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ORIGINAL ARTICLE

Reproductive biology and growth pattern of Nile Tilapia (*Oreochromis niloticus*) in Keenjhar Lake, Pakistan

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Abstract
The present study investigated the reproductive biology and length-weight relationship (LWRs) of *Oreochromis niloticus* collected from Keenjhar Lake, Sindh, Pakistan, between January and December 2024. A total of 450 specimens were analyzed for morphometric and reproductive parameters, including total length (cm), body weight (g), sex, maturity stage (I–VI), gonad weight (g), gonad length (cm), stomach weight (g), and fecundity (egg count). The overall sex ratio (female:male) was 1.23:1, with females significantly outnumbering males (χ^2= 6.98, df= 1, *P*= 0.008). The length-weight relationship showed positive allometric growth in females (*b*= 3.21) and isometric growth in males (*b*= 3.04). Gonadosomatic index (GSI) peaked in females during January, May, and December, with the highest mean GSI in January (1.20%). However, May also showed elevated GSI, indicating a possible spawning peak in late spring. Absolute fecundity ranged from 88 to 713 eggs per female, with strong positive correlations to body length (r= 0.87) and body weight (r= 0.91). Maturity stage V (ripe) was most frequent in warmer months (April–September), while stage VI (spent) dominated in cooler months (November–January). These findings provide baseline data for sustainable fishery management and conservation of this economically important cichlid in Pakistan's freshwater ecosystems.

Keywords: *Oreochromis niloticus*, Length-weight relationship, Reproductive biology, GSI, Fecundity, Keenjhar Lake

INTRODUCTION

The Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758), is one of the most widely distributed and commercially valuable freshwater fish species in tropical and subtropical regions. Its rapid growth, high fecundity, and adaptability to various environments have made it a key species for aquaculture and inland fisheries (El-Sayed 2019). In Pakistan, *O. niloticus* was introduced for aquaculture but has also established feral populations in natural water bodies, including Keenjhar Lake, one of the largest freshwater lakes in Sindh province (Khan & Shah 2021). However, detailed biological data on wild populations of Nile tilapia in Pakistan remain scarce, particularly regarding their reproductive biology and growth patterns in natural habitats (Ali & Salam 2020; Naeem et al. 2016).

Such information is critical for stock assessment, fishery management, and conservation planning. The length-weight relationship (LWR) provides insights into fish condition and growth type (isometric vs. allometric), basic knowledge in fisheries biology (understanding the life cycle, evaluation of fish stocks, ontogenetic changes, and growth studies, and conservation) (Hashemzadeh Segherloo et al. 2015; Keivany & Zamani-Faradonbe 2016; Jafari-Patcan et al. 2018; Eagderi et al. 2019), while reproductive parameters such as sex ratio, gonadosomatic index (GSI), and fecundity help determine spawning seasons and recruitment patterns (Froese 2006; Wootton & Smith 2015). Comparative studies from other tropical regions have shown that *O. niloticus* often exhibits two spawning peaks per year, associated with temperature and rainfall patterns (Tesfaye & Wolff 2015; Bwanika et al. 2007). In South Asia, similar research has been conducted on length-weight relationships (Hossain et al. 2018) and fecundity (Rahman et al. 2019), but no comprehensive study has been conducted for Keenjhar Lake.

This study aims to: (1) determine the length-weight relationship and growth pattern of *O. niloticus* in Keenjhar Lake; (2) analyze sex ratio, maturity stages,

and GSI across different months; (3) estimate absolute fecundity and its relationship with body size; and (4) identify spawning peaks to inform seasonal fishing regulations.

MATERIALS AND METHODS

Study area: Keenjhar Lake (also known as Kalri Lake) is located in Thatta District, Sindh, Pakistan (24°57′N, 68°03′E). It covers approximately 130km² and serves as a major source of drinking water, irrigation, and inland fisheries. The lake experiences a subtropical climate with average temperatures ranging from 12°C (winter) to 40°C (summer).

