

## ECO-MORPHOLOGICAL DIFFERENTIATION OF TILAPIA SPECIES IN SELECTED RESERVOIRS OF KANO STATE, NIGERIA

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### ABSTRACT

Morphological differentiation among intra-specific fish populations often depicts their living conditions directly influenced by differences in their environmental conditions. This study evaluates the eco-morphological differentiation of three commercially significant cichlids (*Oreochromis niloticus*, *Sarotherodon galilaeus*, and *Coptodon zillii*) across five heterogeneous reservoirs (Kanye, Tiga, Thomas, Bagwai, and Pada) in Kano State, Nigeria. Morphometric data from 270 fish specimens ( $n=30$  per population) were characterized using thirteen body traits to assess phenotypic plasticity. Results indicated distinct habitat-induced size structuring: *O. niloticus* in the large Tiga and Kanye reservoirs displayed robust growth forms (i.e., mean Total Length 18.2–19.2 cm, Body Depth 6.09–6.22cm), whereas *S. galilaeus* in the smaller Thomas Reservoir exhibited significant ( $P<0.05$ ) stunting growth (mean TL 10.7 cm, Body Depth 3.90cm), a possible indication of life-history trade-offs driven by spatial limitation and potential fisheries-induced evolution. Following allometric adjustment, Multivariate Analysis of Variance (MANOVA) and Linear Discriminant Analysis (LDA) confirmed significant population divergence ( $P < 0.05$ ). Key discriminatory traits included Caudal Peduncle Depth (CPD), Body Depth (BD), and Head Length (HL), reflecting possible functional adaptations to ecological imbalance, and trophic niches. The observed phenotypic patterns clearly demonstrate that the reservoir populations function as distinct management units. These findings advocate for site-specific conservation strategies that takes into account for the local stock health and evolutionary pressures

**Key words:** Cichlid, Ecosystem, Man-made, Plasticity, Strain and Structure

### INTRODUCTION

Accurate identification and understanding of fish populations are fundamental to ecological, behavioural, and fisheries management studies. Among fishes, morphometric and meristic analyses remain some of the most practical and reliable methods for distinguishing species and populations (Brraich and Akhter, 2015). Fish often exhibit considerable morphological variation both within and between populations, largely as a response to environmental factors such as habitat type, water quality, food availability, and temperature (Hussain *et al.*, 2010). Morphometric characteristics therefore provide useful indicators of environmental adaptation, stock structure, and population health, serving as valuable tools for sustainable fisheries management (Mojekwu & Anumudu, 2015).

Kano State is endowed with approximately 26 man-made reservoirs, ranging from small impoundments of a few hectares to large water bodies extending up to 17,000 hectares (Yahaya *et al.*, 2024). These reservoirs were originally constructed to provide water for irrigation, domestic use, livestock rearing, and flood control (Ahmad & Haie, 2018; Shanono *et al.*, 2023). Over time, they have evolved into important fishing grounds that support rural livelihoods and provide a major source of animal protein for surrounding communities (Muhammad *et al.*, 2018).

Tilapia—a common name for several species of cichlids belonging to the genera *Oreochromis*, *Sarotherodon*, and *Tilapia*—is widely distributed across Africa's freshwater and brackish ecosystems (Ahmad *et al.*, 2021; Canonico *et al.*, 2005). These species are among the most important cultured and wild-caught fishes on the continent due to their adaptability, fast growth, and thus contribution to food security. In some reservoirs of Kano State, *Tilapia* species constitute between 12.0% and 67.9% of the total fish assemblage, highlighting their ecological and economic importance (Abdul-Azeez *et al.*, 2024; Attah *et al.*, 2023; Suleiman *et al.*, 2018). Despite this significance, there remains a dearth of published studies on the eco-morphological differentiation of *Tilapia* populations in Kano's reservoirs, leaving a gap in understanding how environmental variation among these water bodies influences population structure and adaptation.

This study therefore aims to investigate the morphological differences of *Tilapia* species across selected reservoirs in Kano State, Nigeria, that can be linked to their environment. By examining morphometric variation in relation to different environmental settings, the study seeks to identify potential habitat-driven phenotypic differentiation within *Tilapia* populations. The findings will provide insights into how environmental heterogeneity shapes morphological traits, contributing to effective conservation and management of fish biodiversity in the region's reservoirs.

**MATERIALS AND METHOD**

**Study Area**

The study was carried out across five reservoirs located in different parts of Kano State, Northern Nigeria. These

reservoirs vary considerably in size, age, and hydrological characteristics, representing some of the most important inland water resources supporting fisheries in the region (Table 1).

