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NONLINEAR REGRESSION MODELLING OF RELATIONSHIP AMONG GROWTH PARAMETERS OF TILAPIA (*Oreochromisniloticus*)

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ABSTRACT

Nile tilapia (*Oreochromisniloticus*) is a globally significant and economically vital fish species, requiring effective management to sustain its benefits for local communities. This study utilized secondary data from a mixed factorial experiment to examine the effects of water temperature, location, and week on Nile tilapia growth. The growth parameters considered include total length, standard length, and weight. Water temperature levels considered include room temperature (20°C) as control, 28°C, 30°C, and 32°C for 12-week period and three(3) locations. Nonlinear regression techniques were used to model the relationships between total length and weight, and standard length and weight, under each temperature level. Analysis of variance (ANOVA) technique was then used to examine the effects of location, week, and temperature on fish weight. The constructed nonlinear models were then compared using the error sum of squares (SSE) criterion in F-test. The findings showed that model three is the best fit with SSE of 3137.143 and 3099.227, respectively, for *total length x weight*and*standard length x weight*interaction effects. ANOVA revealed significant effects of location, week, and temperature, along with their interactions (except *location x week*for total and standard lengths), on fish weight with p-values below 0.0001 ($p < 0.0001$). Estimated marginal means indicated a consistent increase in fish weight across all temperatures. The fitted regression model between total and standard lengths explained 96% of the total variability, indicatingan excellent fit. These findings provide valuable insights for fisheries managers and scientists to enhance tilapia stock managementand exploration.

Keywords: Nile Tilapia, Factorial Design, Standard Length, Total Length, Nonlinear Regression Model, ANOVA, Marginal Means

INTRODUCTION

It is widely recognized that Nigeria's population is growing rapidly and at an alarming pace. The most recent population estimate stands at over 218.5 million, according to report by (Nnabuko, 2022). This is a confirmation to the fact that immediate action needs to be taken in order to meet the food needs of people, especially protein in the face of recent world crisis in food production and availability. It has been reported that the average protein intake, approximately 50-55% per capita per year, is insufficient and lower than the recommended 75% per capita per year set by the Food and Agriculture Organization (Mekouar, 2018). This indicates that the animal production sector is failing to meet the population's demand, and the overall standard of living is low, making it difficult for the average person to afford even inexpensive protein sources like fish. While fish contributes around 180 calories per person per day, this level is typically only reached in countries where locally grown alternative protein sources are scarce and where a strong preference for fish has been established and sustained (Tidwell & Allan, 2001). By increasing the production of fish products such as fillet, oil, feeds, paste, and sauce, fish farming can significantly contribute to food security. Due to their high biological value and generally high nutrient content, fish and fish products are ideal for growth. Compared to other sources, fish is a less expensive source of protein, lipids, minerals, oils, and vitamins that are necessary for tissue repair and body building. Fishing also provides employment and income for many individuals, including those involved in fish buying, selling, processing, packaging, and recreational activities such as sport fishing (Ibiwoye *et al.*, 2006). The food security situation in Nigeria has worsened, with malnutrition and micronutrient deficiencies now being significant issues in Nigeria and other developing nations (Tulchinsky, 2010). In many communities, the widespread prevalence of poor nutrition and infectious diseases often create a vicious cycle, leaving millions trapped in persistent hunger. Fisheries and aquaculture, as key components of agriculture, offer potential solutions to the country's food shortage challenges. However, these sectors face several obstacles, including the lack of access to high-quality seed stock, which hinders efforts to enhance and increase fish production (Barange, 2018). Tilapia is significant both ecologically and economically, playing a crucial role in shaping the dynamics and structure of aquatic ecosystems. It is also highly valued as a food source, especially among low-income earners, due to its delicious taste and affordable price. Length frequency distribution measurements are essential in various areas of fisheries science, with the level of precision needed for length samples depending on the purpose of the sampling. Regardless of the assessment method used, the focus is on the shape of the length frequency distribution, rather than just simple statistical summaries like the mean or variance (Gerritsen & McGrath, 2007). Understanding the length frequency distribution of a fish population is important for assessing the size structure of that population in the wild. It is the initial step in evaluating gear selectivity of catches made by different types of gear in the same water (Bagenal, 1978). The length-weight relationship is one of the most commonly used techniques for analyzing fisheries data (Mendes *et al.*, 2004). In fisheries research, these relationships are vital for estimating weights when only length data are available (Karna *et al.*, 2012) and they serve as an index of the fish's condition factor (Abujam & Biswas, 2016). This relationship is particularly significant in studies of fisheries biology (Silvano & Valbo-Jørgensen, 2008). Additionally, it allows for the estimation of standing crop biomass (Morey *et al.*, 2006) and enables the tracking of seasonal variations in fish growth (Ahmed *et al.*, 2014). The majority of research on fish improvement, specifically tilapia, was conducted in Egypt, but studies on fish genetic diversity in Nigeria have concentrated primarily on the freshwater tilapia species *Oreochromisniloticus*. However, the primary focus of these investigations was the stock's population dynamics in Kainji Lake. Because so little is known about the diversity of Tilapia (*Oreochromisniloticus*) in its natural populations, it is crucial to evaluate the genetic diversity of this species in order to improve it and so increase the nation's food security.

