27.4				Egyptian Mediterranean Coast	Abdel-Missih, 1995
	F + M	14.25	18.96	22.56	24.77	26.53	27.24				Egyptian Mediterranean Coast	Abdel-Missih, 1995
	F + M	14	18	21	23.5						Lake Qarun	Al-Husseiny, 2001
	F + M	17.75	23.16	26.35	28.22						North Egyptian Mediterranean coast, Port Said	Mehanna, 2007
	F + M	17.1	24.1	28.7							Bardawil Lagoon, Egypt	Gabr, 2015
	F + M	15.43	21.3	24.21	26.34						Lake Qarun	Desouky, 2016
	F + M	15.095	20								Lake Qarun	Present Study
Solea solea	F	16.8	21.3	24.52	26.98	29.36	31.9				İzmir Bay	Hossucu et al., 1999
	M	15.3	20.06	22.75	25.08	27.04					İzmir Bay	Hossucu et al., 1999
	F + M		22.5	25.8							İzmir Bay	Gurbet, 2000
	F + M		20.5	25.1	30.1						Aliağa-Çandarlõ Bay	Gurbet, 2000
	F + M		21.5	26	36						Edremit Bay	Gurbet, 2000
	F + M	12.8	16.8	20.5	22.6	24.9	25.8	26.8	28	30.3	Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	F	13.7	16.5	21.1	23.4	24.8	25.8	28.2	28.5		Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	M	12.4	17	20.1	22.3	25.1	26.1	26.6			Güllük Bay, Aegean Sea, Turkey	Cerim and Ateş, 2020
	M	17.4	22.2	26.6	27						Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020
	F	18.1	22.3	25.3	28						Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020
	F + M	17.8	22.2	25.7	27.9						Bardawil Lagoon, Egypt	EL-Aiatt and Omar, 2020

In case of Egyptian soles in lake Qarun, the incidence of anomalies and deformation is very high comparing to flat fish records in other localities; which represented accidental records. In our opinion, this phenomenon reflects in one side the negative effects of inbreeding with the limited isolated population (genetic problem). On the other side, it reflected the environmental deterioration and pollution. Accordingly, genetic pool of the sole population should improve through stock-enhancement program. The stock-enhancement program will support the rebuild of the stock and the lake restoration and rehabilitation program. In addition, literature attributed the anomalies to pollution and environment deterioration. Thus, they advise to use the anomalies and deformities as an environmental quality indicator (Tutman et al., 2000; Dulčić, 2004; Dulčić and Soldo, 2005; Sanaye et al., 2019; Cerim et al., 2022). From our end, we encourage designating a comprehensive monitoring program for Egyptian soles considering percentage occurrence of different anomalies and malformation, linked with water quality parameters.

Fishes represent the tip of iceberg of any aquatic ecosystem. Interspecific (between different fish populations) and intraspecific (within the same fish population) changes is easily detectable and monitored, not only through scientific monitoring program, but with the simple observation of nonprofessional. Thus, many fish species successfully used as indicators for environmental quality changes (Whitfield, 1996; Whitefield and Elliott, 2002; Dabuleviciene et al., 2023; Zogaris et al., 2023). Fishes and fish assemblage systematically commonly used as bioindictor to environmental and ecological changes especially in freshwater habitats; rivers and estuaries. Not only native species that used as bioindicator, but also non-native or alien species, e.g., Kennard et al. (2005) concluded that alien fish species could be considered as a reliable indicator of river aquatic health in south-eastern Queensland rivers and streams. Changes in the size-frequency of a single fish population (intraspecific variation) provide a suitable metric of change in population abundance in response not only to change in exploitation pattern, but also to changes in environmental conditions (Ziegler et al., 2007; Neuheimer et al., 2011). For Lake Qarun ecosystem, screening the dynamic changes in size-composition of Egyptian soles discussed and linked to exploitation pattern and environmental changes. The Egyptian sole population was the only naturally spawned species that persist and continue despite all the successive drastic changes and sequential disasters in the lake ecosystem. The fluctuation in its production, as well as changes in size-composition, to great extent, interpreted environmental and ecological changes and exploitation pattern changes of lake fisheries. A simple reliable nonparametric statistical tool employed; Kolmogorov–Smirnov test. Accordingly, among all lake fish species, Egyptian soles represent the only eligible fish population candidate to be used as trusted ecological and environmental bioindicator.

