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ENHANCING *OREOCHROMIS NILOTICUS* STOCK ASSESSMENT IN THE NILE RIVER IN ASWAN, EGYPT, BY USING TROPFISHR FOR SUSTAINABLE FISHERIES MANAGEMENT

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ABSTRACT

This study investigated the length-based stock assessment parameters and reproductive biology of *Oreochromis niloticus* in the River Nile (Aswan, Egypt), aimed to identify strategies for sustainable yield. The **TropFishR** package in R is used to visualize and assess the stock status of *O. niloticus* in this work. A total of 739 fish were analyzed, with males representing 75.2% and a male-to-female ratio of 1:0.33. The gonadosomatic index revealed two distinct spawning seasons: March-April and September. Growth parameters for the stock were $L\infty$ = 33.61 cm, K = 0.339/year, and Φ = 2.85. Total mortality (Z) was calculated as 4.03 year^{-1}, with natural mortality (M) at 0.586 year^{-1} and fishing mortality (F) at 3.44 year^{-1}, resulting in an exploitation rate (E) of 0.85. These results indicate that the stock is severely overfished, with an F_{curr}/F_{max} ratio of 1.9. It is recommended that fishing pressure be reduced and that strong, evidence-based management techniques be implemented to support the maintenance and restoration of spawning biomass.

INTRODUCTION

Fisheries play an essential role in a particular region's food security, economy, and environmental sustainability. Egypt is no exception, and here the fisheries sector contributes significantly to the national food supply, with the River Nile and its tributaries being home to a range of fish species. Nile tilapia (*Oreochromis niloticus*) is perhaps the most well-known commercially important fish or, more precisely, aquaculture animal as well as a vertebrate in the region, particularly, the Aswan area (Abouelfadl *et al*., 2020). *O. niloticus* is of great importance to the economy and food security of the local people. Appropriate stock evaluation and sustainable management practices for O. niloticus are necessary to secure the future of fisheries in the River Nile.

The *O. niloticus* fish is found in the Nile and its affluents, coastal lagoons, and Lake Nasser in Egypt (Authman *et al*., 2012). Nonetheless, the recent analysis shows a drop in fish catches in the basin of the River Nile, which raises the problem of overfishing and stock depletion (FAO, 2020). Overexploitation of fish stocks, environmental changes, and habitat deterioration present a serious obstacle to the sustainable management of fisheries resources (Mohammed-Abdallah *et al.,* 2022). These issues require an innovative stock assessment to evaluate fisheries population dynamics and guide proper management efforts accurately.

Knowing the reproductive features and population dynamics of *O. niloticus* is crucial for family management and resource allocation strategies, as well as for environmental protection efforts (Muchlisin, 2014). Analyzing biological parameters such as age composition, growth, and reproduction can help clarify population sustainability. Newer models of fishery assessment, i.e., the Yield per Recruit model, improve the predictive evaluation of the outcome of fisheries exploitation on resources and ecosystems, aiding conservation efforts while sustaining economic demands (Ganga, 2017).

Although many studies have been conducted on *O. niloticus* populations in Egyptian waters, those near the Nile at Aswan have been scarce (Kassem *et al.,* 2023). To improve stock assessment, this study demonstrates how TropFishR, an advanced fisheries analysis tool, could be integrated into data evaluation as an assessment technique. This research aims to extend knowledge of the population structure and reproductive processes of *O. niloticus* using advanced, integrated, intensive assessment methods along the River Nile in Aswan. The research results will help inform economic management of fisheries to optimize the remaining ecological value of the river system.

MATERIAL AND METHOD

Study area

About 18.6 Kilometers in length, the study was conducted in several chosen fishing communities in Aswan River Nile, geographically between Lat. 24° 2'4.68"N” and Lat. 24° 11'35.14". (Fig. 1). To cover the whole area, four stations of fishing grounds were chosen (Ferial, Elmahata, Aboelrish and Bahreef), the ground of these areas is characterized by muddy and rocky bottom with depths ranging between 1.5 to 2.5m (Saber *et al.,* 2024).