Fuentes-Andraca *et al.* (2023) investigate the effect of stocking density on the growth dynamics of Nile tilapia (Oreochromisniloticus) at the pre-grow-out stage. Four growth models—von Bertalanffy, Logistic, Pütter, and Gompertz—were evaluated, with adjustments made to consider the effects of stock density and growth variability. Nonlinear regression was used to fit homogeneous growth (HmG) models, whereas heterogeneous growth (HtG) models used quantile regression across several percentiles (0.05 to 0.95).The Logistic model performed best for HmG, while von Bertalanffy was optimal for HtG, demonstrating that growth performance decreases with increasing stocking density. Quantile regression proved superior in predicting growth variations within the population, offering a nuanced understanding of individual growth trajectories. These findings are valuable for aquaculture farmers in designing stocking strategies and determining optimal transfer times for tilapia juveniles, especially under different density conditions. Al-Wan & Mohamed (2019) investigate the biological aspects of the invasive Oreochromis aureus population in the Garmat Ali River. The study, which ran from September 2018 to August 2019, looked at 1050 specimens collected using various fishing methods. Individuals ranged in length from 6.6 to 22.9 cm, with the majority (61.6%) measuring between 14.0 and 18.0 cm. The development pattern for both sexes was positive allometric (males: b = 3.317; females: b = 3.231; all individuals: b = 3.283).Age estimation based on scales indicated that the population consisted of fish between 1 and 5 years. The von Bertalanffy growth parameters were estimated as l_∞= 27.6 cm, K = 0.193, and t_0 = 1.18, with a growth performance index ϕ of 2.17. The study found a near-equal sex ratio (1:1.04), with females maturing earlier than males (6.6 cm vs. 9.2 cm). Mohamed & Salman (2020) studied the population dynamics and management of invasive blue tilapia (*Oreochromis aureus*) in the Ali River, Basrah and Iraq. They used FiSAT II software for data analysis, including growth parameters, mortality rates, probability of capture, and yield per recruit. A total of 1664 fish were collected from October 2019 to September 2020. The most frequent length groups were 8.0-11.0 cm and 14.0-17.0 cm, with dominant individuals ranging from 13 to 17 cm, making up 62% of the catch. The length-weight relationship was established as W = aL^b, with a significant positive allometric growth (t = 4.97, P < 0.05). Mehanna *et al.* (2020) analyzed the growth, mortality, and recruitment of Nile tilapia (*Oreochromis niloticus*) from Manzala Lake, Egypt. They used virtual population analysis and the relationship between scale radius and total fish length was calculated as TL = a + b(R). Age determination was done using scale readings, and the maximum lifespan of Nile tilapia was 5 years. The study recorded back-calculated lengths for different age groups, ranging from 14.23 cm at age I to 30.14 cm at age V. The Von Bertalanffy growth model was used for growth parameters, with constants l_∞, K, and $t_0$for length growth. In the study by Ezenwaka *et al.* (2024),Specimens were dissected for the investigation of their alimentary canal in 90% saline solution and fixed in 70% alcohol/saline solution after morphometric measurements of the identified fishes (total length, standard length, and wet body weight) were obtained. The author discovered that three out of the twenty-seven specimens that were analyzed had an acanthocephalan sp. infection, with a mean intensity of two parasites per infected host and a prevalence of 11.1%. A low infection rate and abundance were recorded, despite the fact that the study was carried out during the rainy season, when acanthocephalan abundance should be at its highest. This is explained by the limited sample size (n=27) and potential shifts in the intermediate host population of the parasite. The low rate of parasite infection reported may have contributed to the good condition factor, which ranged from 34.3 to 48.6. Amponsah *et al.* (2020) examined the population parameters of *Oreochromis niloticus* (L) in Ghana Lagoon and their management implications. The study utilized the ICLRAM Stock Assessment Tool (FISAT) to estimate the population parameters, and the growth pattern was determined through the length-weight relationship using Virtual Population Analysis (VPA). Data was collected quarterly between August 2017 and June 2018, with the total length of 229 specimens ranging from 4.5 to 18.5 cm. The growth parameter (K) was estimated at 0.54 year–1, with an asymptotic length (L∞) of 19.4 cm. Recruitment occurred year-round with two peaks. The total (Z), natural (M), and fishing (F) mortality rates were 1.83 per year, 1.50 per year, and 0.33 per year, respectively. The exploitation rate (E) was 0.29, and the relative yield/biomass per recruit (E_{max}) was 0.48. The study indicated a low fishing effort, with catches primarily consisting of small individuals. The findings highlighted growth-overfishing, suggesting that increasing the mesh size, alongside reducing fishing effort, could help preserve the species' population.

MATERIALS AND METHODS

Materials

In this thesis, JMPis the statistical software package used as the analytical tool. The study employs nonlinear regression modeling to elucidate the intricate relationships among key growth parameters of Tilapia, offering insights into the growth dynamics of this species. JMP's robust analytical capabilities and user-friendly interface enable effective data exploration, visualization, and model fitting, ensuring precision and reliability in uncovering these complex interactions.