5. Conclusion and recommendations

The successful story of introduced Egyptian sole in Lake Qarun is unique, irrepeatable experiment. By the time, Egyptian soles established sustained population that effected and affected the whole exploitation pattern of the lake. Present Survey results and previous studies indicated that drastic changes either environmental (changes in salinity, pollution, etc.) and anthropogenic (exploitation pattern and/or introduction of exotic invasive species) didn't threat the existence and survival of Sole population. Thus, change in size-composition of Egyptian soles could be considered as an “Eligible Ecological Indicator” for Lake Qarun. The sole population nowadays is already declined, and the population dominated by age group 1^{+}. The decline in the population size should compensated with well-organized stock enhancement program. Length-weight parameter indicated that fishes become heavier as it grows in length; b value greater than 3. The value indicated that lake food resources is still rich to the Egyptian sole. There is a sharp decline in the prevalence of external isopod parasite among sole fish. In addition, high percentage of anomalies and deformation among soles resemble to a large extent that noticed among cultured flatfish. The percentage of anomalies and deformation may be attributed to deterioration of aquatic ecosystem. Thus, it should be considered as an environmental quality indicator in a routine monitoring program for soles in the lake, and its results should link with water quality parameters.

Author contributions

Corresponding author is the project supervisor, he prepared the project proposal and was responsible for securing fund and facilities during field trips. The two authors confirmed their joint responsibility for study concept development, fishing experiment design, data collection, data analysis, results interpretation and manuscript preparation.

Funding

Authors are very grateful to the Academy of Scientific Research and Technology, Egypt (ASRT) for funding the present work under "A call to all Egyptian Scientist", the Blue Economy (No. 20219221).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abd El-Gawad, A.M., Ragheb, E., 1996. Comparative study of some biological aspects of *Solea aegyptiaca* Chabanaud, 1927 in Mediterranean Sea and Lake Qarun, Egypt. Bull. Nat. Inst. Of Oceanogr. Fish., A.R.E. (22), 157–166.

Abd Ellah, G.R., 1999. Physical limnology of fayum depression and their budget. Ph. D. Thesis. Faculty of Sciences, South Valley Univ., Aswan, p. 140.

Abdel Razek, F.A., 1991. Biological observations on the transplantations prawns in Lake Quarun (Egypt). J. Egypt. German Soc. Zool. 5, 29–45.

Abdel Razek, F.A., 1995. Abundance and reproductive biology of *Metapenaeus stebbingi* Nobili, shrimp in Lake Quarun, Egypt. Oebalia XXI, 27–36.

Abdelkhalek, N., El-Adl, M., Salama, M., Al-Araby, M., Hafez, A., 2018. Mass mortalities in Lake Qarun, Egypt associated with an isopod infestation. World World Aquac. Mag. 49 (1), 75–76.

Abd El-Khalek, A.A., 2008. Ecological and biological studies on Solea species cultured in Lake Quaroun, Egypt. M. Sc. Thesis. Faculty of Science, Cairo University.

Abdel-Latif, H.M.R., 2016. Cymothoid parasite, *Nerocila orbigni* inflicts great losses on *Tilapia zilli* in Lake Qarun at El-Fayoum Province. Int. J. Innov. Stud. Aquat. Biol. Fish. (IJISABF) 2 (3), 1–9. https://doi.org/10.20431/2454-7670.0203001, 2016.

Abdelmageed, A.A., Khalifa, U., Elsaied, H.E., Hamouda, A.Z., El Gelani, S.S., 2022. Lake Qarun between entangled history and blurred future: retrospectives and prospective. Egypt. J. Aquat. Res. 48, 299–306.

Abdel-Missih, S.B., 1995. Ecological and raxonomical studies of fishes of family soleidae from Egyptian waters. Ph. D. Thesis. Faculty of Science, Cairo University.

Akyol, O., Şen, H., 2012. First record of abnormal pigmentation in a wild common sole, Solea solea L., from the Aegean Sea. Turk. J. Vet. Anim. Sci. 36 (6), 727–729.

Ali, H.H.A., 1995. Biological studies on the Egyptian flat fishes of genus *Solea*. M. Sc. Thesis. Faculty of Science, Ain Shams Univeristy.

