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MORPHOLOGICAL HETEROGENEITY IN *COPTODON ZILLII* (CICHLIFORMES, CICHLIDAE) FROM NIGERIA: IMPLICATIONS FOR POPULATION DIVERGENCE

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Morphological heterogeneity in *Coptodon zillii* (Cichliformes, Cichlidae) from Nigeria: implications for population divergence. Oladimeji, T. E. & Ayinde, Z. A. — The population divergence of three populations of *Coptodon zillii* (Gervais, 1848) from Aiba reservoir, Asejire reservoir, and Igbokoda river in Southwestern Nigeria was determined by characterising their morphometric measurements and meristic counts. Twenty-five morphometric measurements and six meristic counts were recorded on 50 individuals from each location. The morphometric data were size-corrected and analysed using the Kruskal-Wallis test and Principal Component Analysis (PCA), while the meristic data were analysed using Correspondence Analysis (CA). Results of the Kruskal-Wallis test revealed considerable morphological heterogeneity among the populations, with measurements of 13 morphometric traits significantly different at $p \leq 0.05$. The PCA also indicated morphological divergence among populations, as the Asejire population formed a distinct cluster, while the Aiba and Igbokoda populations exhibited partial overlap. The PCA-based loading plot identified the pectoral spine length and lower jaw width as the most significant morphometric traits driving morphological divergence among the populations. Correspondence analysis revealed a large overlap of the meristic data, suggesting that the meristic traits could not effectively delineate the populations. The study, therefore, concluded that the *C.zillii* populations from Aiba reservoir, Asejire reservoir, and Igbokoda river are morphologically divergent based on their morphometric characters only and should thus be managed accordingly.

Keywords: *Coptodon zillii*, Meristics, Morphometrics, Population, Differentiation.

Introduction

Fish populations often exhibit significant morphological heterogeneity due to environmental influences and local adaptations (Arbour & López-Fernández, 2013). These morphological variations could accumulate over time, forming distinct morphotypes. Persistent morphological divergence could indicate underlying genetic differentiation and ongoing speciation, as the distinct morphotypes may evolve into new species over time (Foote, 1997). Locally adapted populations should be uniquely managed to preserve their adaptive traits and prevent the disruption of ongoing evolutionary processes (Reznick & Ghalambor, 2001). Morphometric measurements and meristic counts are phenotypic traits that can be shaped by environmental changes such as habitat alteration, construction of dams, changes in water chemistry, floods, availability of food, prey-predator relationships, and the introduction of invasive species (Gilbert et al., 2020; Price et al., 2015). They are widely used in population studies to assess inter- and intraspecific variations as a basis for studying short- and long-term evolutionary changes (Turan, 2004). Morphological studies also have wide applications in fish biology for stock assessment and the development of aquacultural breeds (Ihssen et al., 1981; Innal & Giannetto, 2017)

Coptodon zillii (Gervais, 1848), a cichlid fish formerly known as *Tilapia zillii,* is native to Africa and the Middle East. Its areas of natural occurrence include the Niger-Benue system, the Chad basin, the Senegal River, the Volta System, the Nile River basin, the southern coast of Morocco, and the Congo River basin. In the Middle East, it is naturally found in the Jordan River system, Lake Kinneret, and several rivers along the coast of Israel (Trewavas, 1982). It has been intentionally introduced into several continents, including Australia, the USA, Europe, Asia, and the Caribbean, for a range of purposes such as aquaculture development, enhancement of recreational fisheries, and the biological control of aquatic macrophytes and insect vectors (De Silva et al., 2004; Innal & Giannetto, 2017; Tarkan, 2022). *C. zillii* inhabits a wide range of ecologically diverse environments, including freshwater, brackish water, seawater with 60–70% salinity (Chervinski & Hering, 1973), and full-strength seawater (Nehemia et al., 2014). This broad distribution reflects its euryhaline nature (Szitenberg et al., 2012), which enables the species to thrive in various aquatic ecosystems. In Nigeria, *C. zillii* is largely exploited by artisanal fisheries across both inland and coastal water bodies. The species also holds significant importance in aquaculture, being extensively cultured at both small and commercial scales, thereby contributing substantially to local livelihoods and the broader national and global economies (FAO, 2018). Morphological variation among *C. zillii* populations may reflect either genetic divergence or neutral environmental adaptation; it is therefore essential to study these traits across different waterbodies (Szitenberg et al., 2012). Understanding the scope of phenotypic variation is critical for effective fisheries management, conservation initiatives, and the sustainable exploitation of the species. Additionally, recognising distinct populations can inform fisheries policies, optimise stock management strategies, and support breeding programs for *C. zillii* globally.