Experimental Set-Up

Ayanwale *et al.* (2013) conducted an experiment that provided the secondary data for this study. 150 fingerling tilapia fish were placed in each of the twelve (12) 25-liter plastic indoor aquarium tanks (55*35*35 cm³) that were filled with borehole water up to a 20-cm level. To keep the fish from jumping out of the experimental tanks, a net was placed over them. For twelve weeks, the fingerlings were fed a commercial food (Coppens) every morning and evening until they were completely satisfied. The experiment employed four different water temperature levels, with treatment 1 being the control (room temperature water), and treatments 2, 3, and 4 having the tank water kept at 28°C, 30°C, and 32°C, respectively using thermo-regulator. The inverter helped to ensure a steady supply of power. A 3x12x4x10 mixed factorial design was used for the experiment, which was carried out in three distinct sites and reproduced ten (10) times for each treatment combination (location x week x temperature). Twice a week, each tank was drained and then filled with brand-new borehole water in the morning. After feeding, the fecal samples and leftover feed in the tanks were drained right away. For twelve (12) weeks, the Mustafa *et al.*

(2016) approach was used to assess the water's physio-chemical characteristics, such as dissolved oxygen, biochemical oxygen required, water PH, conductivity, and ammonia, once a week between 9:00 and 10:00 am

Data Collection

At the end of every week and for every location, 10 fish from each tank was randomly sampled (that is replicate) under each of the four water temperatures using the method described by (Kerdchuen & Legendre, 1994), using a piece of fine mesh net, gently placed on paper towels in order to absorb most of the adhering water through the net. Weight of each sampled fish was then determined using a weighing scale. Other parameters measured from each of the sampled fish weekly include standard length (SL), total length (TL), respiratory rate and physio-chemical parameters. The following performance parameters were also measured from each of the treatment groups; weight gain, percentage weight gain and specific growth rate. However, this work only makes use of the data on the fish total length, standard length, and weight.Measurements of the total and standard lengths were taken for each sampled fish after excess water on each has been drained with filter paper. Using a fish measuring board, the length was measured to the closest 0.1 cm. The distance between the fish's mouth-closed snout tip and the tip of the longest caudal fin ray is known as its total length (TL), and the distance between the mouth-closed snout tip and the end of the caudal peduncle is known as its standard length (SL).

Model Fitting

For each of the weeks under study, the nonlinear regression modeling technique was used to establish the weight-total length and weight-standard length relationships based on the concept of (Le Cren, 1951), using the model

$$Y = b_0 \mathrm{X}^{b_1} + \epsilon \qquad (1)$$

where Y is the response variable (body weight of the sampled Tilapia fish) in grams (g), the parameter b_0 is the intercept serving to estimate the value of the fish weight in the absence of the (total or standard) length; X is the input (Fish Total length or Standard length) variable in centimeters (cm); and b_1 is the slope or allometry coefficient, which estimates the rate by which the weight (Y) changes with the total length or the standard length.

Now the error sum of squares for the nonlinear model (1) and the given data is defined as

$$L = \sum_{u=1}^{n} \epsilon_u^2 = \sum_{u=1}^{n} \left\{ Y_u - \hat{Y}_u \right\}^2 \qquad (2)$$

where

$$\hat{Y} = \hat{b}_0 \mathrm{X}^{\hat{b}_1} \qquad (3)$$

It should be noted here that since Y_u and X_u are fixed observations, the sum of squares in (2) are functions of the parameters $b_0$and b_1. The least squares estimate ($\hat{b}_0$and $\hat{b}_1$) of $b_0$and b_1 are their respective values that minimizes the error sum of squares in (2).

To estimate the parameters of the model (1), that is, to find the least squares estimates of $\hat{b}_0$and $\hat{b}_1$, equation (2) need to be differentiated with respect to $b_0$and b_1. This provides the two normal equations, which must be solved for $\hat{b}_0$and $\hat{b}_1$. Such normal equations take the form

$$\sum_{u=1}^{n} \left\{ Y_u - b_0 {\mathrm{X}_u}^{b_1} \right\} \left[\frac{\partial L}{\partial b_0} \right] = 0 \qquad (4)$$

and

$$\sum_{u=1}^{n} \left\{ Y_u - b_0 {\mathrm{X}_u}^{b_1} \right\} \left[\frac{\partial L}{\partial b_1} \right] = 0 \qquad (5)$$

where L is the SSE given by equation (2).

The normal equations in (4) and (5) are in the form of nonlinear equations in the parameters$b_0$and b_1 since the model (1) is nonlinear in the b's.

Now the solution of the normal equations (4) and (5) are extremely difficult to obtain. In fact, to further compound the difficulties. Therefore, iterative and several available methods currently employed in computer packages (SAS, JMP, STATA etc.) for obtaining the parameter estimates in nonlinear models are often used. This work make use of the JMP Pro (JMP version 17) software.

From equation (1), the exponent (b_1) value of 3 in length-weight relationship of fishes is said to be isometric, that is, the fish does not change its form along the ontogenetic growth (Akter *et al.*, 2020). Growth is considered allometric if the b_1 value deviates from 3, meaning that the fish's shape changes as it becomes larger. When allometric growth exceeds three, it is positive; when it falls below three, it is negative. Growth is negative if the fish gets thinner as it gets bigger, and positive allometry if it gets fatter as it gets bigger. The length-weight connection can therefore be used to determine the growth rate, growth dynamics, and population health of fish, all of which are important for species management.

Linearization of equation (1) can also be achieved using the logarithmic transformation as:

$$LogY = Logb_0 + b_1 LogX \qquad (6)$$

Analysis of variance was further performed on the entire data set to assess the effect of each of the factors (location, week and water temperature) on the fish total length, standard length and weight, using the model:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \tau_k + (\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\alpha\beta\tau)_{ijk} + \varepsilon_{ijkl} \begin{cases} i = 1,2,3 \\ j = 1,\dots,12 \\ k = 1,\dots,4 \\ l = 1,\dots,10 \end{cases} \qquad (7)$$

where y_{ijkl} is the response (Fish Total length, Standard Length, or Weight) from replicate l due to the effects of the ith location, jth week and kth temperature; μ is the overall mean; α_i is the effect of the ith location; β_j is the effect of the jth week; τ_k is the effect of the kth temperature; $(\alpha\tau)_{ik}$, $(\beta\tau)_{jk}$, and $(\alpha\beta\tau)_{ijk}$ are their respective interaction effects, and ε_{ijkl} is the random error component term, which is normally distributed with mean 0 and variance σ_ε^2.