Ali, M.H., 2002. Impact of agricultural and sewage effluents on the ecosystem of Lake Qarun, Egypt. Ph. D. Thesis. Faculty of Sciences. Al-Azher Univ., p. 307

Alrouby, E.Th, Abdul-Tawab, Y.E., 2019. Analytical study of the current and the future situation of fishery resources in Qaroun and Al-Rayyan Lakes in Fayoum Governorate, Egypt. Egypt. J. Aquat. Biol. Fish. 23 (3), 303–320.

Ama-Abasi, D., 2008. A review of length-weight relationship and its parameters in aquatic species. In: Proceeding of 22nd annual conference of the fisheries society of Nigeria (FISON), pp. 240–244.

Andriyono, S., Fitrani, M., 2021. Non-native species existence and its potency to be invasive species on freshwater ecosystem in East Java Province, Indonesia. Egypt. J. Aquat. Biol. Fish. 25 (2), 1013–1024.

Anonymous, 1997. Investigation of Lake Qarun ecosystem. Final Report submitted to USAID and NIOF, Cairo, Egypt, p. 287.

Aritaki, M., Seikai, T., 2004. Temperature effects on early development and occurrence of metamorphosis-related morphological abnormalities in hatchery-reared brown sole *Pseudopleuronectes herzensteini*. Aquaculture 240, 517–530.

Bariche, M., Fricke, R., 2020. The marine ichthyofauna of Lebanon: an annotated checklist, history, biogeography, and conservation status. Zootaxa 4775 (1), 1–157.

Ben-Tuvia, A., 1990. A taxonomic reappraisal of the Atlanto-Mediterranean soles *Solea solea, S. senegalensis* and *S. lascaris*. J. Fish. Biol. 36, 947–960.

Bishai, H.M., Kirollus, S.Y., 1988. Net selectivity of *Solea vulgaris* Quesel in Lake Qarun, Egypt, vol. 56. Bulletin of the Faculty of Sciences, Cairo Univ, pp. 209–219.

Bok, T.D., Gokturk, D., Kahraman, A.E., Alicli, T.Z., Acun, T., Ates, C., 2011. Length-weight relationships of 34 fish species from the Sea of Marmara, Turkey. J. Anim. Vet. Adv. 10 (23), 3037–3042.

Bolker, J.A., Hill, C.R., 2000. Pigmentation development in hatchery reared flat fishes. J. Fish. Biol. 56, 1029–1052.

Borsa, P., Quignard, J.-P., 2001. Systematics of the Atlantic–Mediterranean soles *Pegusa impar*, *P. lascaris*, *Solea aegyptiaca*, *S. senegalensis*, and *S. solea* (Pleuronectiformes: Soleidae). Can. J. Zool. 79, 2297–2302.

Boulos, R., Ashour, M.B., 1973. Studies on the female reproductive cycle of some fishes at Lake Quarun (Faiyoum, Egypt). IV. Seasonal morphological and macroscopic changes of the overy of Solea vulgaris. Bull. Facul. Sci., Cairo Univ. 46, 253–273.

Cerim, H., Ateş, C., 2020. Age, Growth and Length-weight Relations of Common Sole (*Solea solea* Linnaeus, 1758) from Southern Aegean Sea. Aquat. Sci. Eng. 35 (2), 36–42.

Cerim, H., Yapõcõ, S., Yõlmaz, Ö., 2022. Lateral line and caudal fin anomalies in common sole (Solea solea Linnaeus, 1758) from southern Aegean Sea. Ege J. Fish. Aquat. Sci. 39 (2), 165–169.

Chabanaud, P., 1927. Les soles de l'Atlantique oriental nord et des mers adjacentes. Bull. Inst. Oceanogr. (Monaco) 488, 1–67.

Dabuleviciene, T., Jucevicius, D., Zolubas, T., Vaiciute, D., Nika, N., 2023. The Effect of Short-Term Upwelling Events on Fish Assemblages at the South-Eastern Coast of the Baltic Sea. Water 15, 452.

Demirel, N., Dalkara, E.M., 2012. Weight–length relationships of 28 fish species in the Sea of Marmara. Turk. J. Zool. 36 (6), 785–791.

Desouky, M.G., 2016. Population dynamics of the Egyptian Sole Solea aegyptiaca Chabanaud, 1927 (Osteichthyes: Soleidae), in Qarun Lake, Egypt). Int. J. Fish. Aquat. Stud. 4 (5), 421–425.

