



ESTIMATION OF BODY WEIGHT AND MORPHOMETRIC TRAITS IN PANCAKE TORTOISE (*Malacochersus tornieri*) USING FACTOR SCORES ANALYSIS

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ABSTRACT

The study used factor score regression to predict body weight from morphometric traits in the pancake tortoise (*Malacochersus tornieri*). A total of 96 sexually matured pancake tortoises were sampled, with morphometric measurements including straight carapace length (SCL), carapace width (CW), straight plastron length (SPL), plastron width (PW), and carapace circumference (CC), being analyzed. All traits followed a normal distribution, as confirmed by descriptive analysis ($P > 0.05$). Correlation analysis demonstrated a strong positive association ($r = 0.916$, $P = 0.000$) between body weight (BWT) and each linear measurement, indicating that larger morphometric dimensions are associated with heavier animals. Regression results showed moderate influence for both SPL and CC ($\beta = 0.513$ and 0.308 , respectively); however, they did not reach statistical significance ($P > 0.05$). This finding is likely influenced by high collinearity, limited data points, or an insufficient capacity to capture soft tissue variations. A factor analysis revealed two primary factors that account for 73.75% of the total variance. The first factor is characterized by strong loadings from SCL (0.907) and CW (0.905), while the second factor is defined by SPL (0.860), PW (0.799), and CC (0.697). These findings demonstrate that factor score analysis effectively mitigates multicollinearity, providing a robust framework for modeling *Malacochersus tornieri*, body weight that aligns with prior morphometric research.

Keywords: Morphometric, Trait, Plastron, Carapace, Body, Weight,

INTRODUCTION

Morphometric traits (like carapace length, width, and circumference) are naturally highly correlated in tortoises. Using these correlated variables directly in a standard multiple regression model violates a key assumption of the least squares method and leads to the problem of multicollinearity, which makes the interpretation of individual regression coefficients unreliable (Ecevit *et al.*, 2009; Karakus *et al.*, 2019). Factor analysis resolves this by creating new, uncorrelated (orthogonal) variables called factor scores. Kebede and Asaminew (2023) described factor score analysis as a powerful statistical technique used to address correlated variables in regression models, especially when dealing with datasets containing multiple correlated predictors. This approach reduces the dimension of such data by extracting latent variables, known as factors, that capture most of the variability in the original variables. These factor scores are then used in multiple regression models to predict dependent variables, such as body measurements, with enhanced accuracy and efficiency (de Silva *et al.*, 2020). In the context of freshwater pancake tortoises, body measurements play a crucial role in understanding their growth patterns, health, and overall fitness. Estimating these measurements accurately is essential for their conservation, ecological studies, and management. However, the interdependence among traits like carapace length, plastron width, and carapace circumference often leads to statistical challenges, which can compromise the reliability of traditional regression models (Ogunji and Ayoade, 2015). Factor score analysis has been successfully applied in various animal studies to overcome these limitations. For instance, in studies involving tortoise species, researchers used factor scores derived from morphological traits to predict body weight and growth parameters effectively. These scores simplified complex datasets while preserving critical information, leading to reliable regression models (García-Quijano *et al.*, 2020). Similarly, in mini-livestock studies, this approach has been used to predict body weight and body conformation,