A graph of the estimated marginal means of each of the growth parameters (Fish Total length, Standard Length, and Weight) was plotted against the weeks so as to study the behavior of the growth parameters throughout the duration (12 weeks) of the experiment for each location under each of the water temperature factor levels (the control, 28, 30, and 32 degrees Celsius).

RESULTS AND DISCUSSION

Length-Weight Relationships

Relationship between the Fish Weight and Fish Total length

The relationship between the fish total length (TL) and the fish weight (TL-WT) is first established for each of the twelve (12) weeks under review, using equation (3).

Figure 1 gives the fitted curves of the fish weight against the fish total length, respectively, for weeks 1 – 12. Directly under each plot is the nonlinear regression model for the fitted curve and the standard error of the effect of the input variable (total length).

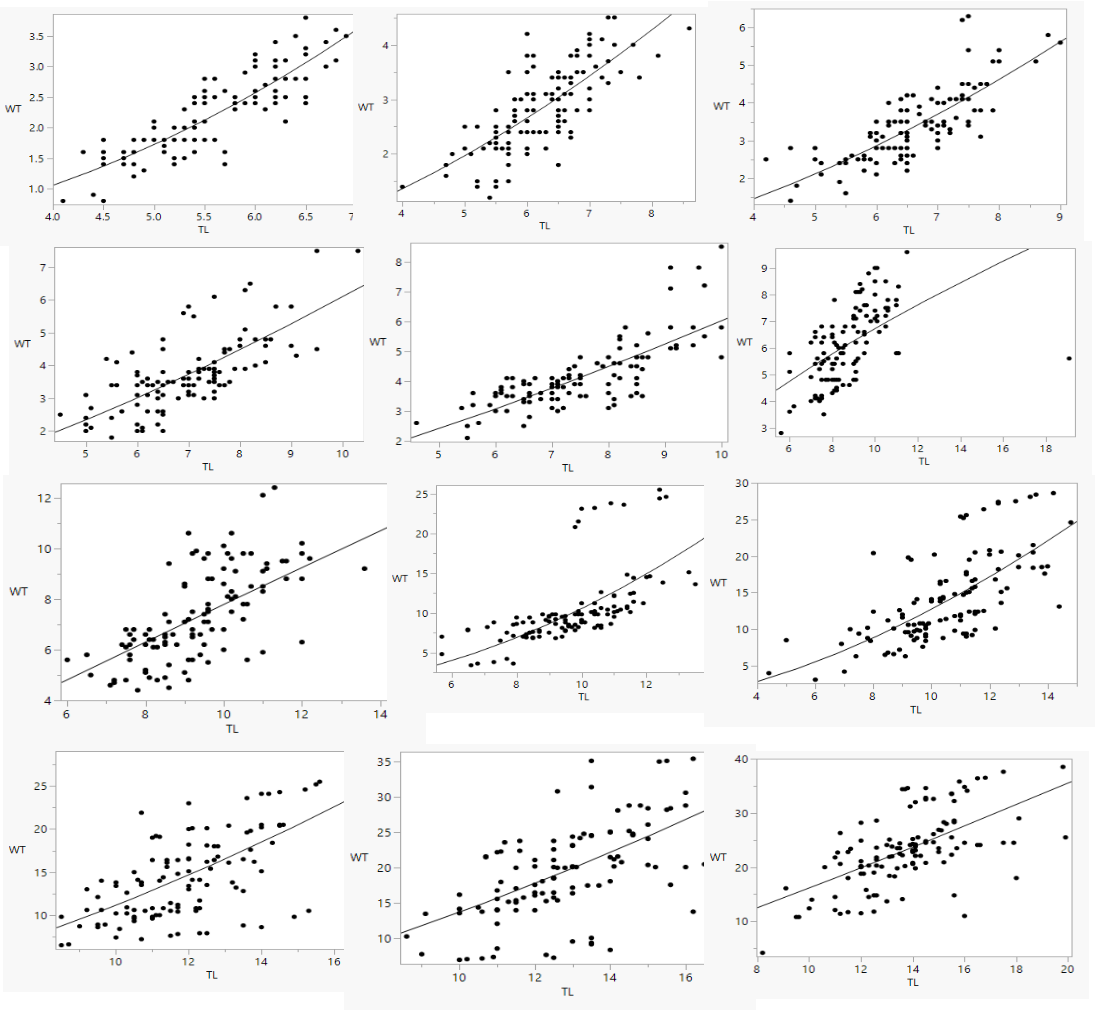

Figure 1: Fitted curve and observations of fish weight and fish total length for week1-12

The 12 graphs collectively illustrate the nonlinear relationship between fish weight (WT) and total length (TL) across a 12-week period. Each graph represents a distinct week, showing a fitted curve that captures the growth dynamics of fish weight as influenced by total length. The nonlinear regression models applied highlight how this relationship evolves over time, with varying slopes and patterns indicating differences in growth rates or biological factors influencing the fish in each week. The fitted nonlinear regression models from the Figure 1 are;