C. zillii has scarcely been studied for its phenotypic plasticity across different locations in different parts of the world. A few available reports include those of Szitenberg et al. (2012), who used both morphological and molecular (mitochondrial control region sequences) tools to characterise the population structure of *T. zillii* in four Israeli aquatic systems. Oladimeji et al. (2015) similarly employed morphological and molecular (Ran-

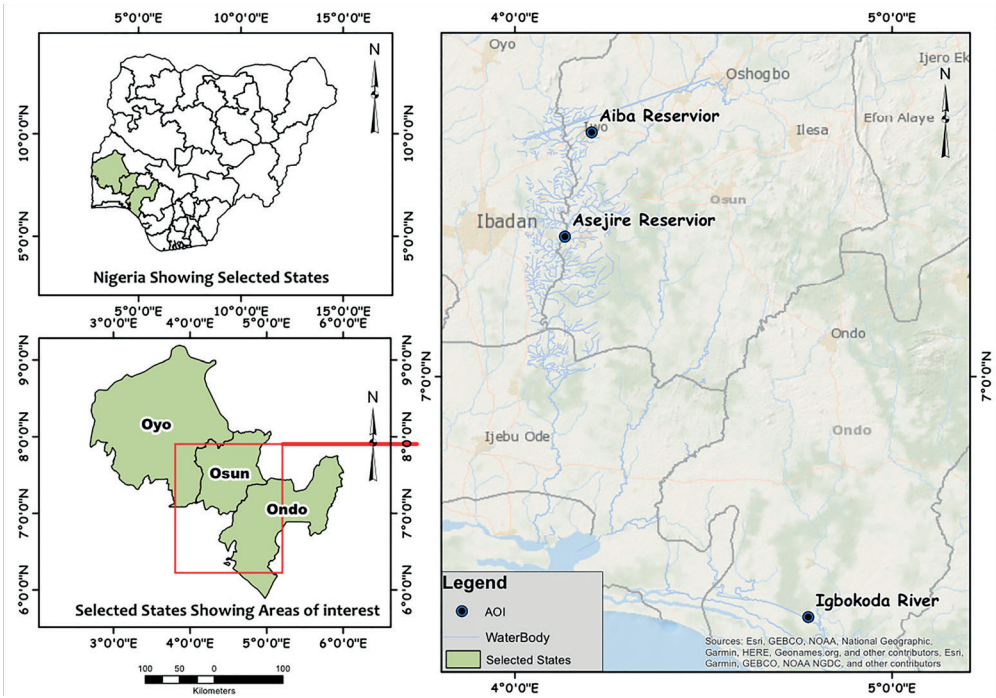

Fig. 1. Map of Nigeria showing the study areas (adapted from Oladimeji et al., 2025 a)

dom Amplified Polymorphic DNA) methods to characterise *T. zillii* from three Nigerian reservoirs. Another study by Oladimeji and Olaosebikan (2017) investigated the morphological variability of *Tilapia zillii* from selected reservoirs (Opa, Ero and Asejire) in Southwestern Nigeria using their morphometrics and meristic characters. The present study advances existing knowledge on the morphological heterogeneity of *C. zillii* populations by incorporating a riverine population, the Igbokoda River, and comparing it with newly sampled reservoir populations. This enables a comparative assessment of populations from contrasting aquatic systems and provides deeper ecological insight into habitat-related morphological divergence, thereby broadening knowledge on the population dynamics of this species in southwestern Nigeria. Despite the ecological and economic significance of *C. zillii*, there is limited information on its morphological divergence across varying habitats in Nigeria. This study, therefore, presents the comparative morphometric and meristic analyses of *C. zillii* from Aiba Reservoir, Asejire Reservoir, and Igbokoda River in Southwestern Nigeria.

Material and Methods

Coptodon zillii samples were collected from three different water bodies in Nigeria, namely Aiba Reservoir in Osun State (07°38' N; 004°13' E), Igbokoda River in Ondo State (5°57'3 N; 5°3' E), and Asejire Reservoir in Oyo State (07°21'45" N; 004°13'33" E) (Fig. 1). From each water body, fifty freshly dead *C. zillii* specimens were collected from the catches of commercial fishermen, totalling 150 samples from the three water bodies. The fish samples were collected over a period of six months from January to June, 2024. Animal ethics approval was not required for this study because live

fish samples were not collected. Species identification was done using the taxonomic keys according to Paugy et al. (2003).

Morphometric and Meristic Characteristics

Twenty-five (25) morphometric characters according to Dunz & Schliewen (2010) were measured to the nearest centimetre on each fish with a standard metre rule and a digital vernier calliper (DCLA-0605 0-6). These characters include: total length (TL), standard length (SL), head length (HL), body depth (BD), snout length (SNL), cheek depth (CHD), eye length (EYL), dorsal fin length (DFL), anal fin length (AFL), length of last dorsal spine (DSL), length of third anal spine (ASL), pelvic fin length (PFL), pre-dorsal distance (PDD), upper lip length (ULL), lower jaw length (LJL), lower lip width (LLW), lower lip length (LLL), pectoral fin length (PeCFL), pre-orbital distance (POD), caudal peduncle length (CPL), caudal peduncle depth (CPD), lower jaw width (LJW), pelvic spine length (PSL), pre-anal distance (PAD), distance lower jaw to pelvic fin (PELD). Six meristic characters were also recorded on each specimen, and these include the number of scales on the lateral line, dorsal spines, dorsal rays, number of gillrakers, anal fin rays, and anal fin spines

Statistical Analysis

Statistical analysis, which includes univariate and multivariate analysis, was conducted separately on the morphometric and meristic data. This is because morphometric variables are continuous and subject to environmental influences, while meristic characters are discrete and typically less variable with respect to the environment. Morphometric data often require size correction to account for allometric effects. Therefore, a true and precise characterisation of the morphometric traits of organisms in a population should be independent of size to avoid misinterpretation of the results (Junquera & Perez-Gándaras, 1993).