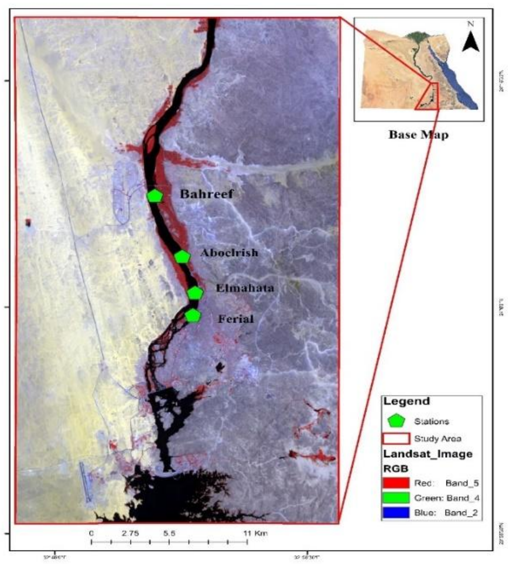

Figure 1. Map of the study area of the River Nile in Aswan city.

Sampling

739 Individuals were sampled from four regions along the River Nile in Aswan city (Ferial, Elmahata, Aboelrish, and Bahreef) to cover the whole area. Fish samples of *O. niloticus* were collected monthly from January 2021 to December 2021 using a trammel net with inner layers mesh sizes of 56, 64, and 76mm, while the outer layer mesh size was 152.4mm for three nets. The three nets were constructed with the same twine diameter, 0.13mm in the inner layer and 0.21mm for the outer layer. The nets were used by small fishing vessels (symbok) without engines, working by paddle. Sampling was carried out. All individuals were taken to the laboratory for accurate measurements. All individuals were measured to the nearest mm for total length (TL) and to the nearest g for total weight (WT). Finally, the sex of each specimen was recorded.

sex ratio

The sex ratio was calculated from the formula of Sex ratio (M:F) = Number of Females/Number of males (Vazzoler, 1996). This ratio was determined across different months and length groups.

Gonado-somatic index (GSI)

Gonado-somatic index (GSI) is a measure that describes the state of maturity of a fish by expressing the wet weight of the gonads as a percentage of fish weight. The GSI was calculated using the following formula: G.S.I. = (gonad weight/fish gutted weight) x 100 (Sokal and Rohlf, 1969).

Growth Parameters

Growth parameters, including curvature parameter (K), asymptotic length ($L\infty$), theoretical age at length zero (to), and the growth performance index (Φ'), were estimated using the ELEFAN_ SA. The growth performance index was calculated as $\Phi' = 2 \log TL\infty + \log K$ (Pauly and Munro, 1984). Analyzing data's TropFishR v.4.4.1 R package was used.

Mortality

Total mortality (Z) was estimated from the length converted catch curve of Pauly (1983), and natural mortality (M) was calculated using the empirical formula of Pauly (1980) as Log M=-0.065–0.287 Log TL∞+0.604 Log K+0.513 Log T, with a mean annual water temperature T of 22.5 °C. The estimate of (F) was obtained by subtracting (M) from (Z). Then, the exploitation ratio was computed as E = F/Z (Eberhardt and Ricker, 1977). TropFishR v.4.4.1 R package was used to evaluate the data.

Virtual Population Analysis (VPA):

Virtual population analysis as modified in Jones and Van Zalinge (1981) was applied to assess the *O. niloticus* stock in River Nile, Aswan city by using TropFishR package. The inputs for VPA included ‘a’ and ‘b’ constants from length weight relationship, fishing mortality (F), natural mortality (M), terminal fishing mortality (Ft) and growth parameters (L∞ and K).

Relative yield and biomass per recruit

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

(Y`/R) = E*U(M/K) *[1- 3U/(1+m) + 3U2/(1+2m) -U3/(1+3m)]

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

RESULT

A total of 739 *O. niloticis* individuals, with a total length ranging from 12 to 24.3 cm, including 556 males and 183 females, were collected for reproductive biology studies.

Sex ratio

The sex distribution is illustrated in the Table (1). The two sexes did not appear in equal proportions during the several seasons, with males prevailing in all seasons. The overall sex ratio (M: F) was 1:0.33. The number of males exceeded that of females. Fig. 2 illustrates the variance in male to female sex ratios of *O. niloticus* across different length groups. The seasonal variation in the sex ratio of O. niloticis is shown in Fig. 3.