$Weight = 0.05047(TL)^{2.19279}$ (8)
$Weight = 0.13802(TL)^{1.65071}$ (9)
$Weight = 0.14417(TL)^{1.66702}$ (10)
$Weight = 0.25294(TL)^{1.38204}$ (11)
$Weight = 0.28840(TL)^{1.31946}$ (12)
$Weight = 1.40607(TL)^{0.67974}$ (13)
$Weight = 0.89086(TL)^{0.94166}$ (14)
$Weight = 0.12973(TL)^{1.90896}$ (15)
$Weight = 0.29378(TL)^{1.63653}$ (16)
$Weight = 0.35176(TL)^{1.50071}$ (17)
$Weight = 0.51343(TL)^{1.42645}$ (18)
$Weight = 1.17407(TL)^{1.13819}$ (19)

Models 8-19 indicated that the slope (b) of the fish TL-W relationship from the experiment ranged between 0.67974 and 2.19279. This finding contrasts with the results of El-Moghazy *et al.* (2018), whose study reported that the b values for fish species from both the Atbara River and KhashmelGirba reservoir in Sudan ranged from 2.278 to 3.680. It also differs from Pauly *et al.* (1988) findings, which showed a b value range of 2.5 to 4.0 for various fish species.

Weight by standard length relationship

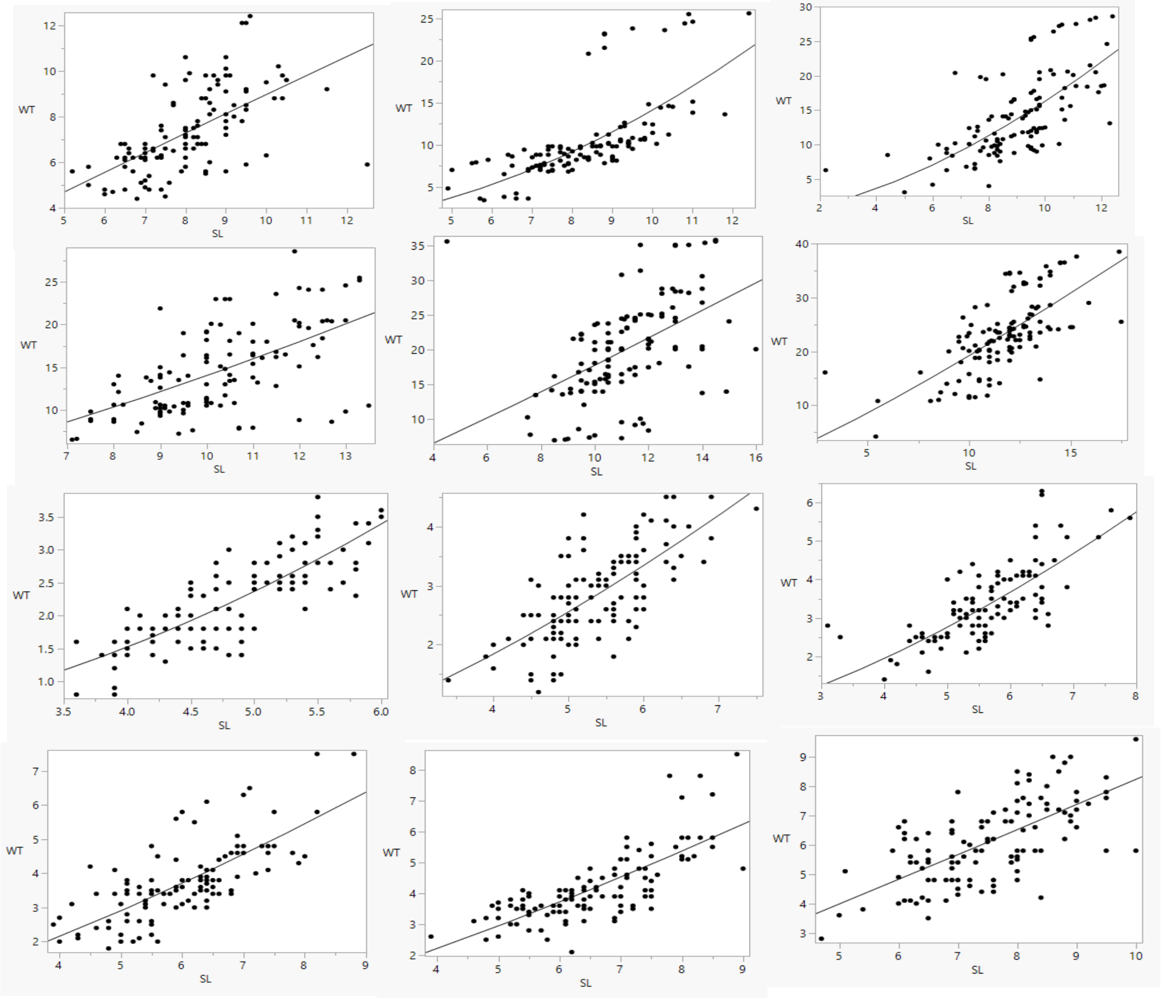

Figure 2: Fitted curve and observations of fish weight and fish standard length for week1-12