In this study, the morphometric measurements of each fish were initially corrected for size using the percentage of their standard length according to Reist (1985) as follows:

$$Mn = Mo / SL, \%,$$

where: *Mo* — is the original measurement, *SL* — is the standard length.

The morphometric data, now comprising 24 measurements after removing standard length, were tested for normality using the Shapiro-Wilk test. Because the data were not normally distributed, a nonparametric test (Kruskal-Wallis) was used to assess significant differences in the morphometric variables among the three populations using R version 4.5.2.

For PCA, the morphometric data were logarithmically transformed to normalise the distribution (Cuadras, 1989) and subsequently analysed using PAST version 5.2.1 (Hammer et al., 2001). The meristic datasets were analysed using correspondence analysis.

Results

The descriptive statistics of the morphometric and meristic data from the three study locations are presented in Tables 1–3. Kruskal-Wallis test revealed significant differ-

ences ($p \leq 0.05$) both within and between groups in 13 of the 24 size-corrected morphometric traits of *C. zillii* populations from Aiba Reservoir, Asejire Reservoir, and Igbokoda River (Table 4). These traits include head length, snout length, eye length, anal fin length, length of last dorsal spine, upper lip length, lower lip width, lower lip length, pectoral fin length, pelvic spine length, caudal peduncle length, caudal peduncle depth, and lower jaw width. The PCA scatter plot of the morphometric measurements of the *C. zillii* populations revealed partial overlap of clusters between the Ig-

Table 1. **Descriptive Statistics of the 25 morphometric measurements (cm) and six meristic counts of *Coptodon zillii* from Igbokoda River**

Morphometric and Meristic Traits	N	Min	Max	Sum	Mean	Std. error
Total Length	50	13	17.5	741.1	14.82	0.15
Standard Length	50	10.5	14.3	601	12.02	0.13
Head Length	50	4.0	5.6	244.7	4.89	0.04
Body Depth	50	4.6	6	254.2	5.08	0.05
Snout Length	50	1.1	1.7	71.4	1.43	0.02
Cheek Depth	50	1.2	1.9	77.5	1.55	0.02
Eye Length	50	1.1	1.6	65.5	1.31	0.02
Dorsal Fin Length	50	5.9	7.9	336	6.72	0.07
Anal Fin Length	50	1.8	2.6	111.2	2.22	0.03
Length of Last Dorsal Spine	50	1.5	2.3	99.3	1.99	0.02
Length of Third Anal Spine	50	1.4	2.3	83.4	1.67	0.02
Pelvic Fin Length	50	3.2	4.8	191.3	3.83	0.05
Pre-dorsal Distance	50	3.9	5.4	224.8	4.50	0.04
Upper Lip Length	50	1.1	1.6	66.8	1.34	0.02
Lower Jaw Length	50	1.1	2.5	101.2	2.02	0.04
Lower Lip Width	50	1.0	1.5	62.4	1.25	0.01
Lower Lip Length	50	1.0	2.3	64.1	1.28	0.03
Pectoral Fin Length	50	3.3	4.8	209	4.18	0.05
Pre-orbital Distance	50	1.0	1.5	59.73	1.19	0.02
Caudal Peduncle Length	50	1.0	2.6	68.4	1.37	0.06
Caudal Peduncle Depth	50	0.3	2.4	97.8	1.96	0.04
Lower Jaw Width	50	1.1	2.2	88	1.76	0.05
Pelvic Spine Length	50	1.1	2.3	99	1.98	0.03
Pre-anal Distance	50	4.9	9.7	415.7	8.31	0.11
Distance Lower Jaw to Pelvic Fin	50	4.1	5.4	227.8	4.56	0.04
Number of Scales on Lateral Line	50	26	32	1454	29.08	0.28
Dorsal Spines	50	15	16	786	15.72	0.06
Dorsal Rays	50	10	13	589	11.78	0.10
Gill Rakers	50	10	15	619	12.38	0.17
Anal Fins	50	9	11	478	9.56	0.09
Anal Spines	50	3	3	150	3.00	0.00

