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Comparative Analysis of Length-Weight Relationships and Condition Factors of Pond-Grown Nile Tilapia (*Oreochromis niloticus* L.) Across Sexes and Life Stages During the Wet Season in Lubao, Pampanga, Philippines

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ABSTRACT

Assessing biometric parameters such as length-weight relationship (LWR) and condition factor (*K*) is vital in aquaculture for evaluating fish growth performance, health, and adaptability under specific culture conditions. This study investigated the influence of sex and life stage on the LWR and *K* of the Nile tilapia (*Oreochromis niloticus* L.) cultured in ponds during the wet season in Lubao, Pampanga, Philippines. A total of 400 specimens were collected from 20 earthen pond farms, comprising 267 males and 133 females with 142 juveniles and 258 adults. Total length (TL) and weight (W) were recorded, and LWR and *K* were determined. Statistical analysis revealed no significant difference in LWR slopes between sexes (P= 0.878; r^2= 0.90 for both), indicating uniform growth patterns under consistent feeding and environmental conditions. In contrast, juveniles and adults differed significantly in LWR slopes (P< 0.001), with adults exhibiting higher mean TL (17.29 ± 2.60cm) and W (119.10 ± 49.16g) than juveniles (11.68 ± 1.10cm; 31.39 ± 10.19g). *K* values ranged from 1.76 to 2.06, within the optimal range for healthy tilapia, with adults showing slightly higher values than juveniles. Both sexes displayed positive allometric growth, while life stages showed negative allometry, reflecting ontogenetic shifts in mass allocation. These findings emphasize that while sex may not significantly affect LWR under well-managed conditions, life stage strongly influences biometric patterns, underscoring the importance of stage-specific management in wet-season tilapia culture.

INTRODUCTION

The Nile tilapia (*Oreochromis niloticus* L.) is a globally popular aquaculture species known for their rapid growth, environmental adaptability, and high reproductive rates, making them ideal for intensive farming **(Alqahtani *et al.*, 2025)**. These traits make

it suitable for diverse culture systems such as ponds, tanks, and cages, contributing to its global aquaculture prominence **(Moses *et al*., 2021)**. Hence, tilapia farming is one of the fastest growing industries in the Philippines; and in the first quarter of 2025, tilapia production rose by 4.7%, reaching 80,180 metric tons (MT), up from 76,550 MT in the previous quarter **(BFAR, 2025)**.

Growth performance is a critical criterion in selecting candidate species for aquaculture **(Dash *et al*., 2022)**. The length-weight relationship (LWR) serves as a fundamental tool for assessing growth patterns, enabling the estimation of weight from length data and vice versa, and providing insights into the species' growth form under specific environmental and management conditions **(Jisr *et al*., 2018)**. Alongside LWR, the condition factor (*K*), particularly Fulton's condition factor, offers a quantitative measure of the fish's well-being, derived from length-weight data, and reflects the effects of environmental and biological factors on growth, reproduction, and survival **(Gan *et al*., 2016)**. A higher *K* value indicates better condition, often influenced by fat reserves, gonadal development, feeding status, and environmental factors **(Godde *et al*., 2021)**. These parameters are essential for evaluating both the current health status of fish populations and their potential for sustained productivity in aquaculture systems **(Breck, 2014)**.

Morphometric relationships like LWR can change with life stage and maturity and aid in species identification **(Datta *et al*., 2013)**. In addition, established LWR models can be applied to datasets containing only length measurements, facilitating yield estimations and population comparisons over space and time **(Gray, 2019)**. LWR is also valuable for evaluating relative well-being, fatness, and gonadal development and has applications in stock assessment, standing biomass estimation, and ontogenetic comparisons across populations **(Jisr *et al*., 2018)**. Seasonal changes, sex, stress, feed availability, and water quality can also affect *K* values **(Godde *et al*., 2021)**.

In the tropical aquaculture system, the wet season significantly alters the dynamics of ponds, directly influencing the growth performance and management requirements of cultured fish **(Doan *et al*., 2025)**. Rainfall during this season often results in changes in water parameters such as temperature, salinity, pH, and dissolved oxygen **(Godde *et al*., 2021)**. Such changes influence primary productivity and feeding dynamics in culture systems, thereby affecting the energy available for growth **(Doan *et al*., 2025)**.

This paper aimed to compare the LWR and Fulton's condition factor of the Nile tilapia reared in earthen ponds in Lubao, Pampanga, the Philippines during wet season. The specific objective was to determine the possible influence of sex and life stage on the LWR and *K*.

MATERIALS AND METHODS

1. Study area and sampling period

The study was conducted in Lubao, Pampanga, Philippines, during the wet season. Lubao is situated in the southwestern part of Pampanga and is characterized by a tropical monsoon climate, with the wet season bringing increased rainfall and relatively stable warm temperatures **(Cabildo *et al.*, 2023)**. Sampling was carried out from 20 different tilapia culture farms within the municipality (14.9268° N, 120.5879° E) to obtain a representative dataset of the local Nile tilapia population. The map of Lubao, Pampanga is shown below.