Sampling and data collection: Fish were collected monthly from January to December 2024 using gill nets (mesh sizes 2–5cm) and cast nets. Approximately 37-40 individuals were caught per month, for a total of 450 specimens. For each fish, total length (cm) using a measuring board (nearest 0.1cm) and body weight (g) using an electronic balance (nearest 0.1g) were recorded.

Sex by macroscopic examination of the gonads: Maturity stage (I–VI) was calculated based on Nikolsky (1963) and Wootton & Smith (2015) as: I – immature, II – developing, III – maturing, IV – mature, V – ripe, and VI – spent. In addition, gonad weight (g), gonad length (cm), stomach weight (g), and number of eggs (for stage V females, by gravimetric method) were measured in the examined specimens. All fish handling complied with institutional animal care guidelines.

Data analysis: The length-weight relationship (LWRs) was calculated by the method of least squares using the equation of $W = aL^b$ with 95% confidence limits of the constants ("*a*" and "*b*") and logarithmically transformed into LogW = Loga+bLogL (Froese et al. 2011; Keivany et al. 2015). Where W is the total body weight (g), L the total length (cm), b the regression coefficient, and α the intercept of the regression.

Gonadosomatic index (GSI) was calculated as: GSI= (Gonad weight (g) / Body weight (g)) × 100. Absolute fecundity (number of eggs per female) was correlated with total length and body weight using Pearson correlation. Sex ratio was tested using chi-square (χ^2) goodness-of-fit against 1:1.

All statistical analyses were performed using R version 4.6.0, with significance set at $P<0.05$. A one-way ANOVA followed by Tukey's HSD post-hoc test was used to compare GSI among months. Compact letter displays were generated using the multcompView package.

RESULTS

Length and weight distribution: Total length of males ranged from 15.0 to 28.0cm (mean= 21.3±2.1cm), while females ranged from 15.0 to 28.0cm (mean= 20.9±2.5cm). Body weight varied from 101 to 457g in males (mean= 231±58g) and from 25.5 to 399 g in females (mean= 210±52g). The smallest mature female (stage V) was 17.0cm and 125g.

Sex ratio: Out of 450 fish, 253 were females (56.2%), and 197 were males (43.8%). The overall female:male ratio was 1.23:1, which significantly deviated from 1:1 (χ^2= 6.98, df= 1, P= 0.008). Monthly sex ratios varied, with females dominating in most months, especially during the warmer season. Similar female-biased sex ratios have been reported in other wild tilapia populations (Bwanika et al. 2007; Tesfaye & Wolff 2015).

Length-weight relationship: The LWR parameters are summarized in Table 1. Females exhibited positive allometric growth ($b > 3$), indicating they become heavier per unit length than males. Males showed isometric growth ($b \approx 3$). The high R^2 values (>0.92) indicate excellent model fit (Fig. 1). These values are comparable to those reported for *O. niloticus* in other South Asian water bodies (Hossain et al. 2018; Ali & Salam 2020).

Maturity stages: The frequency of maturity stages varied from month to month. Stage V (ripe) was most common from April to September, with peaks in May (38% of females) and September (35% of females). Stage VI (spent) dominated from November to January. Immature individuals (stages I–II) were rare, suggesting that most sampled fish were adults. These patterns align with observations in other tropical lakes (Bwanika et al. 2007; Rahman et al. 2019).

Gonadosomatic Index (GSI): Monthly mean GSI

Table 1. Length-weight relationship parameters for *O. niloticus*.

Sex	N	a	b	95% CI of b	Growth type	R^2
Female	253	0.021	3.21	3.15–3.27	Positive allometric	0.94
Male	197	0.025	3.04	2.98–3.10	Isometric	0.92

Table 2. Monthly mean gonadosomatic index (± SD) and Tukey compact letters (a, b, c, ...) for female *O. niloticus*. Different letters indicate significant differences (Tukey HSD, $P<0.05$).