Table 1: Seasonal changes in the sex ratio of Nile tilapia (*Oreochromis niloticus*) in the River Nile, Aswan City.

season	Male		Female		total	sex ratio M:F
	No.	%	No.	%		
spring	113	80.71429	27	19.28571	140	1:0.24
summer	110	72.36842	42	27.63158	152	1:0.38
Autumn	229	79.51389	59	20.48611	288	1:0.26
Winter	104	65.40881	55	34.59119	159	1:0.53
total	556	75.23681	183	24.76319	739	1:0.33

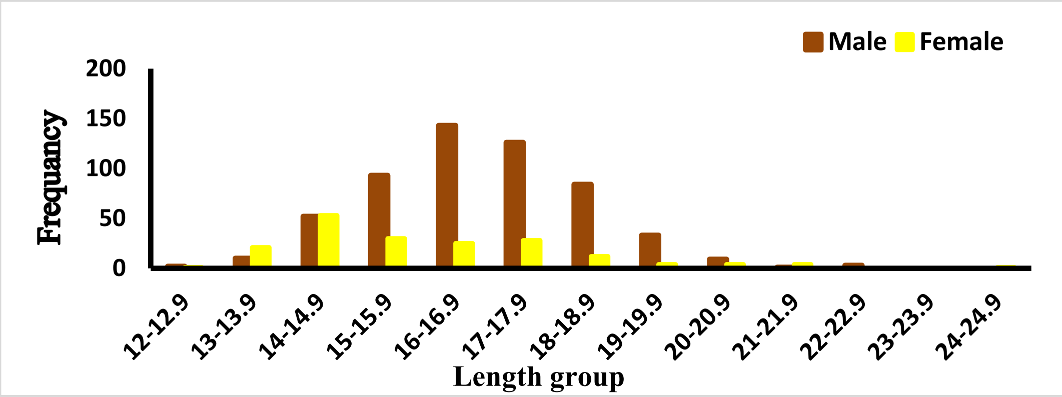

Figure 2. Proportions of male and female *Oreochromis niloticus* by length group.

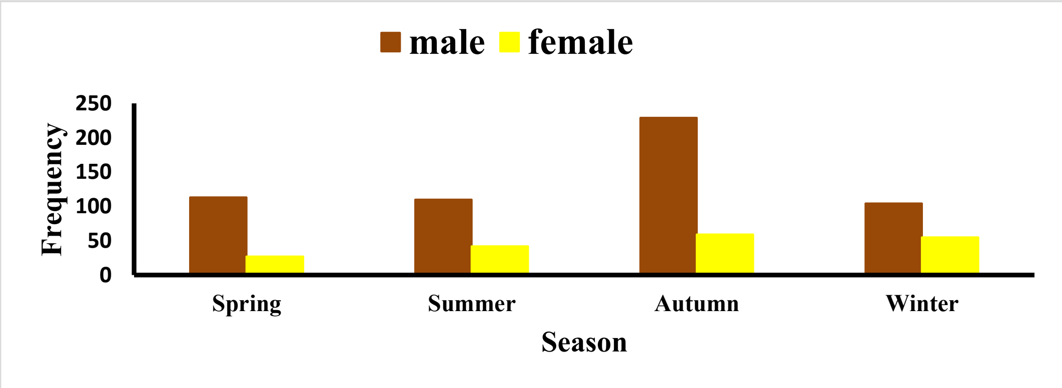

Figure 3. seasonal variation in the percentages of males and females of *Oreochromis niloticus* at River Nile, Aswan city.

Gonado-somatic index (GSI)

Females recorded GSI values much higher than GSI values of males. The overall GSI values were illustrated that *O. niloticus* have two spawning seasons, the first one in March and April and the second one in September (Fig. 4).