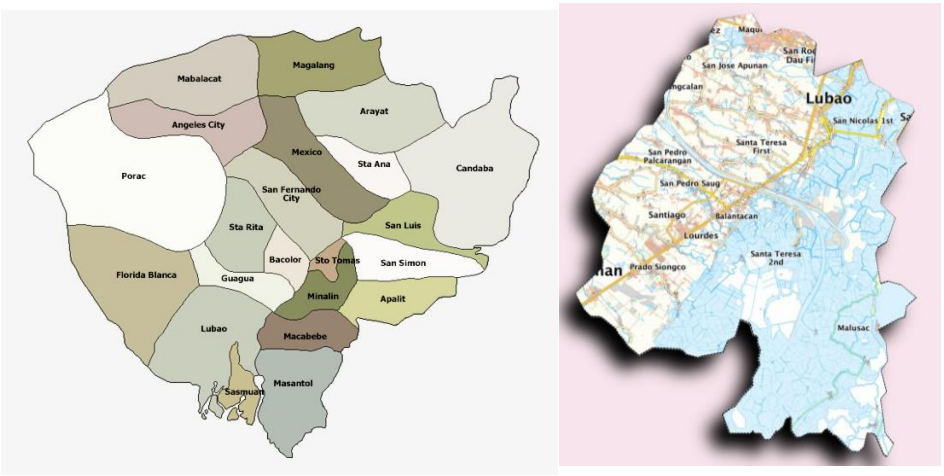


Fig. 1. Location of Lubao within the province of Pampanga (right); barangay-level map of Lubao (right)

2. Sample collection

A total of 400 Nile tilapia specimens were collected from 20 earthen pond farms. From each farm, 20 fish were randomly sampled to ensure representative size and sex distribution. All specimens were handled carefully to minimize stress and physical damage.

3. Sex and life stage determination

Sex determination was conducted by examining the external genital papilla. Males exhibited a single urogenital opening, while females displayed separate urinary and genital openings **(Reyes *et al.*, 2021)**. Life stage classification into juvenile or adult was based on the duration and size of rearing; juveniles were grown for at least 60 days (10 to 50 g) while adults were reared for more than 60 days (>50 g) **(Reyes *et al.*, 2021)**.

4. Morphometric measurements

Prior to measurement, each fish specimen was gently blotted dry using absorbent paper to remove excess water from the body surface. This step is essential to ensure accuracy in weight measurement by eliminating water that could artificially increase the recorded mass. Total length (TL) was measured from the tip of the snout to the end of the caudal fin using a calibrated measuring board, following standard ichthyological protocols **(Schultz *et al*., 2016)**. Body weight (W) was determined with a digital weighing scale accurate to at least 0.01g, ensuring precise mass data crucial for subsequent LWR analyses **(Schultz *et al*., 2016)**. Measurements were taken with minimal handling to reduce stress and error.

Length-weight relationship (LWR) (Panase & Mengumphan, 2015)

$$W = aL^b$$

Where W is weight; L is total length; *a* is the intercept; and *b* is the growth coefficient.

Fulton's condition factor (*K*) (Ragheb, 2023)

$$\text{Condition factor } (K) = (100*W) / L^3$$

Where W is the body weight (g) and L is the total length (cm). This index assumes isometric growth and provides a measure of the fish's general health and robustness.

5. Statistical analysis

Simple linear regression was performed separately for each group (male, female, juvenile, adult) to estimate the intercept (*log a*) and slope (*b*). Differences in LWR between sexes (male vs. female) and between life stages (juvenile vs. adult) were assessed using analysis of covariance (ANCOVA). A significance level of $P < 0.05$ was used to determine statistical significance. Mean *K* values were compared between sexes and between life stages using independent samples T-test. All statistical analyses were conducted using Microsoft Excel with the Data Analysis ToolPak add-in.

RESULTS AND DISCUSSION

1. Sex and life stage determination

The sex and life stage determination of 400 Nile tilapia individuals were taken and recorded during the actual dates of sampling. A total of 267 males and 133 females were recorded, reflecting a sex ratio skewed toward males. Regarding life stage classification, 142 specimens were categorized as juveniles, while 258 were classified as adults.

2. Length-weight relationship analysis

The mean total length and weight of 400 Nile tilapia varied between sexes and life stages during the wet season in Lubao, Pampanga (Table 1). Females showed slightly greater mean length (15.93 ± 3.79cm) and weight (94.15 ± 67.53 g) than males (15.54 ± 3.33cm; 84.49 ± 54.89g), though these differences were minor. Such patterns are consistent with previous reports indicating that female tilapia may allocate more energy to body mass during reproductive development, particularly when approaching or undergoing spawning **(Gan *et al.*, 2016)**. In contrast, life-stage comparisons revealed more pronounced differences, with adults being considerably larger and heavier (17.65 ± 2.68cm; 118.91 ± 51.88g) than juveniles (12.05 ± 1.02cm; 31.00 ± 9.30g). This is an expected outcome of ontogenetic growth, where size and weight increase with age, but the higher variability in adult weights may also reflect differences in maturity stage, feeding history, and environmental conditions across farms **(Rahman *et al.*, 2021)**.