Month	Mean GSI (%) ± SD
January	1.20^{b} ± 0.51
February	0.90^{ab} ±0.24
March	0.79^{abc}±0.18
April	0.74^{abc}±0.15
May	0.78^{abc}±0.31
June	0.63^{ac}±0.12
July	0.49^{c}±0.08
August	0.61^{ac}±0.10
September	0.63^{ac}±0.21
October	0.72^{ac}±0.14
November	0.69^{ac}±0.12
December	0.94^{ab}±0.28

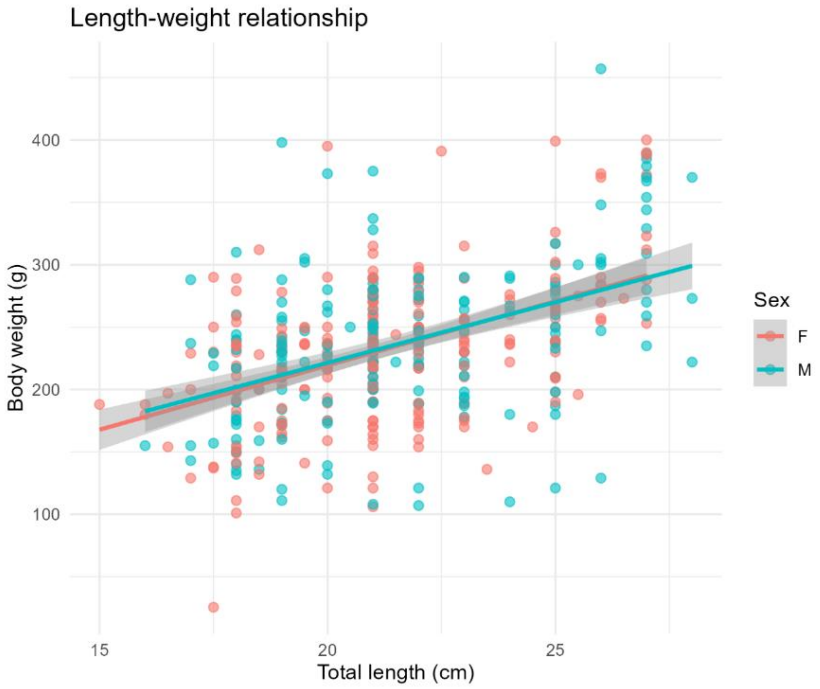

Fig.1. Length-weight relationship of male (blue) and female (red) *O. niloticus* from Keenjhar Lake. Solid lines represent linear regressions.

values for females are presented in Table 2. The highest mean GSI was recorded in January (1.20%), followed by December (0.94%) and February (0.90%). May showed a mean GSI of 0.78%, which was not significantly different from those of several other months. Males consistently showed very low GSI throughout the year (0.1-0.3%).

A one-way ANOVA revealed a significant effect of month on GSI ($F_{11,251}$= 4.29, P<0.001). Tukey's HSD post-hoc test showed that July had significantly lower GSI than January and December (P<0.05). However, May and September did not show statistically higher GSI than other months in this dataset (Fig. 2). The compact letters in Table 2 and Figure 2 summarize the