The 12 graphs collectively depict the nonlinear relationship between fish weight (WT) and standard length (SL) over a 12-week period. Each graph corresponds to a specific week, showing a fitted curve that models how the fish weight changes in response to variations in standard length. The observed patterns reveal week-to-week variations in the growth trends, highlighting differences in the growth rate or biological responses during the study period. These graphs collectively demonstrate the evolving relationship between fish size metrics over time. The fitted nonlinear regression models from Figure 2 are;

$$Weight = 0.098414(SL)^{1.9753278} \quad (20)$$
$$Weight = 0.24037(TL)^{1.46874} \quad (21)$$
$$Weight = 0.22172(TL)^{1.56602} \quad (22)$$
$$Weight = 0.33508(TL)^{1.34126} \quad (23)$$
$$Weight = 0.3771(TL)^{1.27672} \quad (24)$$
$$Weight = 0.73545(TL)^{1.04895} \quad (25)$$
$$Weight = 1.04285(TL)^{0.93459} \quad (26)$$
$$Weight = 0.16495(TL)^{1.93183} \quad (27)$$
$$Weight = 0.37242(TL)^{1.64045} \quad (28)$$
$$Weight = 0.59481(TL)^{1.3718} \quad (29)$$
$$Weight = 1.45464(TL)^{1.08706} \quad (30)$$
$$Weight = 1.31627(TL)^{1.16396} \quad (31)$$

Model Comparison

Table 1 and 2 show, respectively, the error sum of squares for the fitted nonlinear regression models for the Total Length – Weight and the Standard Length – Weight relationships, for each of the twelve weeks under study. Table 1 shows that the fitted nonlinear model for week 1 is the best in precision, as it has the smallest SSE, followed by those of weeks 2 and 3; the week 5 model is better than that of week 4, which, in turn, is better than that of weeks 6, 7, and 8. The week 10 model is better than the week 9 one while week 12 model is better than that of week 11. Table 4.2 for the Standard Length – Weight relationship shows that the fitted nonlinear model for week 1 is the best in precision, as it has the smallest SSE, followed by that of week 2 and 3 while that of week 5 is better than week 4. The week 4 model is better than those of weeks 6, 7, and 8 while that of week 10 is better than that of week 9 and the one for week 12 is better than that of week 11, all in terms of the SSE.

Table 1: SSE for the Fitted Nonlinear Models for the Weight by Total Length – Relationship of Tilapia (*Oreochromisniloticus*)

Week	Sum of Square Error	Rank
1	13.148699001	1
2	30.219101032	2
3	37.664773455	3
4	70.892773288	5
5	58.233194958	4
6	158.39818533	6
7	237.09829781	7
8	1427.3973718	8
9	2108.9247288	10
10	1863.7573863	9
11	3717.3635791	12
12	3406.1347919	11

Table 2: SSE for the Fitted Nonlinear Models for the Weight by Standard Length – Relationship of Tilapia (*Oreochromisniloticus*)

Week	Sum of Square Error	Rank
1	16.184098689	1
2	33.741388768	2
3	45.777602949	3
4	69.970178069	5
5	62.267669991	4
6	130.63848511	6
7	236.02449873	7
8	1349.7721645	8
9	2174.5281879	10
10	1954.1588182	9
11	4660.797943	12
12	2965.0908341	11

Univariate ANOVA tests

Tables 3-5, gives the summary results of the univariate analysis of variance (ANOVA) of the effects of the location, week and temperature factors on the fish total length, standard length, and weight.

Table 3: Univariate ANOVA Results for Effects of Location, Week and Temperature factors on Fish Total Length (TL)
Dependent Variable: Total Length

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	10398.517^{a}	143	72.717	38.243	.000
Intercept	120739.807	1	120739.807	63499.405	.000
Location	19.546	2	9.773	5.140	.006
Week	9727.673	11	884.334	465.088	.000
Temperature	93.007	3	31.002	16.305	.000
location * week	37.447	22	1.702	.895	.602
location * Temperature	165.555	6	27.592	14.511	.000
week * Temperature	104.191	33	3.157	1.660	.011
location * week * Temperature	251.098	66	3.805	2.001	.000
Error	2464.256	1296	1.901		
Total	133602.580	1440			
Corrected Total	12862.773	1439			

a. R Squared = .808 (Adjusted R Squared = .787)

Table 3 shows that the main effects of the location, week and the temperature factors as well as their interaction effects (with the exception of the location x week interaction effect) on the total length, are highly significant with p-values below 0.01 ($P<0.01$). This result is further supported by the coefficient of determination (R-squared) for the fitted univariate ANOVA model, which indicates that the fitted model accounted for a highly significant proportion (80.8%) of the total variability in the data.

This result and the following ones agree perfectly with the findings of Dauda *et al.* (2023) on behavior and growth performance of African cat fish, which shows that the temperature effects are highly significant.

Table 4: Univariate ANOVA Results for Effects of Location, Week and Temperature factors on Fish Standard Length (SL)
Dependent Variable: Standard Length

Source	TypeIII Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	7574.758[a]	143	52.970	34.495	.000
Intercept	89151.364	1	89151.364	58056.943	.000
Location	18.383	2	9.191	5.986	.003
Week	7049.428	11	640.857	417.337	.000
Temperature	63.675	3	21.225	13.822	.000
location * week	32.960	22	1.498	.976	.493
location * Temperature	120.711	6	20.119	13.102	.000
week * Temperature	94.236	33	2.856	1.860	.002
location * week * Temperature	195.365	66	2.960	1.928	.000
Error	1990.118	1296	1.536		
Total	98716.240	1440			
Corrected Total	9564.876	1439			

R Squared = .792 (Adjusted R Squared = .769)

Table 4 shows that the main effects of the location, week and the temperature factors as well as their interaction effects (with the exception of the location x week interaction effect) on the standard length, are highly significant with p-values below 0.01 (P<0.01). This result is further supported by the coefficient of determination (R-squared) for the fitted univariate ANOVA model, which indicates that the fitted model accounted for a highly significant proportion (79.2%) of the total variability in the data.