Table 1. The average total length and weight of the 400 pond-grown Nile tilapia (*Oreochromis niloticus* L.) samples during the wet season in Lubao, Pampanga, Philippines, as segregated based on sex and life stage

	Total Length (cm)	Weight (g)
Sex		
Male	15.54±3.33[a]	84.49±54.89[a]
Female	15.93±3.79[a]	94.15±67.53[a]
Life stage		
Juvenile	12.05±1.021[a]	31±9.3[a]
Adult	17.65±2.68[b]	118.91±51.88[b]

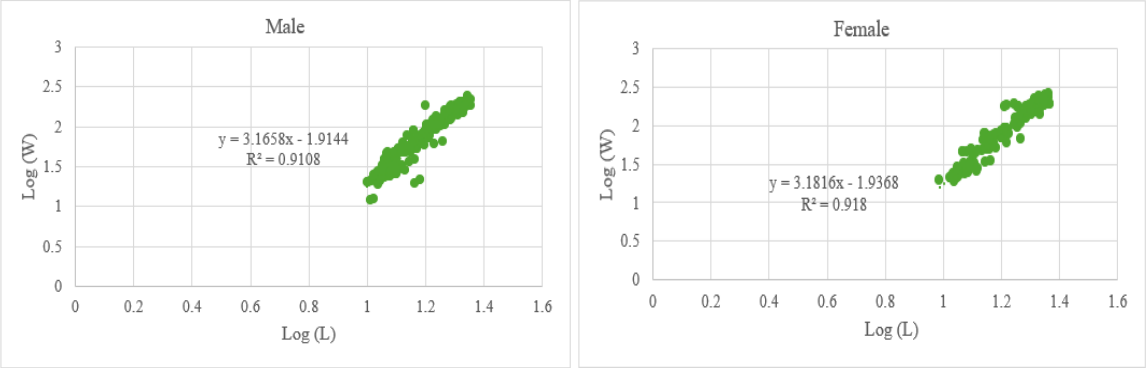
*Means with the same superscript letter are not significantly different at the 0.05 level. Values are presented as mean ± standard deviation.

Fig. (2) presents the LWR linear regression models for male, female, juvenile, and adult *O. niloticus*, and it further supports the size patterns observed in Table (1). Both males (b = 3.17) and females (b = 3.18) exhibited b values greater than 3, indicating positive allometric growth in which body weight increases proportionally faster than body length **(Gan *et al.*, 2016)**. This pattern suggests that, under the wet-season culture conditions in Lubao, fish of both sexes allocate substantial energy toward somatic growth, resulting in greater weight gain as length increases, a trend consistent with tilapia reared under favorable feeding and environmental conditions **(Kamble *et al.*, 2024; Ibrahim *et al.*, 2025)**.

In contrast, juveniles (b = 2.10) and adults (b = 2.75) displayed negative allometric growth, where length increases more rapidly than weight. Comparable result was obtained by **Khalid *et al*. (2023)** in the Nile tilapia samples from Head Panjnad, Punjab, Pakistan. For juveniles, this likely reflects early growth phases when skeletal and structural development precede substantial mass accumulation **(De Castro Silva *et al*., 2015)**. Negative allometry in adults, despite their larger mean size (Table 1), may indicate a shift in energy allocation toward reproduction rather than further somatic weight gain **(Boukal *et al*., 2014)**.

The r^2 values further emphasize differences in growth consistency: males (0.91) and females (0.92) exhibited strong LW correlations, suggesting uniform growth within each sex, whereas juveniles (0.36) and adults (0.85) showed greater variability. This variability, particularly in juveniles, may be linked to differences in diet, metabolic rates, or environmental micro-conditions within farms, reinforcing the size variation trends highlighted in Table (1) **(Saurau *et al*., 2018)**.

Statistical comparison of LWR slopes showed no significant difference between males and females (Fig. 3) (P = 0.878), indicating that both sexes of *O. niloticus* in the sampled farms follow similar LW scaling under the wet-season culture conditions in Lubao, Pampanga. Comparable sex-neutral LWRs have been reported in several tilapia studies where feeding regimes were uniform, suggesting that under consistent rearing conditions, sex per se may not drive major differences in somatic allometry **(Deb *et al*., 2020)**. The high coefficients of determination for male and female regressions ($r^2 \approx 0.9$) further support a uniform growth pattern within each sex, consistent with populations managed under similar stocking densities and feeding regimes **(Ekelemu *et al*., 2010)**.