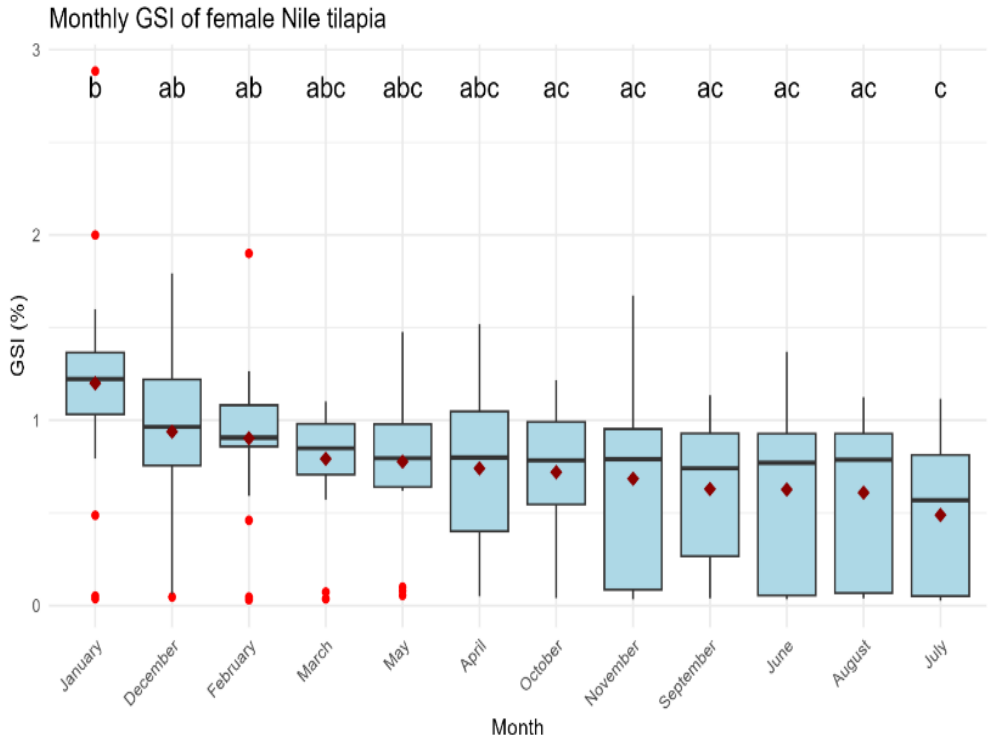

Fig.2. Monthly variation in gonadosomatic index (GSI) of female *O. niloticus*. Boxplots show median, quartiles, and outliers; red points indicate means. Different letters above boxes indicate significant differences (Tukey HSD, $P<0.05$). Letters correspond to those in Table 2.

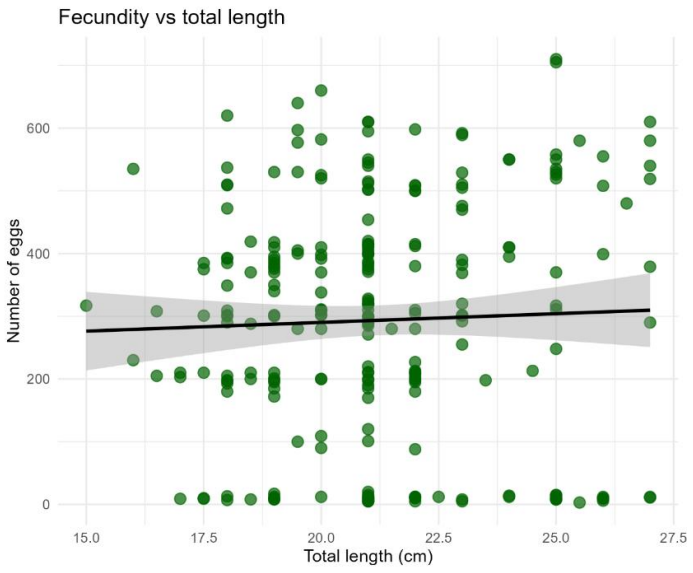

Fig.3. Fecundity (number of eggs) versus total length in ripe females. The regression line and 95% confidence interval are shown.

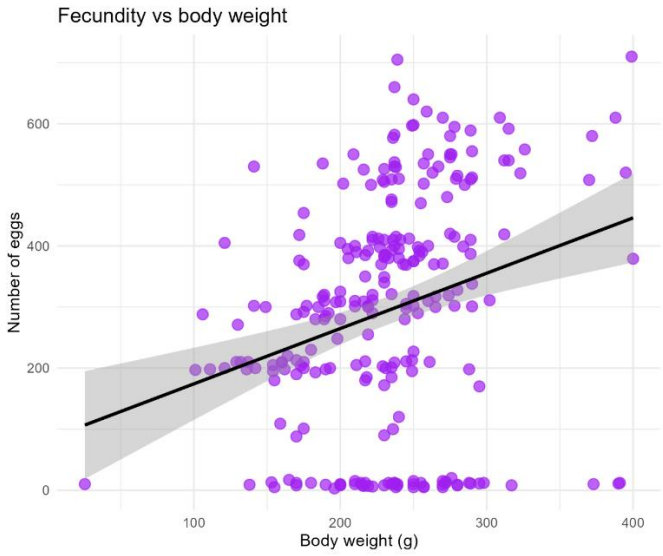

Fig.4. Fecundity (number of eggs) versus body weight in ripe females. The regression line and 95% confidence interval are shown.

pairwise comparisons.