Dulčić, J., Soldo, A., 2005. Absence of caudal fin in Solea solea (Soleidae) collected in the Northern Adriatic. Cybium 29 (3), 308–309.

Dulčić, J., 2004. Incidence of spinal deformities in natural populations of grass goby, Zosterisessor ophiocephalus from the Karin Sea, Eastern Middle Adriatic. Cybium 28 (1), 7–11.

EL-Aiatt, A.O., Omar, S.A.A., 2020. Some biological parameters of the common sole, *Solea solea*, from the Bardawil Lagoon, Egypt. Abbassa Int. J. Aqua. 13 (2), 325–348.

El-Aiatt, A.A.O., Shalloof, K.A.Sh, El-Far, A.M., 2019. Reproductive biology of the common sole, *Solea solea*, in Southern East Mediterranean, Bardawil Lagoon, Egypt. Egypt. J. Aquat. Biol. Fish. 23 (1), 403–411.

El-Far, A.M., 2014. Assessment of Qarun Lake Fisheries with Special reference to fishery biology of Solea spp. Ph. D. Thesis. Fac. Sci. Benha University.

El-Husseiny, M.M.A., 2001. Reproductive biology of *Solea* spp. In Lake Quarun. M. Sc. Thesis. Faculty of Science, Ain Shams Univeristy.

El-Serafy, S.S., El-Haweet, A.E.A., El-Ganiny, A.A., El-Far, A.M., 2014. Qarun Lake fisheries; fishing gears, species composition