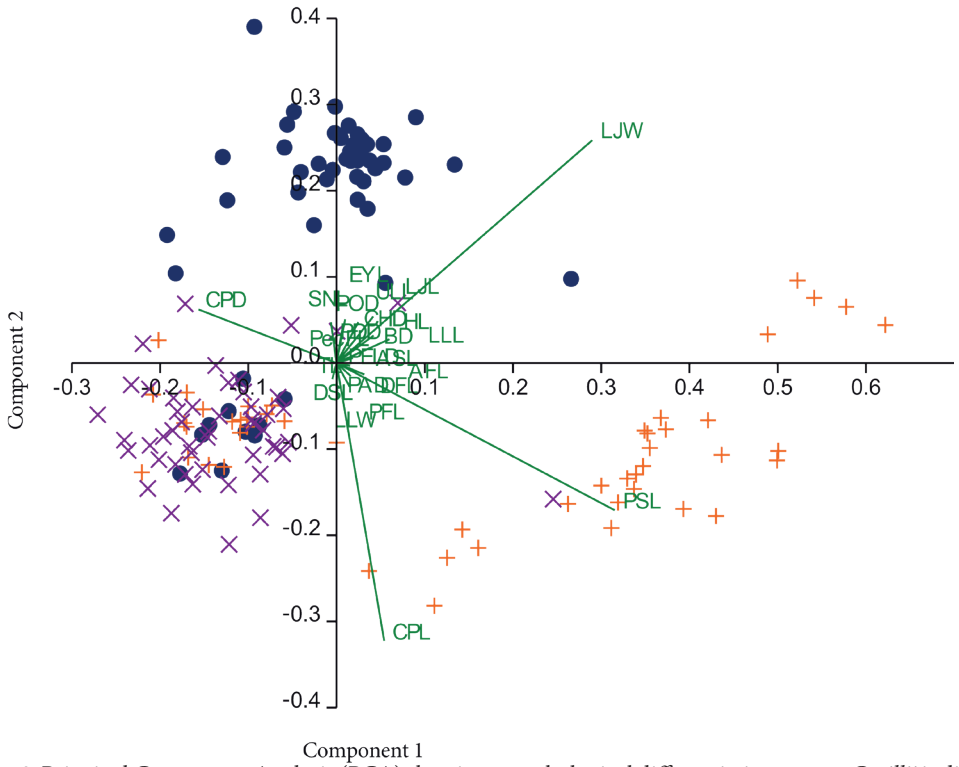

Fig. 2. Principal Component Analysis (PCA) showing morphological differentiation among *C. zillii* individuals from Igbokoda River (●), Asejire Reservoir (+), and Aiba Reservoir (×). Key: PSL — pelvic spine length; CPL — caudal peduncle length; LJW — lower jaw width; CPD — caudal peduncle depth; SNL — snout length; LLL — lower lip length

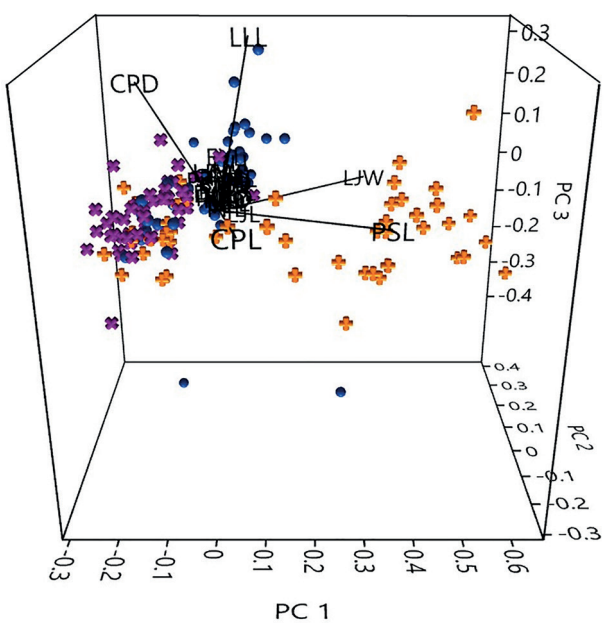

Fig. 3. 3D Scatter PCA diagram of morphometric traits in *C. zillii* from Igbokoda River, Asejire Reservoir, and Aiba Reservoir showing relationships among the first three Principal Components. Key: PSL — pelvic spine length; CPL — caudal peduncle length; LJW — lower jaw width; CPD — caudal peduncle depth; SNL — snout length; LLL — lower lip length

Table 2. **Descriptive Statistics of the 25 morphometric measurements (cm) and six meristic counts of *Coptodon zillii* from Asejire Reservoir**

Morphometric and Meristic Traits	N	Min	Max	Sum	Mean	Std. error
Total Length	50	13.5	26	889.50	17.79	0.36
Standard Length	50	11	21	720.00	14.40	0.29
Head Length	50	4.6	8.3	290.40	5.81	0.10
Body Depth	50	4.8	7.5	305.40	6.11	0.10
Snout Length	50	1.1	2.4	73.40	1.47	0.04
Cheek Depth	50	1.3	2.9	89.70	1.79	0.04
Eye Length	50	1.2	2.1	71.00	1.42	0.02
Dorsal Fin Length	50	6.5	15.9	415.20	8.30	0.22
Anal Fin Length	50	2.0	4.0	144.10	2.88	0.06
Length of Last Dorsal Spine	50	1.9	3.2	119.90	2.40	0.05
Length of Third Anal Spine	50	1.5	3.0	99.00	1.98	0.04
Pelvic Fin Length	50	2.4	7.4	244.50	4.89	0.12
Pre-dorsal Distance	50	4.2	7.9	265.00	5.30	0.10
Upper Lip Length	50	1.0	3.0	74.70	1.49	0.04
Lower Jaw Length	50	1.1	4.4	117.90	2.36	0.08
Lower Lip Width	50	1.1	2.8	76.30	1.53	0.04
Lower Lip Length	50	1.0	3.0	74.20	1.48	0.05
Pectoral Fin Length	50	2.2	7.4	247.90	4.96	0.13
Pre-orbital Distance	50	1.0	1.7	66.30	1.33	0.02
Caudal Peduncle Length	50	1.7	3.8	126.10	2.52	0.06
Caudal Peduncle Depth	50	1.0	3.4	97.50	1.95	0.08
Lower Jaw Width	50	1.0	5.4	107.00	2.14	0.15
Pelvic Spine Length	50	1.7	8.5	208.30	4.17	0.24
Pre-anal Distance	50	7.9	15	510.70	10.21	0.19
Distance Lower Jaw to Pelvic Fin	50	3.7	7.1	268.40	5.37	0.09
Number of Scales on Lateral Line	50	27	39	1543	30.86	0.33
Dorsal Spines	50	14	17	772	15.44	0.08
Dorsal Rays	50	11	14	613	12.26	0.09
Gill Rakers	50	11	16	627	12.54	0.12
Anal Fins	50	8	13	512	10.24	0.17
Anal Spines	50	3	3	150	3.00	0.00