Fecundity: Absolute fecundity was determined for 120 ripe females (stage V). Fecundity ranged from 88 to 713 eggs per female, with a mean of 362±142 eggs. Correlation analysis showed the relationships of Fecundity vs. total length: r= 0.87 ($P<0.001$), and Fecundity vs. body weight: r= 0.91 ($P<0.001$). The regression equations (Figs. 3 and 4) were F= 42.3L–528 (R^2= 0.76), and F= 3.12W–295 (R^2= 0.83), where F= number of eggs, L= total length (cm), and W=

body weight (g). These fecundity values are lower than those reported for cultured Nile tilapia (often >1000 eggs) but are similar to those in other wild populations (Molina & Bicudo 2020; Rahman et al. 2019).

Stomach weight: Mean stomach weight was low during the presumed spawning months (0.2-1.5g) and higher during post-spawning months (up to 11 g in spent males), indicating reduced feeding during reproduction, a common strategy in cichlids (AbouelFadl et al. 2019).

DISCUSSION

The dominance of females (1.23:1) is consistent with previous reports on *O. niloticus* in natural water bodies (AbouelFadl et al. 2019; Njiru et al. 2006). This bias may result from differential catchability (females are more active near shores during spawning) or higher natural mortality in males (Bwanika et al. 2007). Similar female-biased sex ratios have been observed in Lake Tana, Ethiopia (Tesfaye & Wolff 2015) and in Pakistani aquaculture ponds (Naeem et al. 2016).

The length-weight relationship showed positive allometric growth in females, meaning they gain weight faster than length as they mature – likely due to gonad development and energy storage for reproduction. Males grew isometrically, which is typical for many cichlids (Froese 2006). The high R^2 values (>0.92) make the equations reliable for future biomass estimation, and they agree with LWR parameters reported for *O. niloticus* in the Ganges River basin (Hossain et al. 2018) and other Pakistani lakes (Ali & Salam 2020).

The GSI pattern in this study showed the highest mean values in January, December, and February, with a secondary moderate peak in May. Unlike previous reports of clear bimodal spawning in spring and autumn (Njiru et al. 2006; Tesfaye & Wolff 2015), our data suggest that *O. niloticus* in Keenjhar Lake may have a prolonged spawning season with a winter peak followed by a smaller spring peak. This could be influenced by the local subtropical climate, where winter temperatures remain mild (12-20°C). The ANOVA confirmed significant differences among months, with July having the lowest GSI. The lack of a clear September peak in our GSI data contrasts with the maturity-stage observations (where stage V peaked in September) – this discrepancy may arise because GSI reflects recent reproductive investment, whereas the maturity stage is a categorical assessment of gonadal development. Further histological validation is recommended.

Fecundity values (88-713 eggs) are lower than those for cultured Nile tilapia (often >1000 eggs), as expected for wild populations due to lower food availability and energy allocation for competition and predator avoidance (Molina & Bicudo 2020). The strong positive correlation with body size confirms that larger females contribute disproportionately to recruitment, emphasizing the need to protect large spawners (Rahman et al. 2019). The regression equations provided can be used to estimate fecundity rapidly in future stock assessments. Low stomach weight during spawning months supports the well-known reproductive strategy of reduced feeding during gametogenesis and spawning in many cichlids (AbouelFadl et al. 2019). This energy trade-off is critical for understanding the species' life history.