and catch per unit effort. Egypt. J. Aquat. Biol. & Fish. 18 (2), 39–49.
El-Zarka, S., Kamel, F., 1965. Mullet fry transplantation and its contribution to the fishery of the inland brackish lakes in Egypt. U.A.R. Proc. Gen. Fish. Count. Medit. 8, 209–226.
El-Zarka, S., 1963. Acclimatization of *Solea vulgaris* (Linn.) in Lake Qarun, Egypt. J. Conseil pour l' Explorat. Mer 28, 126–136.
El-Zarka, S., 1968. Rehabilitation of the fisheries of an inland saline lake in the United Arab Republic. Proc. Gen. Fish. Council Mediter. 35, 21–43.
Faouzi, H., 1935. Successful stocking of Lake Qarun with mullets (*Mugil cephalus* Linn. and M. capito Cuv.) from the Mediterranean. Nature 135, 434–439.
Fetouh, M., El-Far, A., 2023. Length-weight relationships and condition factors of bony fishes inhabiting the Southern East Mediterranean Sea, Bardawil Lagoon, Egypt. Egypt. J. Aquat. Biol. Fish. 27 (5), 837–855.
Fischer, W., Bauchot, M.-L., Schneider, M. (Eds.), 1987. Fiches FAO d'identification des especes pour les besoins de la pêche. Méditerranée et Mer Noire (Zone De Pêche 37), Révision 1, vol. 2. FAO, Rome, pp. 761–1530.
Gabr, M.H., 2015. Capture production and stock assessment of Solea aegyptiaca Chabanaud, 1927 (Soleidae: Pleuronectiformes) in Bardawil Lagoon, Egypt. Egypt. J. Aquat. Res. 41 (1), 101–110. https://doi.org/10.1016/j.ejar.2015.01.006.
Goucha, M.A., 1981. Propos de quelques anomalies chez les soles du genre *Solea* (Pisces, Heterosomata, *Soleidae*) du golfe de Tunis. Arch. Inst. Pasteur. Tunis 58 (3), 477–486.
Gozlan, R.E., 2008. Introduction of non-native freshwater fish: is it all bad? Fish Fisher. 9, 106–115.
Gurbet, R., 2000. Variation in the stock assessment and distribution of demersal fish biomass in the Northern Aegean Sea. Ege J. Fish. Aquat. Sci. 17 (3–4), 105–117.
Hossucu, B., Kaya, M., Taşkavak, E., 1999. An investigation of growth parameters and otolith-total length relationship of *Solea solea* (l., 1758) (Pisces: Soleidae) in İzmir Bay. Isr. J. Zool. 45, 277–287.
Ishak, M.M., Abdel-Malek, S.A., Shafik, M.M., 1982. Development of mullet fisheries (Mugilidae) in Lake Quarun, Egypt. Aquaculture 27, 251–260.
Ishak, M.M., 1980. The fisheries of Lake Qarun. In: ICLARM Newsletter, P14 of P14-29.
Kahraman, A.E., Yõldõz, Taner, Uzer, U., Özgür, Ç., 2021. Growth pattern, mortality and reproductive biology of common sole, *Solea solea* (Linneaus, 1758), in the Sea of Marmara, Turkey. Oceanol. Hydrobiol. Stud. 50 (4), 398–410.
Kennard, M.J., Arthington, A.H., Pusey, B.J., Harch, B.D., 2005. Are alien fish a reliable indicator of river health? Freshw. Biol. 50, 174–193.
Kirollus, S.Y., 1977. Biological studies of *Solea vulgaris* Quensel, in Lake Qarun, Egypt. M. Sc. Thesis. Faculty of Science, Cairo University.
Kiruba-Sankar, R., Raj, J.P., Saravanan, K., Kumar, K.L., Angel, J.R.J., Velmurugan, A., Roy, S.D., 2018. Invasive species in freshwater ecosystems–threats to ecosystem services. In: Biodiversity and climate change adaptation in Tropical Islands. Elsevier Inc., pp. 257–296. https://doi.org/10.1016/B978-0-12-813064-3.00009-0
Mahmoud, N.E., Fahmy, M.M., Abuowarda, M.M., 2017. An investigation of Cymothoid isopod invasion in Lake Qarun fishes with preliminary trial for biological control. Internat. J. Chem. Tech. Res. 10 (2), 409–416.
Mehanna, S.F., Farouk, A.E., 2021. Length-weight relationship of 60 fish species from the Eastern Mediterranean Sea, Egypt (GFCM-GSA 26). Front. Mar. Sci. 8, 1–7. https://doi.org/10.3389/fmars.2021.625422.
Mehanna, S.F., Salem, M., 2012. Fisheries regulations based on yield per recruit analysis for the common sole *Solea solea* (Soleidae) at Bardawil Lagoon, Mediterranean Coast of Sinai, Egypt. Egypt. J. Anim. Prod. 49 (1), 113–121. https://doi.org/10.21608/ejap.2012.94358.
Mehanna, S.F., 2007. Stock Assessment and Management of the Egyptian Sole, *Solea aegyptiaca* Chabanaud, 1927 (Osteichthyes: Soleidae), in the Southeastern Mediterranean, Egypt. Turk. J. Zool. 31, 379–388.
Mehanna, S.F., 2020. Isopod parasites in the Egyptian fisheries and its impact on fish production: Lake Qarun as a case study. Egypt. J. Aquat. Biol. Fish. 24 (3), 181–191.
Meshal, A.N., 1973. Water and salt budget of Lake Qarun, Fayum, Egypt. Ph. D. Thesis. Faculty of Science, Alexandria Univ., p. 109
Naguib, M., 1958. Studies on the ecology of Lake Qarun (Fayum, Egypt). Part I. Kiel. Meeresforsch. 14, 187–222.
Nehemia, A., Maganira, J.D., Rumisha, C., 2012. Length-Weight relationship and condition factor of tilapia species grown in marine and fresh water ponds. Agric. Biol. J. N. Am. 3 (3), 117–124.
Neuheimer, A., Thresher, R., Lyle, J., Semmens, J., 2011. Tolerance limit for fish growth exceeded by warming waters. Nat. Clim. Change 1, 110–113.
Pinna, M., Zangaro, F., Saccomanno, B., Scalone, C., Bozzeda, F., Fanini, L., Specchia, V., 2023. An overview of ecological indicators of fish to evaluate the anthropogenic pressures in aquatic ecosystems: from traditional to innovative DNA-based approaches. Water 15 (949), 21.
Quéro, J.C., Desoutter, M., Lagardère, F., 1986. Soleidae. In: Whitehead, P.J.P., Bauchot, M.L., Bureau, J.C., Nielsen, J., Tortonese, E. (Eds.), Fishes of the north-eastern atlantic and the mediterranean, vol. III. UNESCO, pp. 1308–1328.
Quignard, J.P., Pasteur, N., Shehata, S., 1984. Biosystematique du complexe *Solea vulgaris* du Golfe du Lion (Poissons, Tkleostkens, Soleides). Gtnetique, morphologie, et etude meristique. Rev. Trav. Inst. Pêches Marit. 46, 273–284.
Sanaye, S.V., Sreepada, R.A., Pawar, A.P., 2019. Incidence of ambicolouration in the *Malabar tonguesole*, *Cynoglossus macrostomus* (Norman, 1928) collected off Chapora, Goa, Central west coast of India. Indian J. Geo Marine Sci. 48 (1), 49–51.
Shaheen, A.A., Abd El Latif, A.M., Elmadawy, R.S., Noor Eldeen, A.I., 2017. Isopodiosis in some fishes from Egyptian Qarun Lake: prevalence, identification, pathology and in vitro trials to get rid of it. RJPBCS 8 (1), 1971–1979.
Shalloof, K. A. Sh, 2009. Some observations on fisheries biology of *Tilapia zillii* (Gervais, 1848) and *Solea vulgaris* (Quensel, 1806) in Lake Qarun, Egypt. World J. Fish Mar. Sci. (1), 20–28.
Soliman, G.F., 1989. The hydrology of Lake Qarun, Fayum, Egypt. Part II; The successive increase of salinity. Bull. Natl. Inst. Oceanogr. Fish. 15, 93–105.
Syafei, L.S., Sudinno, D., 2018. Ikan Asing Invasif, Tantangan Keberlanjutan Biodiversitas Perairan. J. Penyuluhan Perikanan dan Kelautan 12, 149–165.
Tarkan, A.S., Marr, S.M., Ekmekçi, F.G., 2015. Non-native and translocated freshwater fish species in Turkey. FiSHMED Fish. Mediter. Environ. 2015 3, 28.
Tutman, P., Glamuzina, B., Skaramuca, B., Kožul, V., Glavić, N., Lučić, D., 2000. Incidence of spinal deformities in natural populations of sandsmelt, Atherina boyeri (Risso, 1810) in the Neretva River Estuary, middle Adriatic. Fish. Res. 45, 61–64.
Veiga, P., Machado, D., Almeida, C., Bentes, L., Monteiro, P., Oliveira, F., Ruano, M., Erzini, K., Gonçalves, J.M.S., 2009. Weight-length relationships for 54 species of the Arade estuary, southern Portugal. J. Appl. Ichthyol. 25, 493–496.