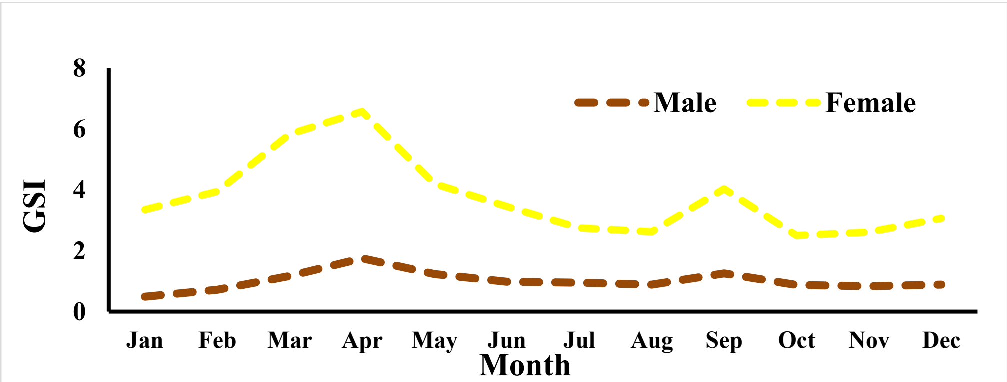

Figure 4. Monthly variation in GSI values for *Oreochromis niloticus* from River Nile in Aswan city

Length distribution

A total of 739 samples of *O. niloticus* were collected throughout the study period. The average, minimum, and maximum lengths of *O. niloticus* were determined to be 16.7 cm, 12 cm, and 24.3 cm, respectively. Thirteen length groups were identified for *O. niloticus* were ranged from 12.5 to 24.5 cm. Table 2 illustrates the length distribution of *O. niloticus*, with December showing the highest sample count (N = 134), while February recorded the lowest sample count (N = 14).

Table 2: Monthly Length-Frequency Distribution of Nile Tilapia (*Oreochromis niloticus*) in the River Nile, Aswan City.

Length Class (cm)	2021 Jan	2021 Feb	2021 Mar	2021 Apr	2021 May	2021 Jun	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec
12	1	0	0	0	0	0	0	2	0	0	0	0
13	4	0	1	2	0	1	5	5	3	0	4	6
14	7	2	7	9	4	9	5	13	2	5	20	21
15	22	0	6	10	4	7	13	4	4	5	9	38
16	21	2	8	17	5	19	11	11	5	17	17	35
17	31	7	12	12	6	9	6	12	13	12	14	19
18	14	2	2	10	2	3	5	7	11	19	11	13
19	6	1	0	4	0	5	1	6	4	7	3	1
20	0	0	1	1	0	0	0	1	1	3	4	1
21	2	0	0	0	0	0	0	1	1	0	1	0
22	0	0	0	0	0	0	0	0	0	2	1	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	1	0	0	0	0	0	0
Total	108	14	37	65	21	54	46	62	44	70	84	134

Fig. 5 displays the restructured length-frequency of O. niloticus with growth curves overlaid. For length-frequency data, the ELEFAN_SA and ELEFAN_GA algorithms were both used. Based on a higher Rn (goodness-of-fit index) value, the ELEFAN_SA results were judged more appropriate for the data set than the ELEFAN_GA results. The asymptotic length ($L\infty$) was 33.61 cm with a growth rate (K) of 0.339 per year. t_anchor was 0.343. ts was 0.91. Growth performance index (Φ') was 2.85. The Powell Wetherall plot showed Z/K to be 1.98 with a 95% confidence interval of 1.77 – 2.19 Fig. 6.

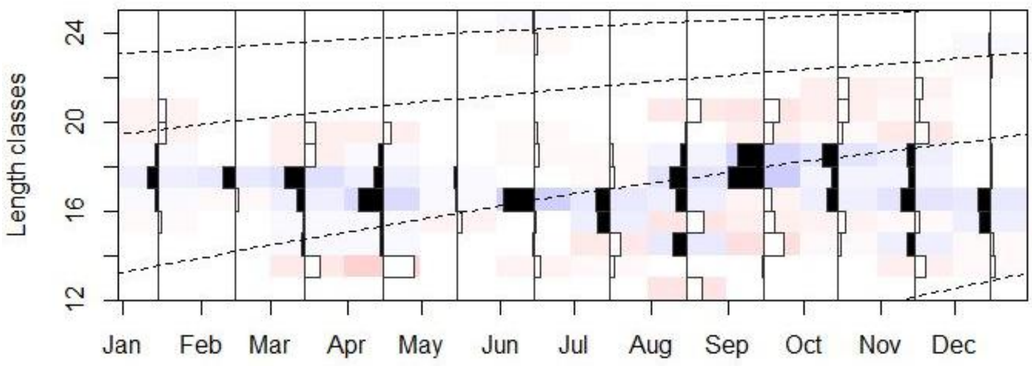

Figure 5. Reconstructed length-frequency distribution accompanied by growth curves.