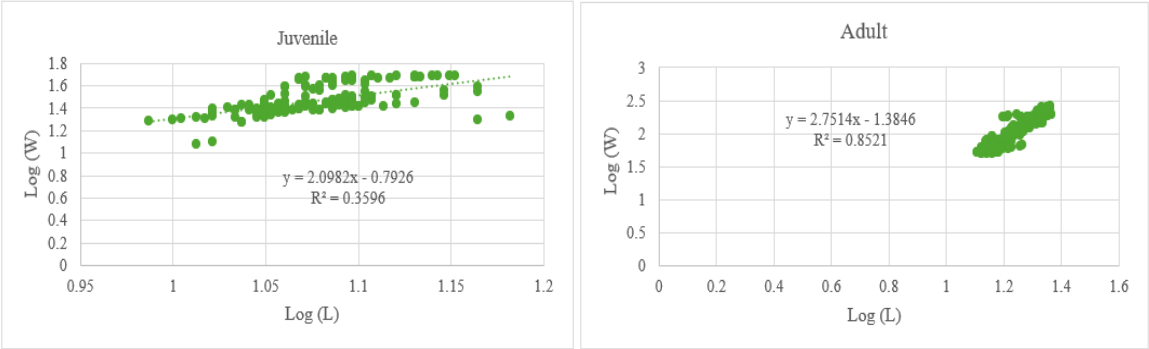


Fig. 2. Linear regression of the length-weight relationship of pond-reared Nile tilapia (*Oreochromis niloticus* L.) according to sex and life stage during the wet season in Lubao, Pampanga, Philippines.

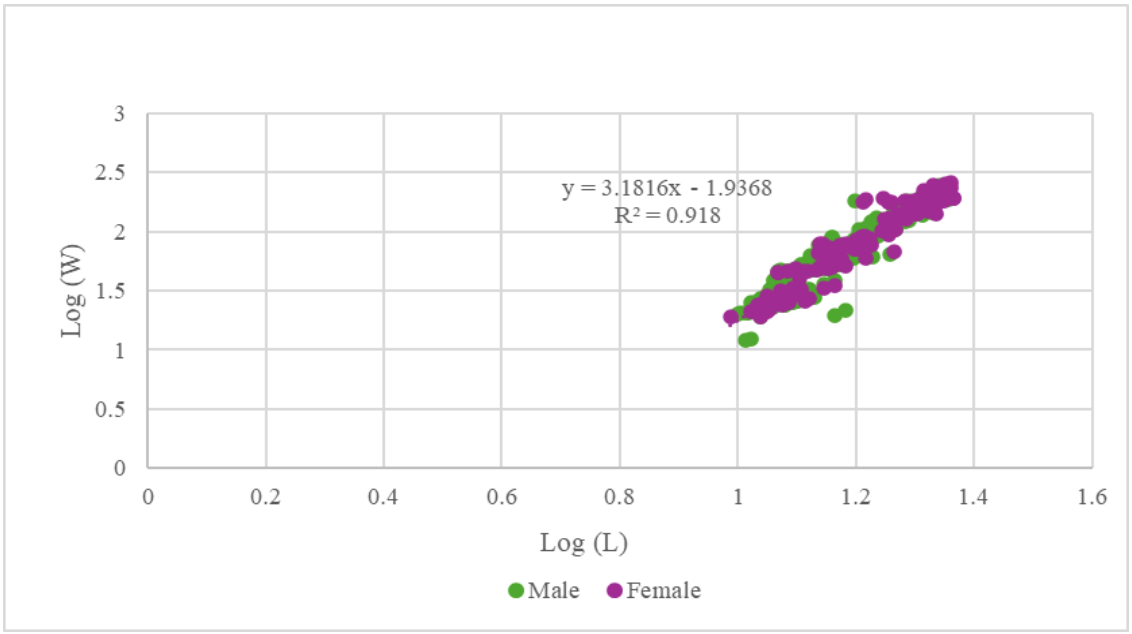


Fig. 3. Comparison of length-weight relationships of male and female pond-grown Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines.

In contrast, the highly significant difference in slopes between juveniles and adults (P = 0.0086) (Fig. 4) indicates an ontogenetic shift in growth allometry. Juveniles (lower b) emphasize lengthwise structural growth, whereas adults show proportionally greater mass accumulation; this ontogenetic pattern is well documented in tilapias and other teleost and is commonly ascribed to changes in diet, energy allocation and reproductive investment as fish mature **(De Castro Silva *et al.*, 2015)**. Juvenile LWRs often exhibit greater variability and lower coefficients of determination (r^2), reflecting inconsistent individual growth rates and size classes. This variability is typical in early

developmental stages, where growth is more focused on skeletal development, leading to less predictable weight-length relationships. In contrast, adult LWRs are generally more tightly correlated, with higher r^2 values, as observed in the present study (juvenile r^2 = 0.36 vs. adult r^2 = 0.85). These ontogenetic differences have practical implications for biomass estimation and harvest planning, since applying a single LWR across mixed age classes can bias weight estimates if life-stage specific allometry is not accounted for **(Jisr *et al.*, 2018)**.