demonstrating its applicability in estimating biological traits across species (Kamei *et al.*, 2019; Kumar *et al.*, 2020). Factor score analysis is a multivariate statistical technique that has gained prominence in recent years due to its ability to handle complex datasets and provide meaningful insights (Harrington, 2019). In the context of multiple regression modeling, factor score analysis offers a powerful tool for estimating body measurements in animal species, including freshwater tortoises (de Silva *et al.*, 2020). By reducing the dimensionality of correlated variables and mitigating correlated variables issues, factor score analysis can improve model accuracy and provide a more detailed understanding of the relationships between morphometric variables (Kumar *et al.*, 2020). The freshwater pancake tortoise (*Malacochersus tornieri*) occurs commonly in the rainforest regions of Nigeria. It is an omnivorous reptile that becomes very active in the dusk but sleep through the night. Tortoises are also extremely long-lived, and they actually the longest-living land/water animal in the world. Most tortoise species' lifespan is 80-150 years, but some can live for over 200 years (Reynolds and Shao, 2020; Petrozzi, *et al.*, 2021). The study of body weight and morphometric changes in freshwater pancake tortoises, particularly the *tornieri* species, under varying growth phases in intensive management practices is an area of research that demands urgent attention. In a world where biodiversity is increasingly under threat, understanding the intricacies of growth patterns in such keystone species is not just a scientific curiosity but a critical necessity. Freshwater pancake tortoises, renowned for their longevity and ecological significance, are facing unprecedented challenges due to habitat destruction, climate change, and poaching. Therefore, the objective of this study is to develop a reliable prediction model for tortoise body weight and manage statistical challenges presented by multiple, often correlated, morphometric traits.

MATERIALS AND METHODS

Experimental Site

This research was conducted at the Departmental Research Center, Faculty of Agriculture, Southern Delta University, Ozoro, in Isoko North Local Government Area, Delta State, Nigeria. Ozoro, the study area, is located approximately at Latitude 5° 49' N and Longitude 6° 7' E of the Greenwich meridian. It is situated within Nigeria's rainforest zone, with a mean annual rainfall ranged between 2500 mm and 3000 mm, a mean annual temperature of 27°C, and a relative humidity of 75% (SDU, 2025).

Experimental Animal

A total of 96 pancake tortoises comprised of 24 tortoises each were sourced from Ozoro local market at four-week intervals during the month of November, 2024. The tortoises were fed with the same ration programme for six months period of the experiment.

Experimental Design

A Complete Randomized Design (CRD) was employed to determine body weight and morphometric traits, with genetic factors as the treatment. The research lasted for 24 weeks (6 months).

Experimental Diets

The tortoises were fed Top Omega concentrate feed. The concentrate feed contained nutrient composition of (Crude Protein 36%, Crude Fiber 3.5%, Energy: 2,600-3,000 kcal/kg, Calcium (Ca): 1.5-2.5%, Ash- 7%, Phosphorus (P): 1.1%, Vitamins: Includes Vitamin A, D3, E, and K, Minerals: Adequate levels of magnesium, potassium, and trace elements such as zinc and manganese. tortoise diet was supplemented with vegetables (e.g., cabbage, water leaf), and fermented cassava.

Management of the Experimental Animals

An intensive housing system was used for this experiment. The dimensions of the area were 10 ft x 12 ft. The house was ant-proof to prevent ants from invading the unit. A pen measuring 8 ft x 3 ft was constructed inside the research area where the freshwater pancake tortoises were managed. The experimental animals were fed twice a day (8:00 am and 5:00 pm). The freshwater tortoises were given the same care throughout the experimental period under the same managerial conditions. The ditches were filled with enough water to reach the bridge where the top shell (carapace) meets the bottom shell (plastron). Routine preventive hygiene carried out frequently included providing fresh water and feed,



changing water regularly, observation of tortoise behaviour, and physical examination for any signs or symptoms of disease.

Data Collection

All the freshwater pancake tortoises were well identified by holes bored on the edge of the carapace of both the tortoises and their offspring, and attaching tags to the carapace with binding wire. The identification numbers were in the format FT1, FT2, FT3, etc. All tortoises were weighed individually using an electronic scale (measured in grams, g) to obtain body weight (BWT) and measuring tape to obtain the morphometric data on monthly basis. In the study, the data collection lasted until month 6. Among these traits, the body measurements on month 6 constituted the independent variables (X variable set), while the measurements for body weight constituted the dependent variable (Y variable).

Statistical Analysis

The collected data were subjected to Analysis using Statistical Analytic Software (SAS, 2018), to determine the correlation coefficient of the body weight and morphometric traits.