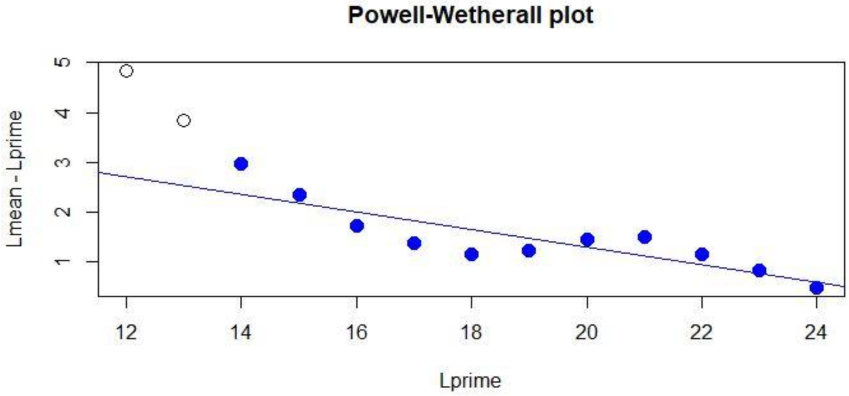

Figure 6. Powell Wetherall Plot of *Oreochromis niloticus*

Mortality parameters

The linearized length-converted catch curve was used for the estimation of total mortality (Z) as illustrated in **Fig. 7**. The total mortality (Z) of *O. niloticus* was 4.03 ± 0.23 per year**,** the natural mortality rate (M) was 0.586 year^{-1} and fishing mortality rate (F) estimated at 3.444 year^{1}. Exploitation rate (E) was 0.85.

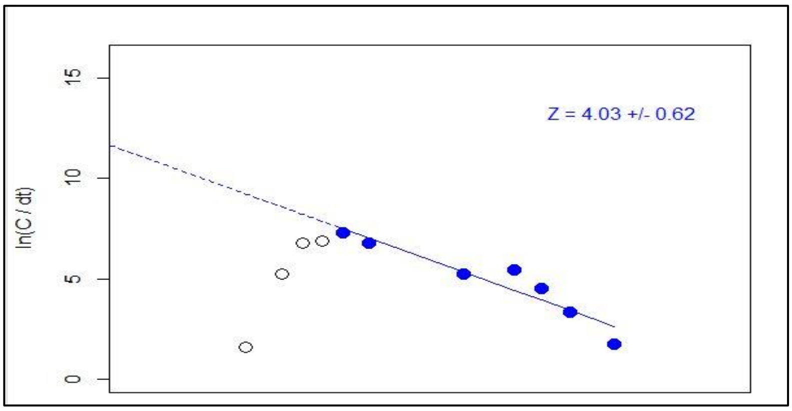

Figure 7. Total mortality estimation (Z) using a linearized catch curve that is converted to length.

Virtual Population Analysis (VPA):

Individuals measuring 16.5 cm exhibited the greatest degree of exploitation, with an annual catch of 159. Natural losses were greatest among individuals measuring 12.5 cm in length. The number of surviving individuals in the stock showed a decreasing trend in response to increasing fishing pressure. The greatest number of survivors in the stock was recorded within the length range of 12.5 cm. The fishing effort reached its peak at F = 3.84 per year for individuals measuring 18.5 cm, while it was minimal at F = 0.001 per year for those measuring 12.5 cm (Fig. 8).