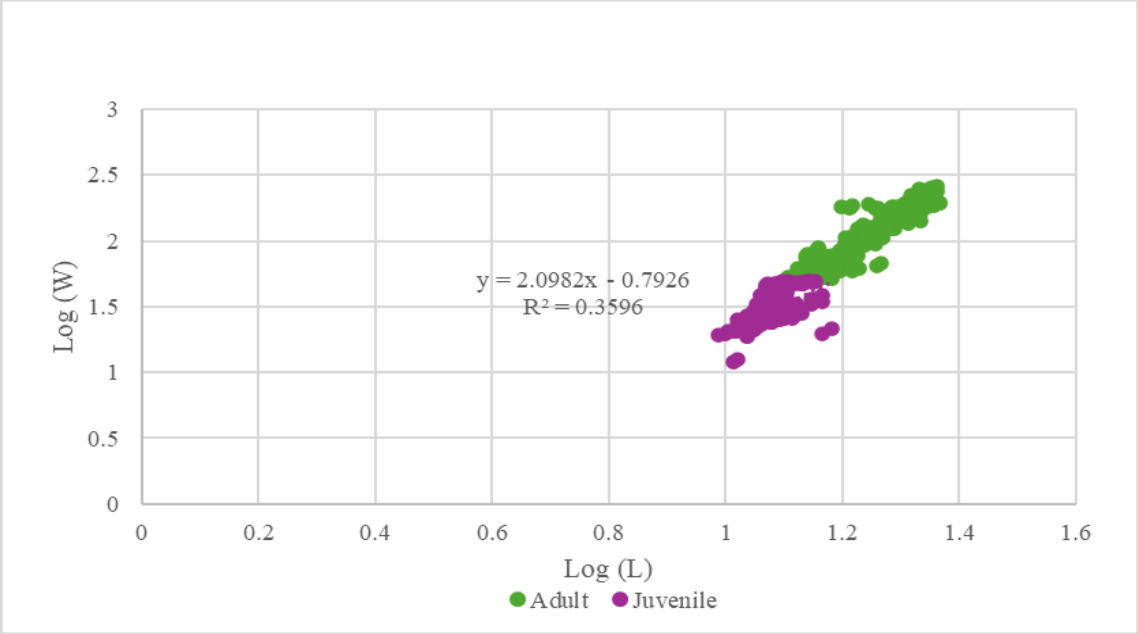


Fig. 4. Comparison of length-weight relationships of juvenile and adult pond-grown Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

3. Condition factor

Table (2) presents the mean Fulton's condition factor (*K*) of the pond-grown Nile tilapia sampled during the wet season in Lubao, Pampanga. Condition factor values ranged from 1.76 to 2.06, indicating generally good physical condition across all groups. Males (1.95 ± 0.40) and females (1.96 ± 0.49) showed nearly identical mean *K* values, suggesting similar body robustness and likely reflecting uniform environmental conditions and feeding practices across the farms sampled. In contrast, more notable variation was observed between life stages. Adults exhibited a higher mean *K* (2.06 ± 0.41) compared to juveniles (1.76 ± 0.42), reflecting greater body mass relative to length in mature individuals. This difference is consistent with expected growth patterns, where adults develop more body depth and fat reserves as they approach or maintain reproductive maturity, while juveniles prioritize length growth over weight gain. Overall, the *K* values observed to fall within the optimal range reported for healthy tilapia,

suggesting that wet season rearing conditions in the study area were favorable for maintaining fish in good condition.

Table 2. The average condition factor of the 400 pond-grown Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines, as segregated based on sex and life stage

	Condition Factor
Sex	
Male	1.95±0.4[a]
Female	1.96±0.49[a]
Life stage	
Juvenile	1.76±0.42[a]
Adult	2.06±0.41[b]

*Means with the same superscript letter are not significantly different at the 0.05 level. Values are presented as mean ± standard deviation.

Statistical analysis indicated no significant difference in *K* between sexes (P = 0.9746) (Fig. 5), while a highly significant difference was observed between life stages (P< 0.0001) (Fig. 6), with adults exhibiting higher *K* than juveniles. The absence of a significant difference in condition factor between males and females suggests that, under the prevailing environmental and husbandry conditions, both sexes had similar body condition. Comparable findings have been reported in other studies on *O. niloticus*, where *K* did not differ significantly between sexes when fish were reared in similar habitats and fed identical diets **(Olurin & Aderibigbe, 2006; El-Bokhtyand & Fetouh, 2019)**. This is consistent with the idea that, outside of peak reproductive periods, gonadal development does not substantially affect body weight in a way that produces sex-based differences in *K* **(Froese, 2006)**.