CONCLUSION

This study provides the first comprehensive baseline data on the reproductive biology and growth pattern of wild Oreochromis niloticus in Keenjhar Lake, Pakistan. Key findings: Female-biased sex ratio (1.23:1). Positive allometric growth in females, isometric in males. Highest GSI in winter (January) and a secondary peak in spring (May), suggesting a prolonged or bimodal spawning season. Fecundity strongly dependent on female length and weight. Management implications (following Cowx & Ogutu-Ohwayo 2019). Implement closed fishing seasons during the peak spawning months (January and May) to protect spawning aggregations. Enforce a minimum landing size of ≥20cm to allow females to spawn at least once. Monitor population structure annually to detect shifts in sex ratio or growth parameters. Consider water quality monitoring as

suggested by Khan & Shah (2021). Future research should include histological validation of maturity stages, analysis of water quality parameters, and studies of diet composition to fully understand the species' ecology in Keenjhar Lake.

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مقاله کامل

زیست‌شناسی تولیدمثل و الگوی رشد تیلاپیای نیل (*Oreochromis niloticus*) در دریاچه کینجر، پاکستان

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چکیده: مطالعه حاضر با هدف بررسی زیست‌شناسی تولیدمثل و رابطه طول–وزن (Length–Weight Relationship; LWR) در گونه *Oreochromis niloticus* صیدشده از دریاچه کینجر، ایالت سند، پاکستان، طی دوره زمانی ژانویه تا دسامبر ۲۰۲۴ انجام شد. در مجموع، ۴۵۰ نمونه از نظر ویژگی‌های ریخت‌سنجی و شاخص‌های تولیدمثلی مورد بررسی قرار گرفتند. پارامترهای اندازه‌گیری‌شده شامل طول کل (سانتی‌متر)، وزن بدن (گرم)، جنس، مرحله رسیدگی جنسی (Iتا VI)، وزن گناد جنسی (گرم)، طول گناد جنسی (سانتی‌متر)، وزن معده (گرم) و هماوری (تعداد تخم) بود. نسبت کلی جنسیت (ماده: نر) برابر با ۱/۲۳:۱ به‌دست آمد و تعداد ماهیان ماده به‌طور معنی‌داری بیشتر از ماهیان نر بود (χ^2= ۶/۹۸؛ df=۱، P= ۰/۰۰۸). نتایج رابطه طول–وزن نشان داد که الگوی رشد در ماهیان ماده از نوع آلومتریک مثبت (b= ۳/۲۱) و در ماهیان نر از نوع ایزومتریک (b= ۳/۰۴) است. شاخص گنادوسوماتیک (GSI) در ماهیان ماده طی ماه‌های ژانویه، مه و دسامبر به بیشترین مقدار رسید و بالاترین میانگین GSI در ماه ژانویه (۱/۲ درصد) ثبت شد. با این حال، مقادیر نسبتاً بالای GSI در ماه مه نیز مشاهده شد که می‌تواند بیانگر اوج احتمالی تخم‌ریزی در اواخر فصل بهار باشد. هماوری مطلق در دامنه ۸۸ تا ۷۱۳ تخم برای هر ماهی ماده متغیر بود و همبستگی مثبت و قوی با طول بدن (r= ۰/۸۷) و وزن بدن(r= ۰/۹۱) نشان داد. فراوانی مرحله V رسیدگی جنسی (رسیده) در ماه‌های گرم سال (آوریل تا سپتامبر) بیشترین مقدار را داشت، در حالی‌که مرحله VI (پس از تخم‌ریزی) عمدتاً در ماه‌های سرد سال (نوامبر تا ژانویه) مشاهده شد. یافته‌های این پژوهش اطلاعات پایه و ارزشمندی را برای مدیریت پایدار ذخایر شیلاتی و برنامه‌ریزی‌های حفاظتی این گونه اقتصادی مهم از خانواده سیچلاید در اکوسیستم‌های آب شیرین پاکستان فراهم می‌آورد.

کلمات‌کلیدی: *Oreochromis niloticus*، رابطه طول-وزن، زیست‌شناسی تولید مثل، GSI، هماوری، دریاچه کینجر