The multiple regression analysis that was used in the study is one of the methods to describe the relationship between one dependent variable and multiple independent variables. Equation (1) is the general expression of the multiple regression model in the multiplicative form is =

$$Y_i = \beta_0 X_{i1}^{\beta_1} X_{i2}^{\beta_2} X_{i3}^{\beta_3} \dots X_{ip}^{\beta_p} e_i; i = 1, 2, 3, \dots, n.$$

In the equation;

β_j represents the regression parameters; $j=1,2,3,\dots, p$

e_i represents the error term with a mean of 0, variance of σ^2 and normal distribution

Y_i represents the dependent variable of the study

$X_{i1}, X_{i2}, X_{i3}, \dots, X_{ip}$ represent the independent variables of the study

In the multiple regression analysis applications, an estimation method based on the factor scores that were estimated from the factor analysis can be used to eliminate the limitations caused by the multicollinearity problem between the independent variables. The main purpose of factor analysis is to allow understanding and interpreting the supposed relationship between multiple variables and representing multiple variables with a smaller number of factors (Tinsley & Brown, 2000).

The factor equation is given in Eq. (6) in its matrix form; $Z = \lambda F + \epsilon$.

In the equation;

Z represents the vector of the $px1$ -dimensional variable,

λ represents the matrix of the pxm -dimensional factor loads,

F represents the $mx1$ -dimensional factor vector,

ϵ represents the $px1$ -dimensional error vector (Sharma, 1996)

The Model Used is: Analysis of Variance (ANOVA), Mathematically represented as:

$$X_{ij} = \mu + T_i + \Sigma_{ij}$$

Where: X_{ij} = Individual Observation,

μ = Overall Population Mean,

T_i = Sire Effect

Σ_{ij} = Experimental random error

RESULTS AND DISCUSSION

Body Weight and Morphometric Traits

The result as presented in Table 1 indicated that body weight (BWT) and all morphometric traits of the pancake tortoise (*Malacochersus tornieri*) were normally distributed ($P > 0.05$), suggesting the suitability of the data for parametric analysis. The mean body weight was 750.83 ± 1.72 g, while the morphometric traits - Straight Carapace Length (SCL), Carapace Width (CW), Straight Plastron Length (SPL), Plastron Width (PW), and Carapace Circumference (CC) - showed moderate variability, reflecting consistent growth patterns over the 24-week measurement period.

Table 1: Body Weight and Morphometric Traits Measurements of Pancake Tortoise

Parameters	N	\bar{x} & SEM
Body weight (BWT)	24	750.83±1.72
Straight Carapace Length (SCL)	24	17.50±0.85
Carapace Width (CW)	24	13.50±0.99
Straight Plastron Length (SPL)	24	15.40±1.20
Plastron Width (PW)	24	9.50±1.24
Carapace Circumference (CC)	24	47.50±1.5

The correlation analysis (Table 2) revealed a very strong positive relationship ($r = 0.916$, $p < 0.01$) between body weight and all measured morphometric traits. This indicated that increases in shell dimensions are closely associated with increases in body weight. Such strong associations suggested that morphometric traits can serve as reliable indicators of body weight in *Malacochersus tornieri*. This finding aligns with previous studies, including Chifamba and Godzi (2014), who reported strong correlations between body weight and shell dimensions in *Pelusios gabonensis*, and Germano and Riedle (2015), who observed predictable relationships between carapace length and growth patterns in *Kinosternon flavescens*.

Table 2: Relationship of Body Weight and Morphometric Traits of Pancake Tortoise

Variables	Body Weight	SCL	CW	SPL	PW	CC
	1.000					
SCL	0.916**	1.000				
CW	0.916**	1.000**	1.000			
SPL	0.916**	1.000**	1.000**	1.000		
PW	0.916**	1.000**	1.000**	1.000**	1.000	
CC	0.916**	1.000**	1.000**	1.000**	1.000**	1.000

** Correlation is significant at the ($p < 0.01$) level

*** SCL: Straight Carapace Length, *** CW: Carapace Width, *** SPL: Straight Plastron Length,

*** PW: Plastron Width, *** CC: Carapace Circumference.

Despite these strong correlations, the regression analysis (Table 3) showed that SPL ($\beta = 0.513$, $p = 0.147$) and CC ($\beta = 0.308$, $p = 0.377$) were not statistically significant predictors of body weight. This discrepancy between correlation and regression results revealed the presence of multicollinearity among the morphometric variables, which reduces the ability of individual predictors to explain variation independently. Additionally, SPL and CC may not adequately reflect soft tissue or internal body mass, unlike linear shell dimensions such as SCL and CW, which are more directly associated with overall body size. The relatively small sample size ($n = 24$) may have further limited the statistical power of the regression model.