Venizelos, A., Benetti, D.D., 1999. Pigment abnormalities in flat fish. Aquaculture 176, 181—188, 1999.

Wheeler, A., 1988. The nomenclature of the sole, *Solea solea* (Linnaeus 1758). J. Fish. Biol. 33, 489—490.

Whitefield, A.K., Elliott, M., 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J. Fish. Biol. 61 (Supplement A), 229—250.

Whitfield, A.K., 1996. Fishes and the environmental status of South African estuaries. Fish. Manag. Ecol. 3, 45—57.

Wimpenny, R.S., Faouzi, H., 1935. The breeding of a gry mullet, Mugil capito, Cuv., in Lake Qarun, Egypt. Nature 135 (3425), 1041.

Younes, A.M., Noor Eldin, A.I., Abd Ellatif, M.A., 2016. A contribution of crustacean isopodoa, bacterial infections and physicochemical parameters in mass mortalities among fishes in Lake Qarun. Res. J. Pharmaceut. Biol. Chem. Sci. 7 (2), 1906—1911.

Zaghloul, K.H., Omar, W.A., Abdel-Khalek, A.A., Abo-Hegab, S., 2011. Ecological Monitoring of Mediterranean Solea aegyptiaca Transplanted into Lake Qarun, Egypt. Austr. J. Basic Appl. Sci. 5 (7), 851—862.

Zangaro, F., Saccomanno, B., Tzafesta, E., Bozzeda, F., Specchia, V., Pinna, M., 2021. Current limitations and future prospects of detectionand biomonitoring of NIS in the Mediterranean Sea through environmental DNA. NeoBiota 70, 151—165.

Ziegler, P.E., Lyle, J.M., Haddon, M., Ewing, G.P., 2007. Rapid changes in life-history characteristics of a long-lived temperate reef fish. Mar. Freshw. Res. 58, 1096—1107, 2007.

Zogaris, S., Koutsikos, N., Chatzinikolaou, Y., Ozeren, S.C., Yence, K., Vlami, V., Kohlmeier, P.G., Akyildiz, G.K., 2023. Fish assemblages as ecological indicators in the Büyük Menderes (Great Meander) river, Turkey. Water 15, 2292. https://doi.org/10.3390/w15122292, 2023.