Table 5: Univariate ANOVA Results for Effects of Location, Week and Temperature factors onFish Weight (W)
Dependent Variable: Weight

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	84621.039[a]	143	591.756	170.479	.000
Intercept	125175.073	1	125175.073	36061.736	.000
Location	102.326	2	51.163	14.740	.000
Week	66975.018	11	6088.638	1754.078	.000
Temperature	2908.215	3	969.405	279.276	.000
location * week	839.708	22	38.169	10.996	.000
location * Temperature	3642.409	6	607.068	174.891	.000
week * Temperature	4708.246	33	142.674	41.103	.000
location * week * Temperature	5445.116	66	82.502	23.768	.000
Error	4498.588	1296	3.471		
Total	214294.700	1440			
Corrected Total	89119.627	1439			

a. R Squared = .950 (Adjusted R Squared = .944)

Table 5 shows that the main effects of the location, week and the temperature factors as well as their interaction effects on the weight, are highly significant with p-values below 0.001 (P<0.001). This result is further supported by the coefficient of determination (R-squared) for the fitted univariate ANOVA model, which indicates that the fitted model accounted for a highly significant proportion (95.0%) of the total variability in the data.

Estimated marginal means plots

Figures 3 -11 respectively, show the plots of the estimated marginal means of Total length, Standard length, and the weight, against the weeks under review for each of the temperature factor levels at each of the three locations.