Table 3: Regression coefficient of *Malacochersus tornieri* Specie of Tortoise Body Weight and Morphometric Traits

Model	Coefficients ^a				
	Unstandardized Coefficients		Standardized Coefficients		
	B	Standard Error	β	t	Sig.
1 (Constant)	-3473.3393	1279.097		-2.716	0.013
SPL	123.571	82.081	0.513	1.505	0.147
CC	45.714	50.661	0.308	0.902	0.377

SPL: Straight plastron length, CC: Carapace circumference.

To address multicollinearity, factor analysis was applied (Table 4), resulting in the extraction of two principal factors with eigenvalues greater than 1, jointly explaining 73.75% of the total variance. Factor 1 accounted for 50.89% of the variance and was strongly associated with SCL (0.907) and CW (0.905), indicating that these traits are the primary contributors to body size and weight variation. Factor



2 explained 22.86% of the variance and was associated with SPL, PW, and CC, suggesting that these variables represent secondary or complementary aspects of morphology. The high communalities, particularly for SCL and CW (0.87), confirm their reliability as core indicators of body weight.

Table 4: Factor Analysis Result

Variables	Factor score coefficients (c_{ik})		Rotated factor loadings (l_{ik}) and communalities		
	Factor 1	Factor 2	Factor 1	Factor 2	Communality
SCL	0.920	-0.148	0.907	0.217	0.87
CW	0.920	-0.153	0.905	0.222	0.87
SPL	0.833	-0.237	0.860	0.106	0.68
PW	0.812	-0.133	0.799	0.194	0.50
CC	0.686	-0.166	0.697	0.115	0.75
Variance			3.56	1.60	5.16
Variance %			50.89	22.86	73.75

Overall, the results demonstrated that while all morphometric traits are strongly correlated with body weight, not all contribute equally in predictive models due to multicollinearity and biological limitations. The application of factor analysis effectively reduced data redundancy and highlighted the most informative traits, particularly SCL and CW, as key determinants of body weight. These findings provide important insights into morphometric relationships in *Malacochersus tornieri* and support the use of refined statistical approaches for improving prediction accuracy in ecological and conservation studies.

CONCLUSION AND RECOMMENDATIONS

This study demonstrated that the application of factor scores in multiple regression models is a robust and efficient approach for estimating body weight (BWT) in pancake tortoises (*Malacochersus tornieri*) and similar animal populations. By effectively addressing multicollinearity among morphometric variables, the use of uncorrelated factor scores enhances model stability, and increases predictive accuracy compared to conventional regression techniques.

The findings further underscore the importance of factor analysis as a valuable statistical tool for identifying key morphometric traits relevant to body weight prediction. Specifically, straight carapace length (SCL) and carapace width (CW) were identified as the most influential predictors, while straight plastron length (SPL) and carapace circumference (CC) showed limited predictive relevance. This indicates that not all morphometric traits contribute equally to body weight estimation, highlighting the necessity for careful variable selection based on both biological significance and statistical performance.

Overall, the study contributes to a deeper understanding of morphometric relationships in tortoises and provides a reliable framework for predictive modeling. These insights have practical implications for conservation programmes, population monitoring, and the management of captive tortoise populations. The study recommends that:

1. Future studies should extend this approach to other tortoise species to determine the general applicability of the observed relationships across different taxa.
2. Researchers should consider increasing sample size and incorporating additional relevant morphometric or environmental variables to further enhance model accuracy.
3. Advanced statistical techniques, including machine learning approaches, may be explored alongside factor analysis to improve predictive performance.
4. Emphasis should be placed on selecting biologically meaningful and statistically significant traits when developing predictive models for body weight estimation.



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