bokoda and Aiba populations, while the Asejire population is more distinct (Fig. 2). The first two principal components accounted for 53.29% of the total variation in the dataset, with 34.41% and 18.88% explained by PC1 and PCII, respectively (Table 5). PCIII accounted for only 7.6% of the variation. A 3D scatter diagram that includes the

Table 3. **Descriptive Statistics of the 25 morphometric measurements (cm) and six meristic counts of *Coptodon zillii* from Aiba Reservoir**

Morphometric and Meristic Traits	N	Min	Max	Sum	Mean	Std. error
Total Length (TL)	50	12.7	24	852.4	17.05	0.29
Standard Length (SL)	50	10.0	16.2	678	13.56	0.20
Head Length (HL)	50	3.0	6.0	246.7	4.93	0.10
Body Depth (BD)	50	4.7	6.9	279.7	5.59	0.06
Snout Length (SNL)	50	1.1	2.1	79.5	1.59	0.04
Cheek Depth (CHD)	50	1.1	2.7	87.4	1.75	0.05
Eye Length (EYL)	50	1.1	1.7	68.6	1.37	0.02
Dorsal Fin Length (DFL)	50	5.5	9.2	379.9	7.60	0.12
Anal Fin Length (AFL)	50	2.0	3.0	124	2.48	0.04
Length of Last Dorsal Spine (DSL)	50	1.8	3.2	121.1	2.42	0.05
Length of Third Anal Spine (ASL)	50	1.1	3.2	99	1.98	0.05
Pelvic Fin Length (PFL)	50	3.0	5.7	226.4	4.53	0.08
Pre-dorsal Distance (PDD)	50	4.2	6.1	257.7	5.15	0.07
Upper Lip Length (ULL)	50	1.1	1.9	69	1.38	0.03
Lower Jaw Length (LJL)	50	1.2	3.1	107.7	2.15	0.06
Lower Lip Width (LLW)	50	1.1	2.4	79.4	1.59	0.04
Lower Lip Length (LLL)	50	0.7	1.6	65	1.30	0.02
Pectoral Fin Length (PecFL)	50	2.2	6.0	241.5	4.83	0.10
Pre-orbital Distance (POD)	50	0.9	1.8	64.9	1.30	0.03
Caudal Peduncle Length (CPL)	50	1.2	2.8	106	2.12	0.04
Caudal Peduncle Depth (CPD)	50	1.6	2.7	109.7	2.19	0.03
Lower Jaw Width (LJW)	50	0.9	2.2	62	1.24	0.04
Pelvic Spine Length (PSL)	50	1.7	2.9	113.4	2.27	0.04
Pre-anal Distance (PAD)	50	7.5	11.7	479.7	9.59	0.16
Distance Lower Jaw to Pelvic Fin (PeLD)	50	3.9	6.7	259.6	5.19	0.09
Number of Scales on Lateral Line	50	27	34	1565	31.30	0.21
Dorsal Spines	50	14	17	763	15.26	0.08
Dorsal Rays	50	9	13	578	11.56	0.14
Gill Rakers	50	10	15	597	11.94	0.16
Anal Fins	50	7	10	439	8.78	0.08
Anal Spines	50	3	3	150	3.00	0.00

contribution of the third principal component (PCIII) is presented in Figure 3. Loadings plot based on PCI identified the pectoral spine length as the most variable morphometric character among the three populations of *C. zillii* studied, closely followed by the lower jaw width (Fig. 4). The scatter plot of the correspondence analysis of the seven meristic counts showed no specific pattern of differentiation, as the clusters largely overlapped (Fig. 5). The bulk of the information on the differentiation pattern represented in the meristic data is explained by axes I and II (Table 6).