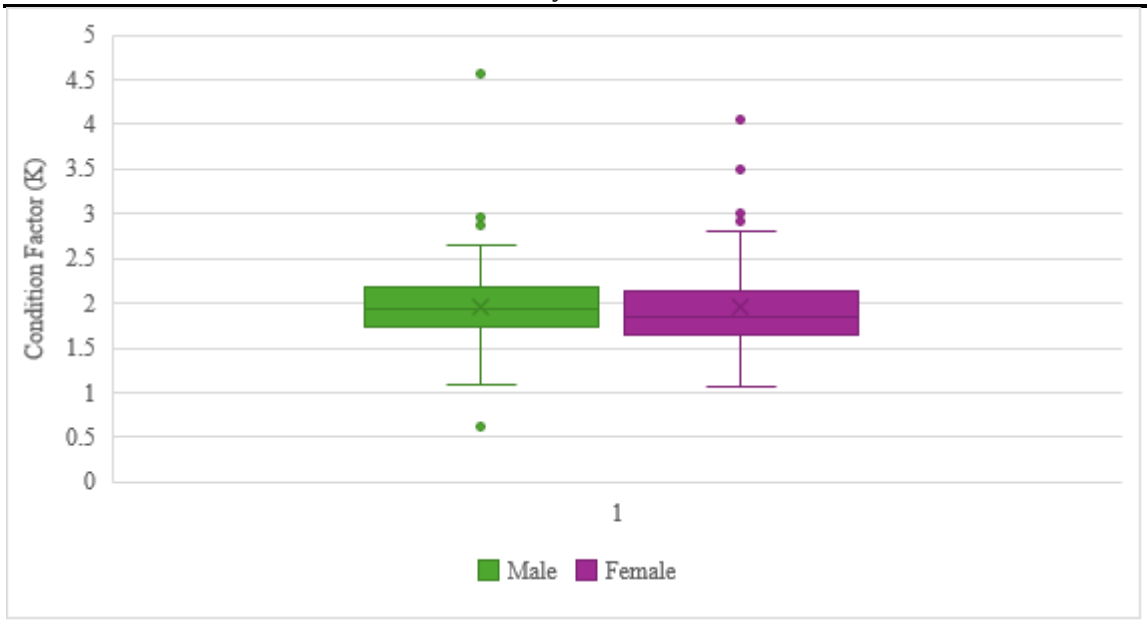


Fig. 5. Comparison of condition factor of pond-reared male and female Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

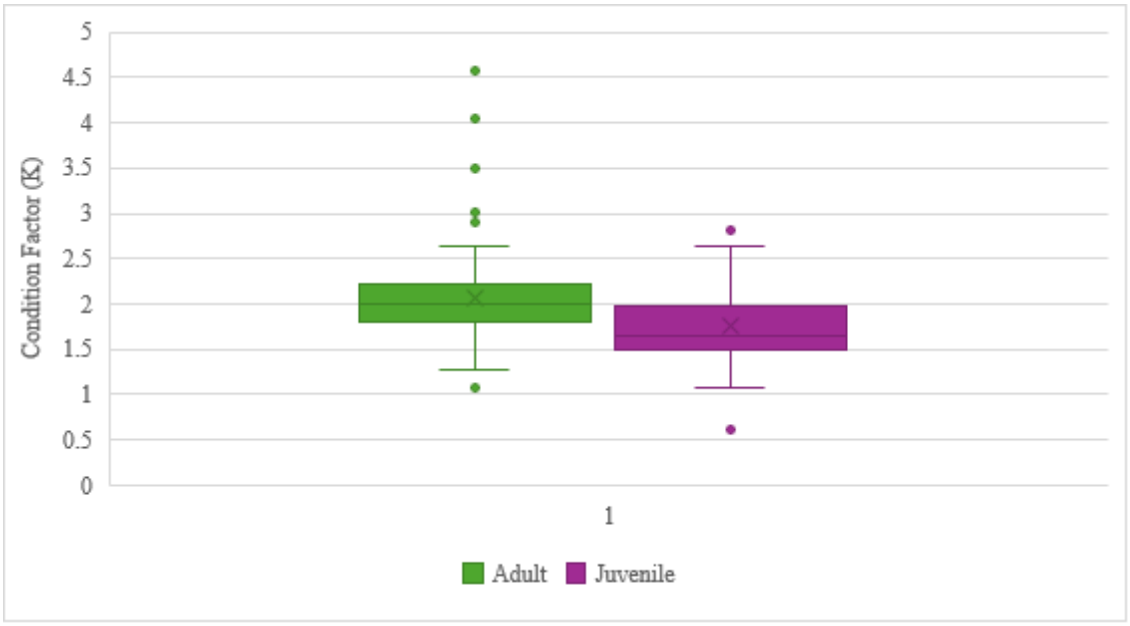


Fig. 6. Comparison of condition factor of pond-reared juvenile and adult Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