**Table 1:** Information on the different reservoir waterbodies

Reservoir	Year of construction	Surface area (storage capacity)	Latitude	Longitude	Reference
Bagwai (Watari)	1977	19.59 km <sup>2</sup> (104.55 Mm <sup>3</sup> )	12.1567°N	8.1367°E	Rabiu <i>et al.</i> (2018)
Pada	1971	NA	12.0333°N	8.5833°E	Muhammad <i>et al.</i> (2018)
Kanye	1969	11.31km <sup>2</sup> (24.6Mm <sup>3</sup> )	12.6167°N	8.0167°E	Abdullahi <i>et al.</i> (2018)
Thomas	1973	0.585 km <sup>2</sup>	12.2667–12.3000°N,	8.5000–8.5167°E	Nafiu <i>et al.</i> (2017)
Tiga Reservoir	1974	178 km <sup>2</sup> (~2 Bm <sup>3</sup> )	11.2500°–11.4833°N	8.2667–8.6333°E	Abdul-Azeez <i>et al.</i> (2024)

NA=Not available

**Fish sampling and identification**

Thirty fish specimens of each species out of the three Cichlid fish used in this study were randomly collected per water body. The sampling per species was replicated in three different reservoirs, representing nine populations all together. The three *Tilapia* species identified are; *Oreochromis niloticus*, *Sarotherodon galilaeus*, and *Coptodon zillii*. Samples were obtained from the catches of artisanal fishermen at the respective landing sites. Immediately after collection, fish were placed in ice-packed coolers and transported to the Fish Biology Laboratory, Department of Fisheries and Aquaculture,

Bayero University, Kano, for morphometric analysis. Species identification and classification were carried out using the fish identification guide of Olaosebikan and Raji (1998).

**Morphometric Measurements**

Thirteen morphometric characters were measured from the left side of each fish specimen using a measuring ruler, Vernier caliper, and divider to the nearest centimeter. All measurements were carefully recorded in Microsoft Excel (2016). The measured morphometric features and their descriptions are presented in Table 2.

**Table 2:** Description of the various morphometric features used for the Study

S/N	Acronyms of the features	Morphological features	Description
1	TL	Total Length	Length from the tip of the snout to the tip of the caudal fin.
2	SL	Standard Length	Length of the tip of the fish snout to the base of the caudal fin.
3	POD	Post-orbital Distance	Length from the tip of the snout to the extremity of the bony orbit
4	HL	Head Length	Length from the tip of the snout to the posterior bony extremity of the operculum.
5	PDD	Pre-Dorsal Distance	Length from the tip of the snout to the structural base of the first dorsal fin ray.
6	PPD	Pre -Pelvic Distance	Length between the tip of the snout and the insertion of the first ray of the ventral fin.
7	PPED	Pre-Pectoral Distance	Length between the tip of the snout and the insertion of the first ray of the pectoral fin.
8	PAD	Pre-Anal Distance	Length between the tip of the snout and the insertion of the first ray of the anal fin.
9	DAD	Dorsal-Anal Distance	Distance from the base of the dorsal fin to the base of the anal fin.
10	DFBL	Dorsal Fin Base Length	Horizontal distance from the beginning of the dorsal fin to the end.
11	CPD	Caudal Peduncle Distance	Horizontal distance from the base end of the dorsal fin to the beginning of the caudal fin.
12	CAD	Caudal-Anal Distance	Horizontal distance from the base end of the anal fin to the beginning of the caudal.
13	BD	Body Depth	The depth of the body at its widest part, measured vertically from the base of the dorsal to the pelvic.



### Data Analysis

Box plots were constructed to detect outliers, and Q-Q plots were used to assess data normality. To minimize size-related variation, all morphometric variables were adjusted using the allometric method of Elliott et al. (1995):

$$M_{adj} = M \left( \frac{L_s}{L_o} \right)^b$$

Where;

M is the original measurement

$M_{adj}$  is the size corrected measurement

$L_s$  is the overall mean of the standard length of all fish,  $L_o$  is the standard length of each fish, and  $b$  is the regression slope of  $\log M$  on  $\log L_o$ .

Multivariate Analysis of Variance (MANOVA) was conducted to find significant difference ( $P < 0.05$ ) among the morphometrics. Where significant difference exists, Univariate Analyses of Variance (ANOVA) and Fisher-LSD *Post hoc* tests of pairwise comparison were employed. Linear discriminant analysis (LDA) plot was made to visualize the population (s) with distinct morphometrics. All statistical analyses were performed using the R statistical software (R Core Team, 2019).