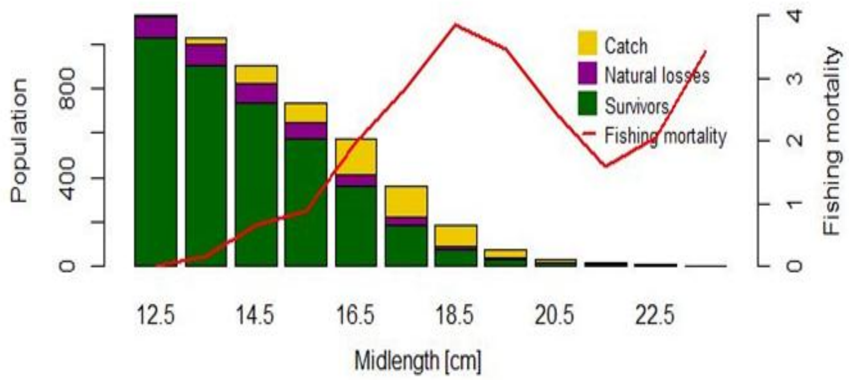

Figure. 8. Length-structured VPA of *Oreochromis niloticus* in the River Nile, Aswan City.

Relative Yield per recruit and Biomass per recruit

Table 3 presents the estimated biological reference points for *O. niloticus*, specifically yield per recruit (YPR) and biomass per recruit (BPR). The present E value (0.85) exceeds the optimal level proposed by Gulland (1969), where F_{opt} equals M or E equals 0.5. The stock can be classified as overfished based on an E_{curr} value exceeding 0.5. The current estimated fishing mortality (F_{curr}) significantly exceeds the optimal biological fishing mortality Fmax (1.81 year−1) and F0.1 (0.87 year−1). The ratio of F_{curr} to Fmax is calculated as 1.9, significantly exceeding the optimal level of 1, indicating another result of overfishing. Figure 9 presents the graphical outputs of the catch curve and yield per recruit (YPR) model.

Table 3. The impact of variations in fishing mortality on the biological reference points of *Nile* Tilapia *(Oreochromis niloticus)* in the River Nile at Aswan city.

Level of F	F	E	YPR	BPR
01	0.87	0.216	51.58	100.7
05	0.65	0.161	47.65	118
Max	1.813	0.449	55.42	63.7
Current	3.44	0.851	53.83	41.2

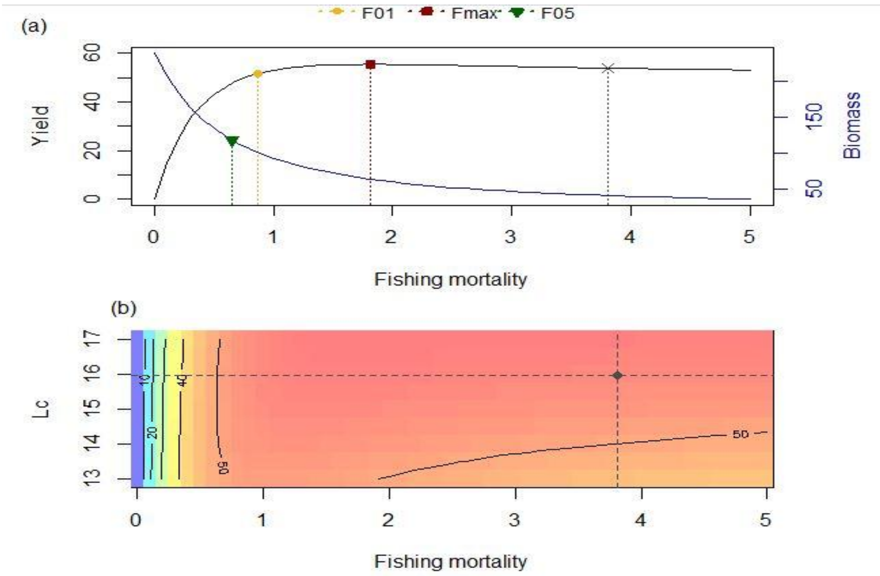

Figure. 9: a) Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) of O. *niloticus* from the River Nile in Aswan City. b) Isopleth plot of *Oreochromis niloticus* from the River Nile in Aswan City.