On the other hand, the significant difference between juveniles and adults, with adults displaying higher *K* values, aligns with common biological patterns in tilapia and the other teleost. Adults typically exhibit greater mass relative to length due to somatic

growth, increased lipid storage, and reproductive tissue development **(Pauly, 1983; Lizama & Ambrósio, 2002)**. Additionally, adults may exploit a broader diet and more efficiently utilize feed resources, leading to higher energy reserves **(Abowei, 2010)**. This trophic and physiological shift explains the higher *K* observed in adults during this study. Seasonal context is also important in interpreting these results. Sampling occurred during the wet season, a period often characterized by increased primary productivity and higher food availability in aquatic systems **(Abowei, 2010)**. However, seasonal variation in *K* is complex; some studies have observed higher *K* in the wet season due to improved feeding conditions, while others have reported declines linked to reproductive investment. The *K* values reported (1.76 to 2.06) fall within the typical range for healthy *O. niloticus* populations (1.4 to 2.3) documented in both cultured and wild environments **(El-Bokhtyand & Fetouh, 2019)**, suggesting that fish in the study area were generally in good condition.

It is important to note that Fulton's *K* assumes isometric growth (weight $\propto$ length^3). If the population exhibits allometric growth, differences in *K* across size classes (*e.g.*, juveniles vs adults) may partly reflect growth scaling rather than true physiological condition **(Froese, 2006)**. Therefore, future analyses should incorporate LWR modeling to estimate the allometric exponent (*b*) and to adjust interpretations accordingly.

This means that, overall, the data indicate that sex does not significantly influence condition factor under the observed conditions, while life stage has a strong effect, with adults exhibiting better condition than juveniles. These findings have practical implications for aquaculture management: monitoring and improving juvenile *K* could enhance growth performance and shorten production cycles.

4. Histogram distributions

The histograms of tilapia biometric data revealed that the length distributions for males, females, adults, and juveniles followed an approximately normal distribution, and a more even spread for females (Fig. 7). The weight distributions displayed a right-skewed pattern, particularly for juveniles, indicating a concentration of smaller fish with a few larger individuals. Adults showed a more uniform distribution (Fig. 8). The *K* factor distributions for males and adults were approximately normal and tightly clustered around 1.0, suggesting consistent body condition. Juvenile and female tilapia exhibited greater variability in their *K* factor values, with a broader spread (Fig. 9).

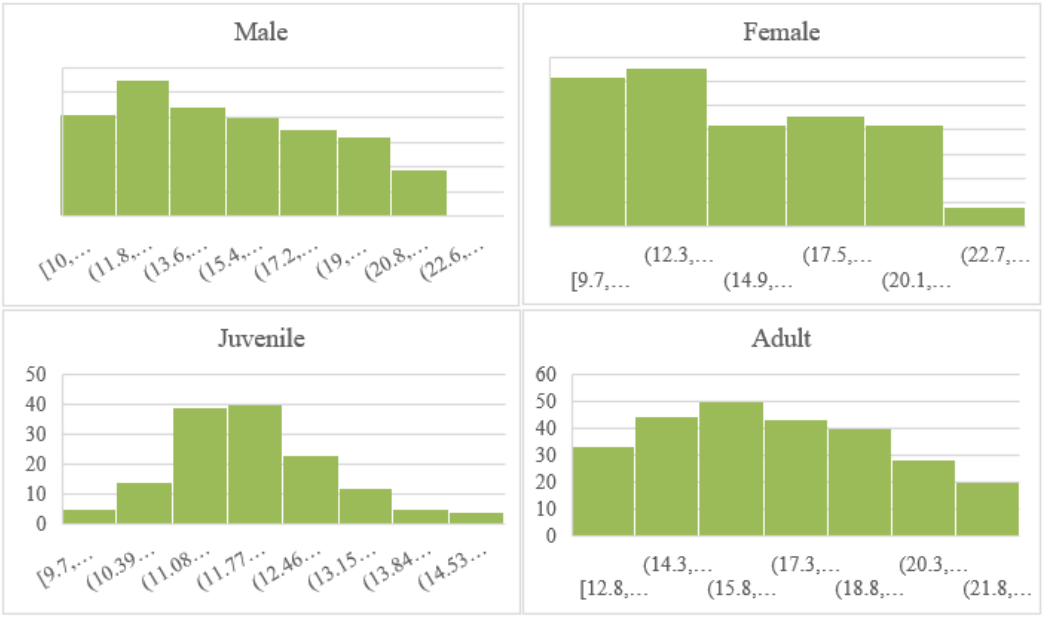


Fig. 7. Length distribution histogram of the 400 pond-reared Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