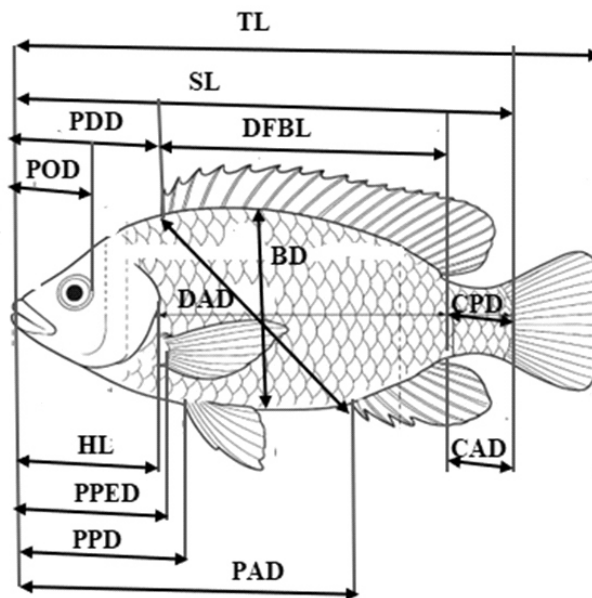


Figure 1: Diagram Showing the Studied Morphometrics

## RESULTS

### Morphometric variation in *Oreochromis niloticus*

Summary statistics for the morphometric characters of *Oreochromis niloticus* populations from Bagwai, Kanye, and Tiga reservoirs are presented in Table 3. The population from Kanye Reservoir exhibited the highest mean values across the majority of morphometric traits. However, lower mean values were recorded in Kanye for Post-Orbital Depth (POD, mean=1.70, range=1.4-2.1), Caudal Peduncle Depth (CPD, mean=1.68, range=1.68-1.0-2.3), Caudal-anal distance (CAD, mean=1.6, range=1.2-2.3) and Body Depth (BD, mean=16.09, range=4.8-7.8) compared to the other two populations.

A Multivariate Analysis of Variance (MANOVA) revealed a statistically significant differentiation among the three *O. niloticus* populations [Pillai's Trace = 0.47,  $F(22, 132) = 1.8649$ ,  $P < 0.05$ ]. Subsequent Univariate Analysis of Variance (ANOVA) confirmed that this morphological differentiation was driven by significant variation in five specific characters (Table 4): POD,

Dorsal-Anal Distance (DAD), CPD, CAD, and BD.

Fisher's Least Significant Difference (LSD) *post-hoc* tests indicated that the Kanye Reservoir population was the most morphologically distinct, showing significant divergence ( $P < 0.05$ ) from the Bagwai and Tiga populations, particularly in caudal and depth-related traits. This separation was visually corroborated by the Linear Discriminant Analysis (LDA) scatter plot (Figure 2). Analysis of the variable contributions (Table 5) indicated that CPD and BD were the primary discriminating variables contributing to the separation along the first (LDA 1) and second (LDA 2) canonical axes, respectively.