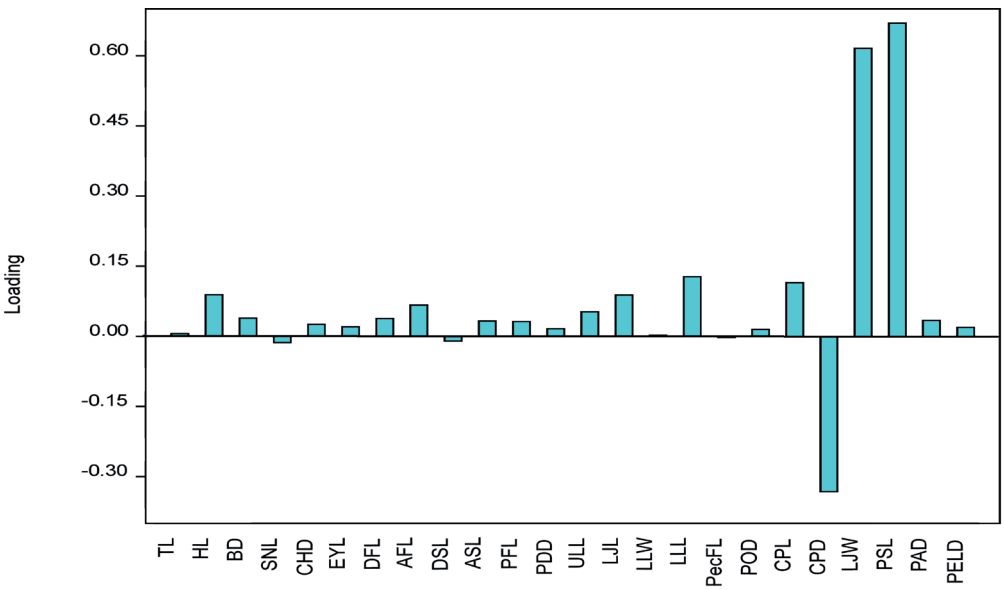

Fig. 4. Respective contributions of morphometric traits to Principal Component I in *C. zillii* Populations of Igbokoda River, Asejire Reservoir, and Aiba Reservoir. Key: TL — total length; HL — head length; BD — body depth SNL — snout length; CHD— cheek depth; EYL — eye length; DFL — dorsal fin length; AFL — anal fin length; DSL — length of last dorsal spine; ASL — length of third anal spine; PFL—pelvic fin length; PDD — pre-dorsal distance; ULL — upper lip length; LJL — lower jaw length; LLW — lower lip width; LLL — lower lip length; PecFL — pectoral fin length; POD — pre-orbital distance; CPL — caudal peduncle length; CPD — caudal peduncle depth; LJW — lower jaw width; PSL — pelvic spine length; PAD — pre-anal distance; and PELD — distance lower jaw to pelvic fin

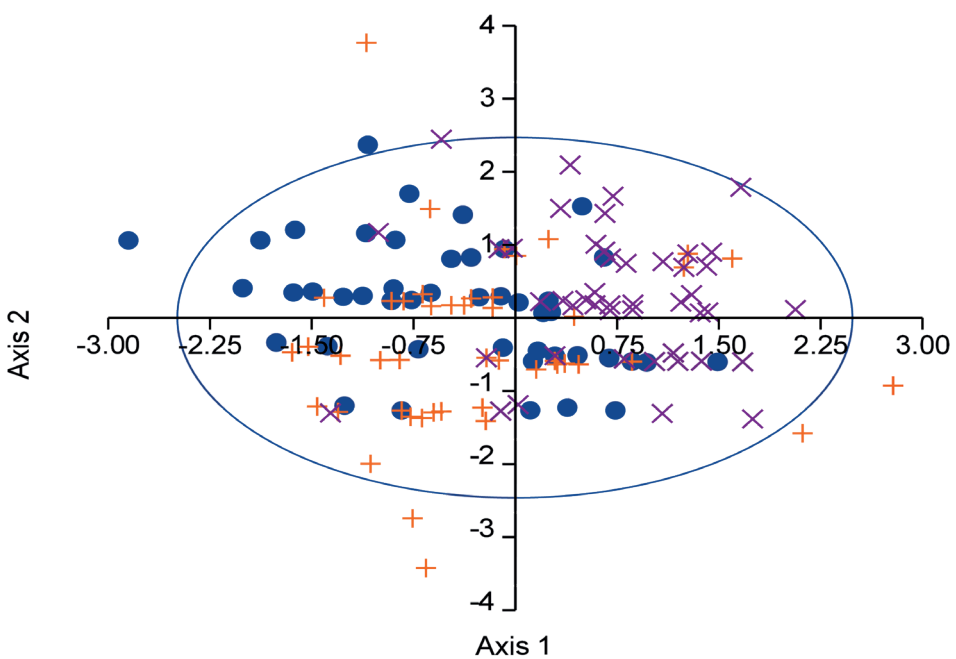

Fig. 5. Correspondence Analysis based on six meristic counts of *C. zilli* from Igbokoda River (•), Asejire Reservoir (+), and Aiba Reservoir (×), showing homogeneity of characters

Table 4. **Kruskal-Wallis Table showing statistical differences among the populations in order of significance**