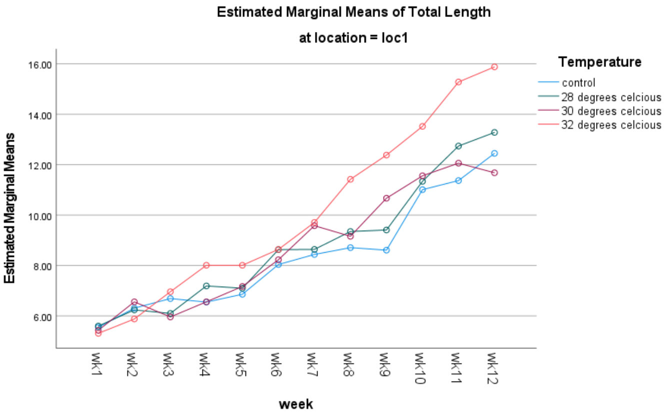

Figure 3: Estimated Marginal Means of Total Length for location 1

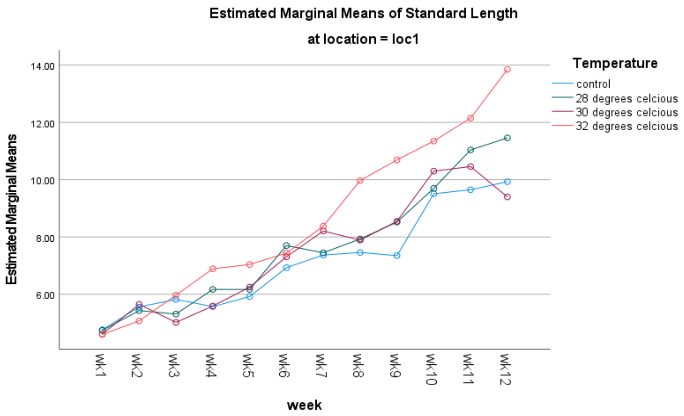

Figure 4: Estimated Marginal means of Standard Length for location 1

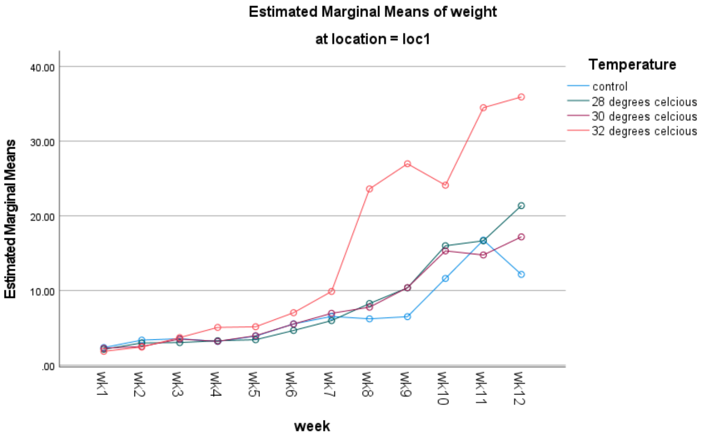

Figure 5: Estimated Marginal Means of Weight for location 1

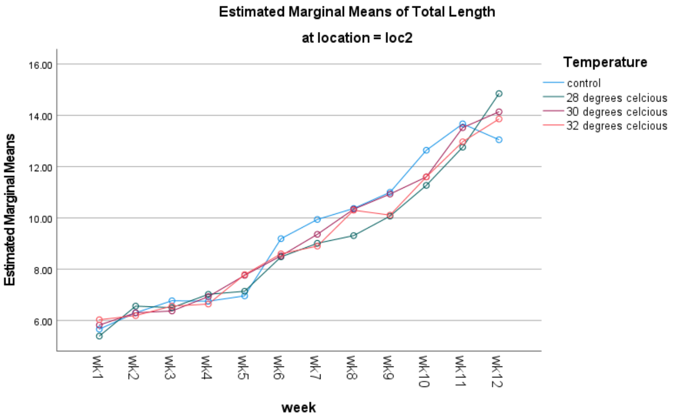

Figure 6: Estimated Marginal Means of Total Length for location 2

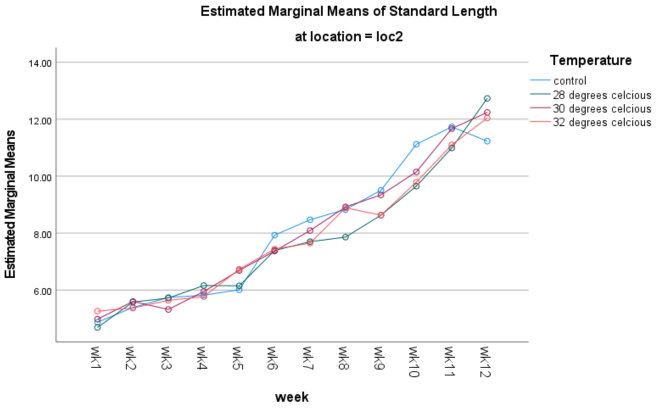

Figure 7: Estimated Marginal Means of Standard Length for location 2

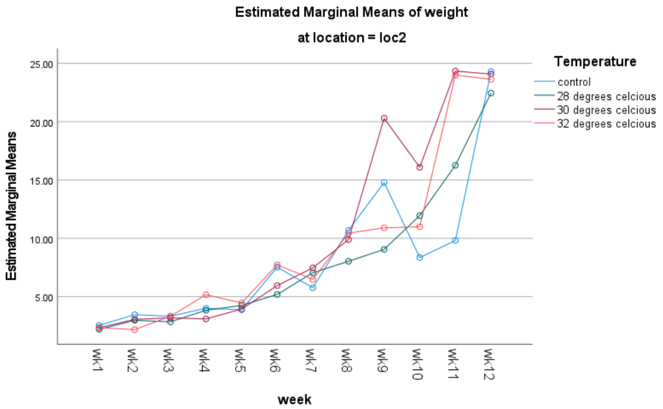

Figure 8: Estimated Marginal Means of Weight for location 2

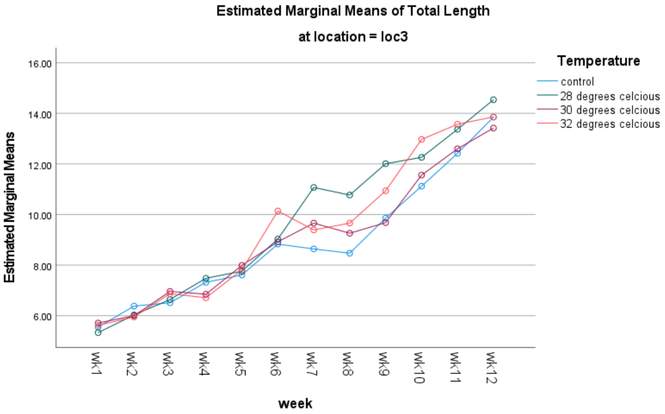

Figure 9: Estimated Marginal Means of Total Length for location 3

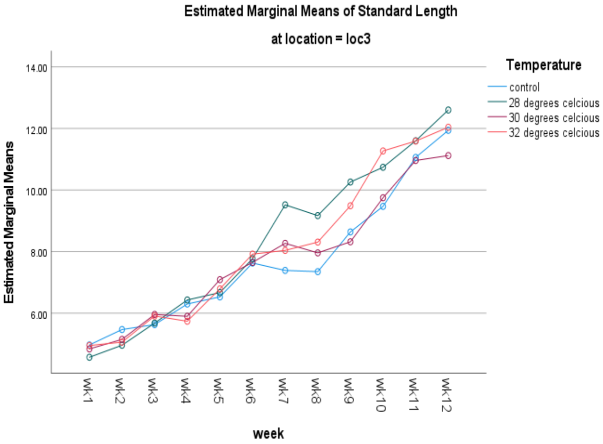

Figure 10: Estimated Marginal Means of Standard Length for location 3

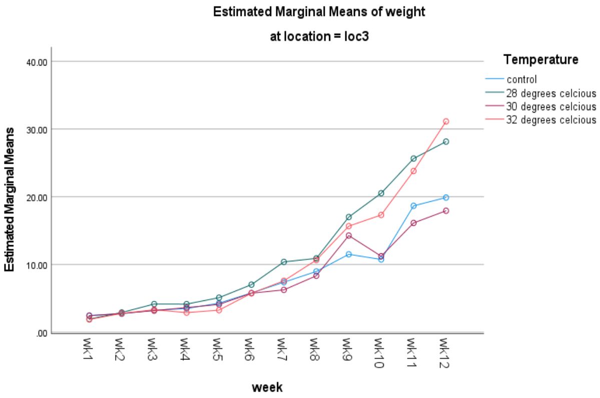

Figure 11: Estimated Marginal Means of Weight for location 3

CONCLUSION

The study reveals that,as the weeks under study progress, the fish continue to grow correspondingly in total length, standard length and weight. The fast-growing fish in the total length, standard length and weight is found in the water temperature at 32°C at location one. The least growing fish in location one of the total length, standard length and weight is found in30°C and control (water at room temperature). The Length - weight relationship of tilapia demonstrated negative allometry growth pattern which might be attributed to the environmental condition.

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