**Table 3:** Summary Statistics of the morphometrics of *O. niloticus* fish Populations.

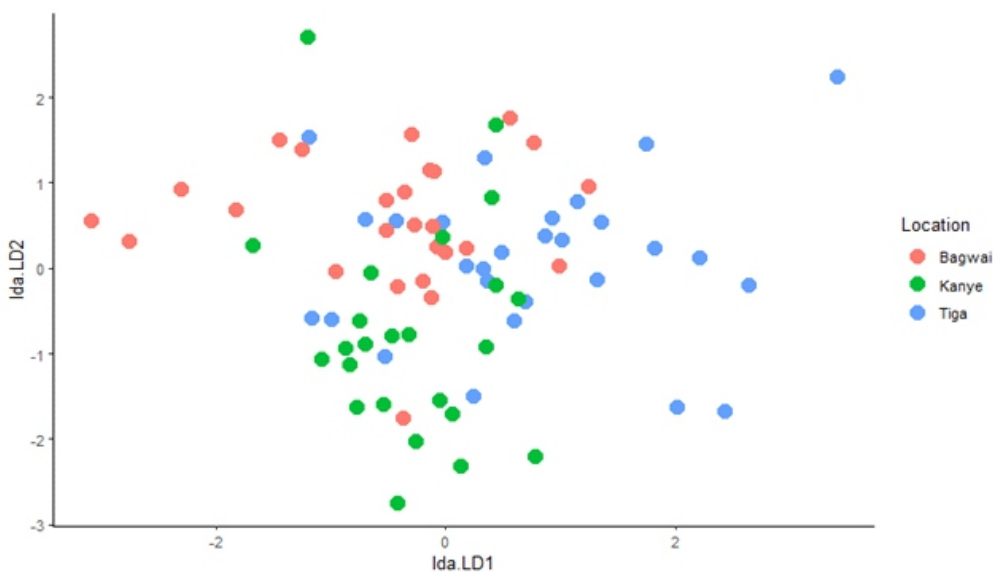
Morphometrics	Bagwai (N=28)		Kanye(N=28)		Tiga(N=28)	
	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)
TL	17.90	15-20.7	18.2	16.3-22.3	19.2	14.2-21.9
SL	14.40	12.1-16.4	15.2	13.0-17.5	14.5	11.9-17.6
POD	1.75	1.3-2.4	1.70	1.4-2.1	1.72	1.2-2.1
PDD	5.27	4.3-6.6	5.36	4.5-6.3	5.09	3.5-6.2
HL	4.72	4.0-5.7	5.02	4.3-5.9	4.82	3.9-6.2
PPD	5.90	4.8-7.0	6.35	5.2-7.8	6.19	4.9-7.2
PPED	5.18	4.4-6.5	5.48	4.0-6.9	5.22	4.1-5.9
PAD	10.70	9.0-12.9	11.6	9.5-13.8	11.2	8.1-13.7
DAD	8.60	5.7-10.4	9.25	7.7-13.8	9.24	7.1-10.9
DFBL	8.80	5.5-10.4	9.36	7.7-11.2	9.17	7.4-10.9
CPD	1.72	1.4-2.1	1.68	1.0-2.3	1.74	1.2-2.2
CAD	1.77	1.2-2.4	1.6	1.2-2.3	1.8	1.3-2.2
BD	6.27	4.7-9.3	6.09	4.8-7.8	6.22	5.1-7.3

TL= Total length, SL= Standard length, POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance

**Table 4:** Pairwise comparison *post hoc* tests between morphometrics of *O. niloticus* populations from the three water bodies.

Morphometrics	Bagwai (Mean±SD(cm))	Kanye(Mean±SD(cm))	Tiga(Mean±SD(cm))
POD	1.815 ±0.248 <sup>a</sup>	1.624± 0.240 <sup>b</sup>	1.795± 0.339 <sup>a</sup>
PDD	5.571 ±0.775	5.009 ±0.785	5.373± 1.068
HL	5.003 ± 0.656	4.659 ±0.603	5.118 ±1.028
PPD	6.225 ±0.848	5.949 ±0.749	6.522 ±1.125
PPED	5.475 ±0.778	5.110 ±0.736	5.529 ±1.063
PAD	11.318 ±1.561	10.757 ±1.326	11.809 ±2.212
DAD	9.138 ±1.589 <sup>ab</sup>	8.589 ±1.143 <sup>b</sup>	9.784 ±1.819 <sup>a</sup>
DFBL	9.304 ±1.395	8.744 ±0.989	9.644 ±1.624
CPD	1.795 ±0.251 <sup>a</sup>	1.585 ±0.277 <sup>b</sup>	1.808 ±0.334 <sup>a</sup>
CAD	1.832 ±0.289 <sup>a</sup>	1.553 ±0.333 <sup>b</sup>	1.872 ±0.325 <sup>a</sup>
BD	1.819 ±0.302 <sup>a</sup>	1.567 ±0.308 <sup>b</sup>	1.839 ±0.415 <sup>a</sup>

POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance



**Figure 2:** Linear Discriminant scatter plot of the three *O. niloticus* populations' morphometrics

**Table 5:** Contribution of the *O. niloticus* populations' morphometrics to the linear discriminant's axis

Morphometrics (Dependent variable)	Linear Discriminant (LD) 1	Linear Discriminant (LD) 2
POD	0.8207251	1.1502746
PDD	-1.6139975	0.9475719
HL	-0.3553062	-1.0364693
PPD	1.2443796	-1.3522545
PPED	0.2366208	0.2150717
PAD	0.4163257	-0.3436761
DAD	0.5043314	0.5344752
DFBL	0.5403942	-0.2646344
CPD	27.6916442	-11.1711029
CAD	1.6586827	2.1292136
BD	-27.2011185	11.9115570

POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance

**Morphometric variation in *Sarotherodon galilaeus***

Summary statistics for the morphometric characters of *Sarotherodon galilaeus* populations sampled from Pada, Kanye, and Thomas reservoirs are presented in Table 6. A distinct pattern was observed where the Thomas reservoir population consistently exhibited the lowest mean values across all measured traits. Conversely, the Kanye population recorded the highest mean values for most morphometric characters, with the exception of Caudal-Anal Distance (CAD), where the Pada population displayed comparable values (Mean = 1.4; Range = 1.0–1.7).