DISCUSSION

The sex ratio is a valuable metric for analyzing spawning populations (Sabrah et al., 2017). The current study indicates that the sex ratio of *O. niloticus* showed a dominance of males throughout the entire study period. These findings agree with the results of Njiru *et al.* (2006) In Lake Victoria, Waithaka et al. (2020)In Lake Naivasha, El-Kasheif *et al.* (2013) in Damietta branch and Bakhoum (2002) in lake Edku. In contrast, these results disagree with Shalloof *et al.* (2008) who reported that females dominated the catch for O. niloticis in Abu-zabal Lake, which is located about 800 km from Aswan (Table 4). The dominance of males may be associated with variations in ecological conditions across different study areas, which can influence sex differentiation based on genetic background and the development of various strains.

The gonado-somatic index (GSI) refers to the relationship between the gonad weight and the fish somatic weight (Wootton, 1990) and the changes in the gonado-somatic index are an indicator of the reproductive seasonality of fish species (King, 1995; Tagarao et al., 2020)**.** In the present study, the results showed that GSI values of females more than those of males for *O. niloticis, which* may be due to low energy investment in gamete production as compared to the female(Buxton, 1990; Panicker, 2021). The present GSI values were illustrated that *O. niloticis* have two spawning seasons, the first one in March and April and the second one in September. These finding agrees with the results of Shalloof et al. (2008) in Abu-zabal Lake and agree with Bakhoum (2002) in lake Edku. (Table. 4).

In the present study, results from fishing trials indicate that a total of 739 O. niloticis were caught, with total lengths between 12 and 24.3 cm. When compared with other studies on the species (Mahmoud *et al.*, 2013; El-Kasheif *et al.* 2015; Khallaf *et al.*, 2018; Assefa *et al.* 2019) the length range is relatively narrower. The main reason for this situation is the use of varying mesh sizes, coupled with the differing environmental conditions across regions. The study utilized commercial traps with a mesh size of 64 mm, alongside low and high-selective trammel nets with mesh sizes ranging from 56 to 76 mm, specifically designed for this research. The use of commercial catch or highly selective fishing tools for Length-frequency data (LFQ) can result in inaccurate estimates of growth parameters and predictions of the length and duration of stock participation, as it may exclude smaller individuals from the dataset.

A comparison was conducted between the total mortality (Z), natural mortality (m), fishing mortality (F), and exploitation rate (E) of O. niloticus and those reported by various authors across different locations (Table 5). The Z, M, and F values were within the ranges observed for these parameters in other populations of the same species. In the present study, the exploitation rate considered the highest value was 0.85, it was very close to Beaune *et al.* (2021) from Nam Theun 2 reservoir, Thailand. The lowest value of E for the species was 0.43, recorded by El-Kasheif et al. (2015)from El-Bahr El-Faraouny Canal, Egypt.

Relative Yield per Recruit (Y`/R) and Relative Biomass per Recruit for *O. niloticus* using the knife-edge selection procedure. The results of the analysis indicated that the present exploitation rate (Epresent= 0.85) of *O. niloticus* was higher than the optimum exploitation rate (E0.1= 0.216 and Emax= 0.449), which indicates that the stock of *O. niloticus* is over exploited.

Table (4): The Spawning season and sex ratio of Nile Tilapia *(Oreochromis niloticus)* in the present study and from various regions by various authors.

species	Region	Author	Spawning season	Sex ratio (M: F)
O. niloticus	Lake Edku, Egypt	Bakhoum., (2002)	Apr – may	1: 0.93
	Victoria, Kenya	Njiru *et al*., (2006)	——	1: 0.7
	Abu-zabal Lake, Egypt	Shalloof *et al.,* (2008)	Mar, Apr, Jun and Sep	1: 1.37
	Damietta branch, Egypt	El-kasheif *et al*., (2013)	——	1:0.68
	Naivasha, Kenya	Waithaka *et al*., (2020)	——	1: 0.48
	River Nile in Aswan city	Present study	Mar, Apr and Sept	1: 0.33

Table (5): Values of total, fishing and natural mortalities (Z, F and M) and exploitation rate (E), of Nile Tilapia *(Oreochromis niloticus)* from various regions by various authors.