Morphometric Variable	Total Sample size	statistic	df	p	p.adj	p.adj.signif
CPL	150	64.40446	2	1.03E-14	2.47E-13	****
LJW	150	59.64826	2	1.12E-13	2.69E-12	****
SNL	150	38.90012	2	3.57E-09	8.57E-08	****
HL	150	32.22119	2	1.01E-07	2.42E-06	****
CPD	150	30.11315	2	2.89E-07	6.94E-06	****
AFL	150	27.94881	2	8.53E-07	2.05E-05	****
PSL	150	23.9099	2	6.43E-06	0.000154	***
LLW	150	20.68696	2	3.22E-05	0.000773	***
PFL	150	20.43257	2	3.66E-05	0.000878	***
EYL	150	20.17878	2	4.15E-05	0.000996	***
ULL	150	19.99966	2	4.54E-05	0.00109	**
DSL	150	16.19059	2	0.000305	0.00732	**
LLL	150	13.55122	2	0.00114	0.02736	*
POD	150	9.529647	2	0.00852	0.20448	ns
DFL	150	9.343213	2	0.00936	0.22464	ns
TL	150	6.961768	2	0.0308	0.7392	ns
ASL	150	6.70325	2	0.035	0.84	ns
BD	150	4.606451	2	0.0999	1	ns
CHD	150	3.080684	2	0.214	1	ns
LJL	150	5.914813	2	0.052	1	ns
PAD	150	5.298238	2	0.0707	1	ns
PDD	150	4.576766	2	0.101	1	ns
PELD	150	2.362626	2	0.307	1	ns
PecFL	150	6.042873	2	0.0487	1	ns

Discussion

This study employed principal component analysis (PCA) and correspondence analysis (CA) as effective multivariate tools to characterise morphological variation among *C. zillii* populations, using morphometric and meristic data, respectively. PCA reduces the dimensionality of morphometric data by identifying eigenvalues that capture the variability in the data. The variation explained by each principal component is quantified by the eigenvalues (Hammer et al., 2001). Similarly, CA reduces the dimensionality of a large contingency table while preserving relationships among variables. PCA, however, analyses continuous data, whereas CA is suitable for characterising counted or discrete data.

In this study, the PCA scatter plot revealed a clear pattern of differentiation among the three populations of *C. zillii* studied. Individuals representing the Asejire Reservoir population were distinctly positioned along the positive axis of PC1 and strongly associated with higher loadings for pectoral spine length (PSL) and caudal

Table 5. **Eigenvalues and Percentage of Variance Explained by Principal Components in the Morphometric Analysis of *Coptodon zillii from***

Principal Component (PC)	Eigenvalue	% Variance	Principal Component (PC)	Eigenvalue	% Variance
1	0.0423818	34.405	13	0.0016792	1.363
2	0.0232589	18.881	14	0.0014623	1.187
3	0.0094083	7.638	15	0.0013949	1.132
4	0.0079041	6.417	16	0.0012362	1.004
5	0.0068868	5.591	17	0.0011059	0.898
6	0.0060075	4.877	18	0.0009027	0.733
7	0.0037835	3.071	19	0.0008487	0.689
8	0.0031531	2.560	20	0.0006547	0.531
9	0.0030668	2.490	21	0.0004419	0.359
10	0.0025691	2.086	22	0.0003309	0.269
11	0.0022525	1.829	23	0.0002610	0.212
12	0.0020600	1.672	24	0.0001333	0.108

peduncle length (CPL). The strong association of the pectoral spine length with the Asejire reservoir population could reflect adaptive mechanisms related to predator pressure in this reservoir. Predator pressure differs across different water flow regimes and habitat structure (Price et al., 2015). Lentic systems such as reservoir environments usually have higher predator pressure compared to flowing rivers due to reduced water flow and greater exposure of prey to visual predators. On the other hand, riverine environments are characterised by higher flow rates, turbidity, and greater habitat complexity, which could promote the safety of the prey while reducing predator efficiency. As a result, selection may favour locomotor efficiency in a riverine environment as opposed to defensive morphology in a lentic system. This ecological contrast likely explains the strong association of pectoral spine length (PSL) with the Asejire Reservoir population observed in the present study, as longer spines provide enhanced protection against predation. Meanwhile, the caudal peduncle is closely associated with swimming performance and hydrodynamic adaptation in response to different water flow regimes (Langerhans, 2008; Franssen et al., 2013). Individuals from Aiba Reservoir were clustered on the negative axis of PC1, significantly influenced by snout length and caudal peduncle depth. The Igbokoda River population was centrally positioned, although some members of the population exhibited a partial overlap with the Aiba Reservoir along the negative axis. Traits related to feeding, such as lower jaw width (LJW), lower lip length (LLL), and lower jaw length (LJL), were more significant in the Igbokoda River population, indicating that these features play a

Table 6. **Axis Contributions to Total Inertia in Correspondence Analysis of the Meristic Data**