Multivariate Analysis of Variance (MANOVA) indicated a statistically significant differentiation [Pillai's Trace = 0.97, F(22, 156) = 6.61,  $P < 0.05$ ] among the populations based on location. Subsequent Univariate Analysis of Variance (ANOVA) and Fisher's Least Significant

Difference (LSD) *post-hoc* tests revealed significant differences ( $P < 0.05$ ) for every individual morphometric variable among the three populations (Table 7).

The morphological distinctness of the populations was visually corroborated by the Linear Discriminant Analysis (LDA) scatter plot (Figure 3). Analysis of the variable contributions to the canonical axes (Table 8) indicated that Pre-Dorsal Distance (PDD) and Caudal peduncle Distance (CPD) were the primary drivers of separation along the first axis (LD1). Conversely, Dorsal Fin Base Length (DFBL) contributed most significantly to the second axis (LD2). Overall, the *S. galilaeus* population from Thomas Reservoir displayed the greatest degree of morphological divergence when compared to populations from the Pada and Kanye reservoirs (Figure 3).

**Table 6:** Summary Statistics of the morphometrics of *S. galilaeus* Populations.

Morphometrics	Pada (n=30)		Kanye(n=30)		Thomas(n=30)	
	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)
TL	15.1	13.2-18.0	16.8	14.7-18.4	10.7	8.7-13.5
SL	11.6	10.0-14.2	13.0	11.5-14.2	8.2	6.0-11.1
POD	2.0	1.6-2.5	2.2	1.4-3.0	1.6	1.3-2.2
PDD	4.2	3.1-5.7	4.9	3.8-5.6	3.4	2.5-5.4
HL	3.8	3.3-4.7	4.3	3.2-5.1	2.7	1.5-4.0
PPD	4.9	4.0-6.2	5.2	3.9-5.9	3.7	3.0-5.5
PPED	4.1	3.1-4.9	4.7	3.9-6.0	3.1	2.5-4.6
PAD	8.9	7.5-11.0	9.8	9.0-10.7	6.4	5.2-8.6
DAD	7.2	5.7-8.8	7.9	5.3-8.7	5.0	4.1-6.4
DFBL	7.0	6.2-8.5	7.9	7.0-8.9	4.6	3.8-5.9
CPD	1.3	1.0-1.7	1.4	1.1-1.9	1.0	0.8-1.6
CAD	1.4	1.0-1.7	1.4	1.0-1.8	0.9	0.7-1.2
BD	5.1	4.3-6.4	5.9	4.6-7.2	3.9	3.1-4.9

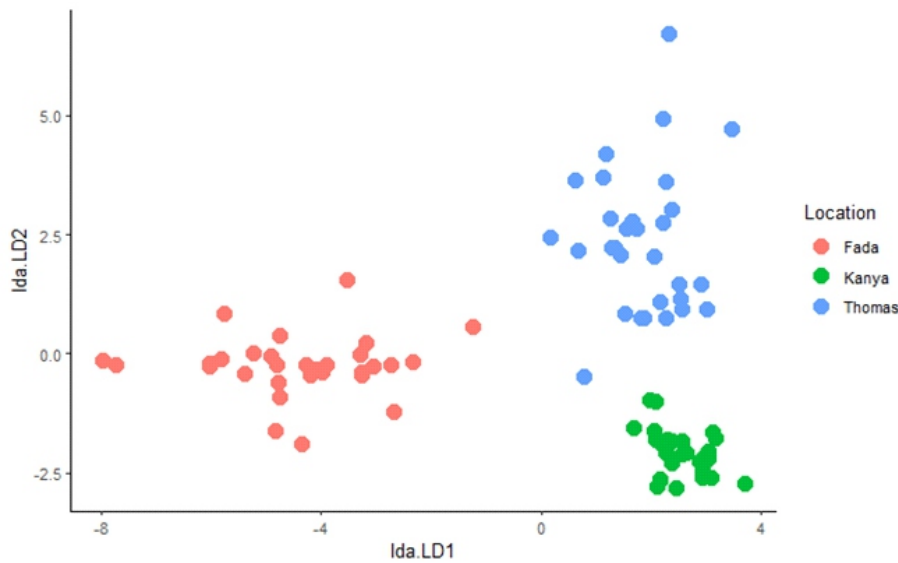
TL= Total length, SL= Standard length, POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance



**Table 7:** Pairwise comparison *post hoc* tests between morphometrics of *S. galilaeus* populations.

Morphometrics	Pada (Mean ± SD(cm))	Kanye (Mean ± SD(cm))	Thomas (Mean ±SD(cm))
POD	1.956 ± 0.356 <sup>b</sup>	1.580 ± 0.282 <sup>c</sup>	2.680 ± 0.600 <sup>a</sup>
PDD	4.128 ± 0.552 <sup>b</sup>	3.377 ± 0.309 <sup>c</sup>	6.241 ± 1.225 <sup>a</sup>
HL	3.690 ± 0.470 <sup>b</sup>	2.752 ± 0.212 <sup>b</sup>	5.679 ± 1.393 <sup>a</sup>
PPD	4.773 ± 0.485 <sup>b</sup>	3.724 ± 0.419 <sup>c</sup>	6.482 ± 1.381 <sup>a</sup>
PPED	3.965 ± 0.393 <sup>b</sup>	3.271 ± 0.395 <sup>b</sup>	5.689 ± 1.540 <sup>a</sup>
PAD	8.692 ± 0.436 <sup>b</sup>	6.631 ± 0.529 <sup>c</sup>	12.271 ± 2.873 <sup>a</sup>
DAD	7.051 ± 0.576 <sup>b</sup>	5.288 ± 0.574 <sup>c</sup>	9.831 ± 2.591 <sup>a</sup>
DFBL	6.847 ± 0.566 <sup>b</sup>	5.016 ± 0.440 <sup>b</sup>	9.939 ± 2.958 <sup>a</sup>
CPD	2.000 ± 0.010 <sup>b</sup>	1.580 ± 0.282 <sup>c</sup>	2.680 ± 0.600 <sup>a</sup>
CAD	1.304 ± 0.285 <sup>b</sup>	0.945 ± 0.135 <sup>c</sup>	1.754 ± 0.425 <sup>a</sup>
BD	4.994 ± 0.483 <sup>b</sup>	4.022 ± 0.323 <sup>b</sup>	7.240 ± 1.678 <sup>a</sup>

POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance



**Figure 3:** Linear Discriminant scatter plot of the three *S. galilaeus* populations' morphometrics.

**Table 8:** Contribution of the *S. galilaeus* populations' morphometrics to the linear discriminant's axis

Morphometrics (Dependent variable)	Linear Discriminant (LD) 1	Linear Discriminant (LD) 2
POD	-0.19852255	-0.27389038
PDD	1.41820744	0.97450987
HL	-0.08016385	0.82906476
PPD	-0.44526490	0.11082685
PPED	0.40577966	-0.44259354
PAD	0.45423826	0.84811634
DAD	-0.56735395	0.06182579
DFBL	0.31590693	-1.04659648
CPD	-4.10472019	0.38006236
CAD	0.42979283	0.03765143
BD	0.15788332	0.20476677

POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance

**Morphometric variation in *Coptodon zillii***

Summary statistics for the morphometric characters of *Coptodon zillii* populations sampled from Pada, Kanye, and Thomas reservoirs are presented in Table 9. A clear morphological gradient was observed: the Kanye population exhibited the highest mean values across all measured traits, whereas the Pada population consistently recorded the lowest mean values.

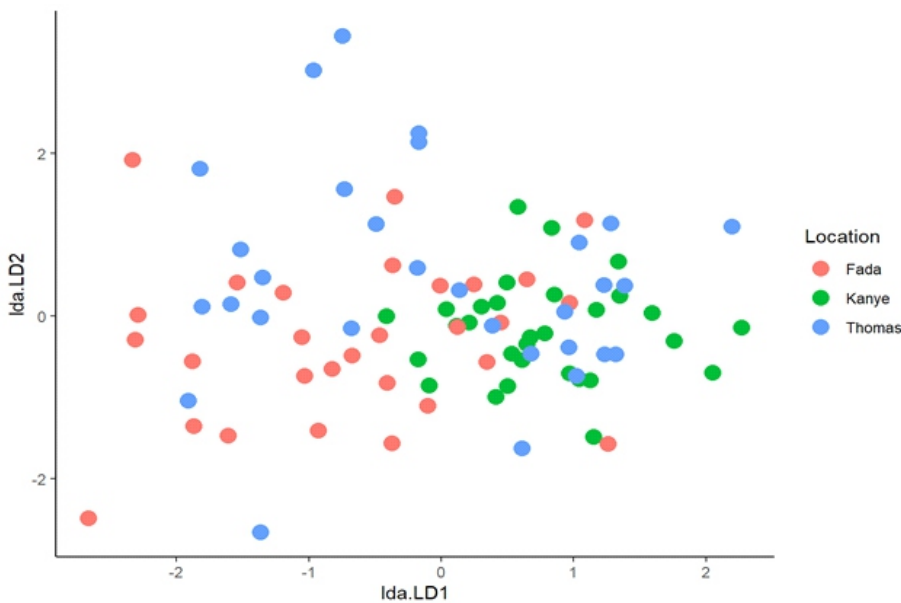
Multivariate Analysis of Variance (MANOVA) indicated no statistically significant differentiation among the *C. zillii* populations based on location [Pillai's Trace = 0.37,  $F(22, 156) = 1.59, P > 0.05$ ]. However, the Linear Discriminant Analysis (LDA) scatter plot (Figure 4)