Species	Region	Author	Z	M	F	E
O.niloticus	Lake Manzalah	El-Bokhty, (2006)	3.38	1.04	2.34	0.59
	Nozha Hydrodrome, Egypt	Mahmoud *et al.,* (2013)	1.365	0.403	0.962	0.705
	River Nile	Hassan & El-Kasheif (2013)	0.97	0.4	0.57	0.58
	El-Bahr El-Faraouny Canal	El-Kasheif *et al.,* (2015)	1.15	0.65	0.5	0.43
	Lake Victoria, Kenya	Yongo & Outa (2016)	2.18	1.14	1.05	0.46
	Lake Tana, Ethiopia	Assefa *et al*., (2019)	2.37	0.98	1.39	0.59
	Hilali reservoir, India	Johnson et al. (2020)	1.32	0.60	0.72	0.54
	Nam Theun 2 reservoir, Thailand	Beaune *et al*. (2021)	1.41	0.30	1.11	0.79
	Danau Siombak, Indonesia	Muhtadi *et al*., (2022)	3.20	1.27	1.93	0.59
	River Nile, Aswan city	Present study	4.03	0.586	3.44	0.85

CONCLUSIONS

This study investigates revealed critical insights into the population's structure, growth, reproductive biology, and exploitation status of Nile tilapia (*Oreochromis niloticus*) in the River Nile at Aswan, Egypt. The findings demonstrated that the stock is currently severely overfished, with exploitation rates significantly exceeding optimal biological levels, indicating unsustainable fishing pressure. The presence of two distinct spawning seasons highlights the importance of temporal protection measures to safeguard reproductive biomass. The male-dominated sex ratio and growth parameters provide valuable biological context for management strategies. To ensure the sustainability of the *O. niloticus* fishery in Aswan, it is essential to implement evidence-based management approaches that reduce fishing pressure and support the restoration and maintenance of spawning stock biomass for long-term fishery productivity and ecosystem health.

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CONFLICTS OF INTEREST

The authors state that there are no conflicts of interest with the publication of this work.

Ethical approve
Ethical approval The Animal Use and Care Committee of the Faculty of Fish and Fisheries Technology at Aswan University in Egypt (Fac. FFT. No. 2/2022) gave its approval for the current study's standard operating procedure.

تعزيز تقييم مخزون سمك البلطي النيلي (*Oreochromis niloticus*) في نهر النيل بأسوان، مصر، باستخدام حزمة TropFishR من أجل إدارة مستدامة للمصايد.

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الخلاصة

هدفت هذه الدراسة إلى تقييم المخزون المعتمد على الطول وبيلوجيا التكاثر لاسماك البلطي النيلي في نهر النيل (أسوان، مصر) لتحديد استراتيجيات تحقيق إنتاج مستدام. تم استخدام حزمة TropFishR في لغة Rالتصوير وتقييم حالة مخزون البلطي النيلي في هذا الدراسة. تم تحليل إجمالي 739 سمكة، شكلت الأسماك الذكور نسبة 75.2% وكانت نسبة الذكور إلى الإناث 1:0.33. كشف مؤشر الغدد التناسلية عن وجود موسمين مميزين للتكاثر هما: مارس–أبريل وسبتمبر. أما معاملات النمو للمخزون فكانت: الحد الأقصى للطول اللانهائي (L∞) = 33.61 سم، ومعامل النمو/ (K) = 0.339 سنة، ومؤشر النمو Φ = 2.85. تم حساب معدل الوفيات الكلي (Z) بقيمة 4.03 في السنة، مع معدل الوفيات الطبيعية (M) بقيمة 0.586 في السنة ومعدل الوفيات نتيجة الصيد (F) بقيمة 3.44 في السنة، مما أدى إلى معدل استغلال (E) قدره 0.85. تشير هذه النتائج إلى أن المخزون يُعاني من الإفراط الشديد في الصيد. ويوصى بتقليل ضغوط الصيد ووضع استراتيجيات إدارة قوية قائمة على الأدلة لدعم صيانة واستعادة الكتلة الحيوية الخاصة بالتكاثر.

الكلمات المفتاحية : البلطى النيلى – بيلوجيا التكاثر – ديناميكية التجمعات السمكية –نهر النيل

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