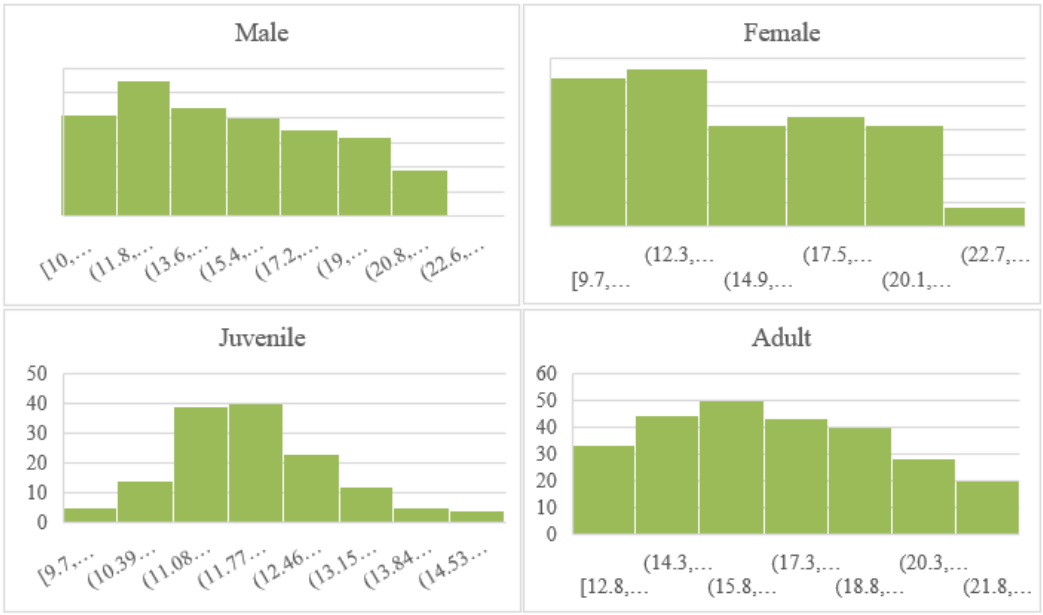


Fig. 8. Weight distribution histogram of the 400 pond-reared Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

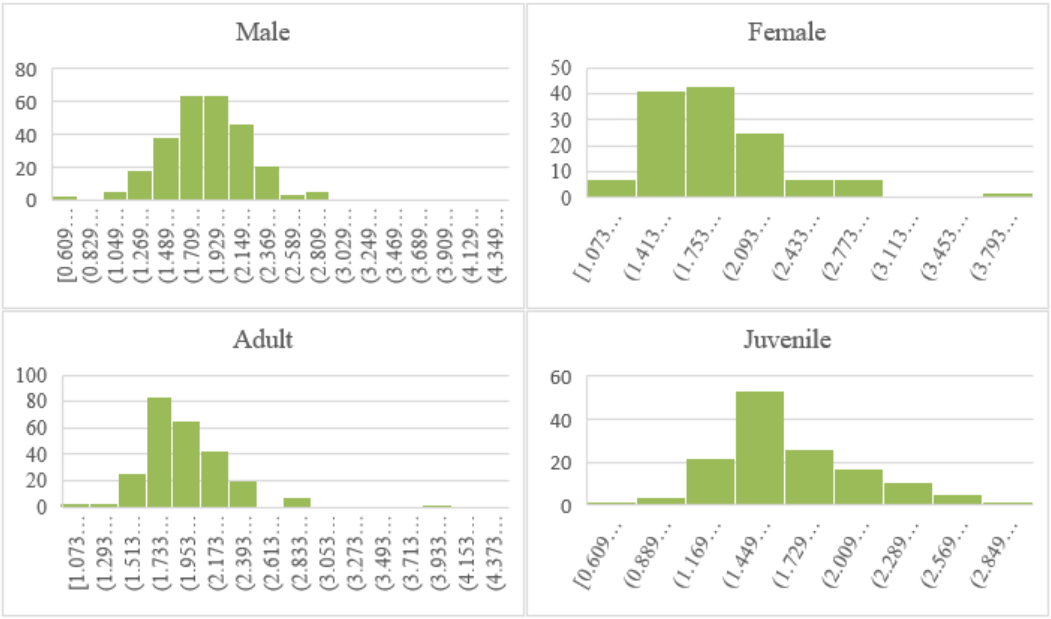


Fig. 9. *K* distribution histogram of the 400 pond-reared Nile tilapia (*Oreochromis niloticus* L.) sampled during the wet season in Lubao, Pampanga, Philippines

CONCLUSION

This study demonstrated that during the wet season in Lubao, Pampanga, the LWR and Fulton's *K* of the Nile tilapia varied more significantly between life stages than between sexes. Males and females exhibited similar growth patterns and *K* values, indicating that sex had no significant influence on overall condition under the prevailing culture conditions. In contrast, juveniles showed lower *K* values and negative allometric growth, while adults displayed higher *K* values and stronger LW correlations, reflecting greater mass accumulation and energy reserves in mature individuals. All condition factor values fell within the optimal range for healthy tilapia, suggesting favorable environmental and management conditions during the wet season. These findings highlight the importance of life stage–specific assessments in biomass estimation, harvest planning, and growth management, particularly to improve juvenile condition and growth performance in aquaculture operations.

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