depicts separation of the morphometrics of the populations in diverse clusters. Analysis of the variable contributions to the canonical axes (Table 10) identified Head Length (HL) and Caudal Peduncle Depth (CPD) as the primary contributors to the first axis (LD1). Conversely, Pre-Dorsal Distance (PDD), Pre-Pectoral Distance (PPD), Dorsal-Anal Distance (DAD), and Dorsal Fin Base Length (DFBL) exhibited the highest contributions to the second axis (LD2). Consistent with these findings, the *C. zillii* population from Kanye Reservoir displayed the most distinct morphological divergence compared to the populations from the Pada and Thomas reservoirs.

**Table 9:** Summary Statistics of the morphometrics of *C. zillii* fish populations

Morphometrics	Pada (N=30)		Kanye(N=30)		Thomas(N=30)	
	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)	Mean(cm)	Range(cm)
TL	16.4	13.0-20.5	18.5	12.7-21.4	16.6	11.2-21.4
SL	12.6	9.9-16.0	15.1	13.2-17.1	13.2	8.9-16.8
POD	1.97	1.0-3.1	2.21	1.6-3.2	2.05	1.2-2.9
PDD	4.51	3.5-6.2	5.53	4.5-6.9	4.77	3.4-6.5
HL	3.94	3.1-5.0	4.86	4.1-6.0	4.10	2.6-5.2
PPD	5.02	4.0-6.6	6.04	5.1-6.7	5.25	3.3-6.9
PPED	4.33	3.3-5.4	5.32	4.1-6.5	4.53	3.1-6.2
PAD	9.48	7.6-11.9	11.3	9.3-13.0	9.71	6.4-12.9
DAD	7.21	5.3-9.0	8.83	7.2-10.1	7.42	4.5-9.8
DFBL	7.26	5.4-9.2	8.86	7.2-10.1	7.37	4.9-9.8
CPD	1.71	1.3-2.4	2.03	1.2-2.6	1.78	1.2-2.4
CAD	1.72	1.1-2.2	2.15	1.6-2.8	1.83	1.0-3.3
BD	5.11	4.0-6.7	6.04	5.3-7.0	5.19	2.8-6.8

TL= Total length, SL= Standard length, POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance



**Figure 4:** Linear Discriminant scatter plot of the three *C. zillii* populations' morphometrics



**Table 10:** Contribution of the *S. galilaeus* populations' morphometrics to the linear discriminant's axis

Morphometrics (Dependent variable)	Linear Discriminant (LD) 1	Linear Discriminant (LD) 2
POD	0.1533088	-0.9122822
PDD	0.7381416	1.2627184
HL	1.2128981	-0.3452306
PPD	-0.1610768	1.1170505
PPED	-0.1334604	0.2332036
PAD	-0.3969322	-0.2214068
DAD	0.5951587	1.0378344
DFBL	-0.8514262	-1.6152536
CPD	-1.1917404	0.1931328
CAD	0.4136690	0.3297319
BD	-0.5183231	-0.8096924

POD= post-orbital distance, PDD= pre-dorsal distance, HL= Head length, PPD= pre-pelvic distance, PPED= Pre-pectoral distance, PAD= pre-anal distance, DAD= Dorsal-anal distance, DFBL= Dorsal Fin Base Length, CPD= Caudal peduncle distance, CAD= Caudal-anal distance and BD= Body distance

## DISCUSSION

The present study investigated morphometric differences among populations of three economically important cichlid species-*Oreochromis niloticus*, *Sarotherodon galilaeus*, and *Coptodon zillii*-inhabiting five reservoirs in Kano State. Our findings consistently indicated significant morphological differentiation among populations of all the three species across the sampled reservoirs, indicating a strong influence of geographical location and associated environmental factors on their body shape. The results aligns with numerous studies reporting high levels of morphological plasticity and local adaptation in cichlids in response to varying environmental conditions (Kwikiriza *et al.*, 2023; Ndiwa *et al.*, 2016).