Axis	Eigenvalue	% of total	Cumulative
1	0.0031158	45.912	45.912
2	0.0017198	25.341	71.253
3	0.0010414	15.346	86.599
4	0.0008509	12.539	99.138
5	5.851E-05	0.86216	100

more significant role in distinguishing this population from those of Aiba and Asejire Reservoirs. This suggests that trophic ecology may be a stronger driver of the morphological divergence observed in this population. Riverine environments such as Igbokoda often present diverse feeding opportunities and fluctuating conditions, which can promote diversification of specialisations in feeding strategy. Overall, higher positive loadings were recorded for traits such as LJW, LLL, and LJL in descending order on PC1 relative to the other morphometric characters. This indicates significant differences in feeding pressure among the three populations. Also, the pelvic spine length (PSL) had the highest loading value across the three populations, suggesting an adaptive defensive mechanism in the fish populations. It has been reported that one of the consistent morphological changes observed in fishes exposed to varying predation pressures is an increase in the number and size of defensive structures, such as fin spines. Similarly, there are reports that spine length increases with the abundance of predators in wild fish populations, which is a form of local adaptation strategy (Januszkiewicz & Robinson, 2007; Weber et al., 2012). Several evolutionary models have demonstrated that predation can modify morphological characters while inducing rapid adaptive changes in phenotypes (Bronmark & Miner, 1992; Langerhans et al., 2004). Meanwhile, caudal peduncle depth (CPD) was the character with the highest negative loading, with a strong contribution to the positioning of Aiba individuals on the negative axis of the PCA scatter plot. CPD is a morphological character associated with swimming efficiency in fish (Breda et al., 2005). Fish with a smaller CPD usually experience reduced turbulence waves, which are generated by the movement of the forebody (Assumpção et al., 2012). The stronger contribution of CPD also suggests adaptation to environmental pressures, particularly those related to locomotor performance across the three populations. Overall, the pattern of phenotypic divergence observed between the *C. zillii* populations from the Aiba and Asejire reservoirs could be attributed to the geographic isolation of the two water bodies. Aiba and Asejire reservoirs are independent water bodies that do not share any direct hydrological connection. Also, the two water bodies are dammed, which would have impacted the fish migration patterns and restricted gene flow between them. Meanwhile, the intermediate positioning of the Igbokoda River population, coupled with its partial overlap with the Aiba Reservoir, suggests greater phenotypic plasticity of this population. Winger & Bates (2015) predicted that geographically and genetically isolated populations will develop increasingly distinct phenotypic traits over time due to both neutral and selective processes. Turan (2004) similarly noted that a high level of isolation by distance can lead to significant phenotypic and genetic differences among fish populations. Populations can adapt and evolve as independent groups in varied environmental conditions in the absence of gene flow. Moreover, populations respond uniquely to different environmental pressures due to variations in adaptive potential, plasticity, tolerance, and biotic interactions (Bernardo & Spotila, 2006; Satler et al., 2016). Morphological divergence could reflect genetically fixed differentiation or purely phenotypic plasticity, so it is important to use appropriate molecular tools to verify the observed population structure. A previous study by Oladimeji & Olaosebikan (2017) similarly reported significant morphological heterogeneity in three populations of *Tilapia zillii* from three reservoirs in southwestern Nigeria, which is consistent with the result of this study. They attributed the observed morphological hetero-

geneity to geographic isolation and variations in ecological pressures such as predator presence, differences in temperature, water velocity, substrate type, etc., across the three water bodies. Gilbert et al. (2020) also reported significant morphological changes in native cichlid populations ~34 years after the damming of the Tocantins River in Brazil. The construction of the Tucuruí dam was reported to have impacted functionally relevant anatomical characters of the fish species, including head, fin, and body shape. Evidence from previous reports and that of this study shows that cichlid fishes are very sensitive to environmental changes, adapting their morphological characters to swiftly respond to the unique and prevailing conditions of their environment. Contrarily, Geladi et al. (2019) documented that characid species exhibit little to no morphological change in response to a major anthropogenic change, damming. These indicate that different taxonomic groups of fish respond differently to similar anthropogenic changes in their environment. These differential responses suggest that anthropogenic impacts operate selectively across species. This underscores the need for integrated, species-sensitive, and ecosystem-based conservation strategies to ensure sustainable fisheries management. In this study, correspondence analysis of the meristic data did not reveal any pattern of differentiation, as the clusters largely overlapped. Differentiating fish populations using multivariate analysis of meristic data is often challenging due to data overlap among groups (Murta, 2000; Oladimeji et al., 2015; Endebu et al., 2021; Oladimeji et al., 2025 b). Moreover, meristic traits of fish, such as rays and fin spines, often exhibit constant or nearly identical values across different populations, regardless of environmental variables. This could be because meristic traits are established early in development and are relatively unaffected by environmental changes (Cheng et al., 2005). Notably, it has been reported that the fin rays of the tribe Tilapini do not vary significantly (Reed et al., 1967; Holden & Reed, 1972). Therefore, it is reasonable to conclude that meristic traits are less effective than morphometric traits in delineating fish populations**.**

Conclusion

This study revealed significant morphological divergence among three populations of *Coptodon zillii*, likely driven by ecological factors and geographic separation. The findings highlight the role of environmental factors in shaping morphological diversity among *C. zillii* populations. It is therefore recommended that a molecular approach using appropriate genetic markers be used to elucidate the genetic structure of the populations and verify the observed phenotypic population divergence pattern.

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