The morphological analysis of *Oreochromis niloticus* indicated a distinct "allometric decoupling" in the Kanye Reservoir population. Despite exhibiting the highest mean values for most linear traits, this population recorded significantly ( $P < 0.05$ ) lower values for depth-related metrics-specifically Body Depth (BD), Caudal Peduncle Depth (CPD), and Post-Orbital Depth (POD). This results in a markedly fusiform (elongated) phenotype, contrasting with the robust, deep-bodied forms observed in Tiga and Bagwai (Price *et al.*, 2019).

This "long but slender" profile strongly of the Kanye Reservoir population suggests a physiological trade-off induced by environmental stress (Akin & Geheber, 2020). Given that Kanye Reservoir's documented high level of metal pollution (Abdullahi *et al.*, 2018), the metabolic costs of removing toxins likely reduces energy that could be available for lateral muscle growth, leading to the observed body thinning (Farooq, 2024). Functionally, the reduced caudal peduncle depth may be an indicative of compromise in sprinting ability where the streamlined shape of the population may offer a compensatory benefit by reducing drag, optimizing energy efficiency for

foraging in a turbid, resource-limited environment (Cooke *et al.*, 2022). Consequently, the Kanye phenotype should be interpreted as a stress response rather than a sign of optimal health.

Populations of *Sarotherodon galilaeus* exhibited significant differences driven by location, with the Thomas Reservoir population showing the most pronounced divergence. The Linear Discriminant Analysis revealed that a broad set of traits-including Pre-Dorsal Distance (PDD), Pre-Pectoral Distance (PPD), and Body Depth (BD)-contributed to this variation. This broad-scale variation likely reflects varying resource availability and predatory pressures (Williams *et al.*, 2017). Specifically, the smaller morphotypes observed in Thomas Reservoir population may result from a combination of spatial limitation and fisheries-induced evolution, where high fishing pressure in a confined environment favours early maturation at smaller sizes (Burns *et al.*, 2024). Furthermore, variations in diet composition might likely favour variations in mouth position and head shape, while varying levels of piscivory influence overall body depth for escape behaviour (Bonato *et al.*, 2017; Heynen *et al.*, 2017).

As no significant differentiation was detected among *Coptodon zillii* populations nevertheless the Kanye Reservoir population displayed little divergence from Pada and Thomas populations. The key contributing traits identified in the LDA, Head Length (HL) for LD1; PDD and DAD for LD2 point towards adaptations in the feeding apparatus. Head length is critically associated with feeding ecology, particularly in cichlids known for dietary flexibility (Bonato *et al.*, 2017).. The divergence in HL suggests that distinct feeding niches exist; the dominance of macrophytes or harder detrital matter might likely drive specific adaptations in jaw morphology or gill raker structure of Kanye Reservoir to maximize energy intake (Podder *et al.*, 2021).

### Limitations and Future Research

While this study clearly demonstrates influence of location differences on morphological divergence, it is important to acknowledge certain limitations. First, the analysis focused primarily on morphometric traits; incorporating meristic counts or genetic analyses would have provided a broader understanding of population structure. Second, while effect of location is evident, specific environmental parameters (e.g., precise water flow rates, predator abundance, and primary productivity) were not quantitatively linked to the observed morphological divergent in a multivariate regression. Finally, sample sizes per reservoir, while adequate for statistical analyses, could be extended to capture a broader range of intra-population variation.

Future studies should focus on identifying precise ecological factors driving these morphological adaptations. This could involve detailed studies on stomach content analysis (diet composition), habitat utilization, and hydrodynamics within each reservoir. Furthermore, integrating genetic analyses with morphometric data would give detail information on whether the observed morphological divergence is primarily due to phenotypic plasticity, genetic differentiation, or a combination of the two. (Nyauchi *et al.*, 2025)

### CONCLUSION

The consistency in the significant morphometric differentiation across all the three cichlid species underscores the powerful role of environmental heterogeneity in shaping fish morphology. The multivariate analysis approach proved instrumental in identifying that *O. niloticus* responds to hydrodynamic stress through caudal modification, while *S. galilaeus* and *C. zillii* exhibit plasticity in body size and cranial traits linked to feeding and life-history strategies. These results imply that reservoir cichlid populations in Kano State are not a single homogenous stock but comprise distinct ecomorphotypes. Conservation and management strategies must therefore be site-specific-protecting vulnerable, stunted stocks in Thomas and Pada from overfishing and all possible forms of ecological imbalance, while recognizing the robust Kanye populations as potential candidates for aquaculture development, pending genetic verification.

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