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PHENOTYPIC DIVERSITY OF THREE POPULATIONS OF THE SILVER CATFISH, *Chrysichthys nigrodigitatus* (Lacepède, 1803) IN SOUTHWESTERN, NIGERIA

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ABSTRACT

Chrysichthys nigrodigitatus, commonly regarded as the silver catfish, is a highly prized and valued food fish with extensive distribution across African waters. Herein, *C. nigrodigitatus* was studied for its phenotypic diversity in three different waterbodies: Asejire Reservoir, Epe Lagoon, and Igbokoda River, using their morphological features. Fifty samples of *C. nigrodigitatus* were collected from each water body, totaling 150 specimens. Thirty morphometric traits and four meristic body counts were recorded on each fish using standard tools. The morphometric measurements were normalized to fish size to eliminate any size-related bias using percentage standard length (SL) and further transformed to common logarithms. Size-corrected data were subjected to One-way analysis of variance (ANOVA) using IBM SPSS 26 and Multivariate analyses (Principal Component Analysis and Cluster analysis) on PAST software. ANOVA showed significant differences ($p<0.05$) within and between groups of 18 out of the 33 morphological parameters of *C. nigrodigitatus* examined. Principal Component Analysis (PCA) and Cluster analysis revealed overlapping data between *Chrysichthys nigrodigitatus* populations from Asejire reservoir and Epe Lagoon, whereas Igbokoda River population formed a distinct cluster. The result suggests that the Igbokoda River population of *C. nigrodigitatus* is morphologically different from the other two populations (Asejire reservoir, and Epe lagoon) and thus can be regarded as a phenotypically separable population.

Keywords: Morphometrics, Morphological differences, Phenotype, Variation

INTRODUCTION

The silver catfish, *Chrysichthys nigrodigitatus* (Lacepède, 1803) popularly known as "Obokun" in the Yoruba language, is a commercially significant fish species in the family Claroteidae. It is a highly prized and sought-after food fish due to its high nutritional value and cultural significance (Abidemi-Iromini *et al*., 2019; Hem *et al.,* 1994). *Chrysichthys nigrodigitatus* is extensively distributed across African waters and is dominant in regional commercial fisheries (Akinsanya *et al*. 2007). According to Ama-Abasi and Uyoh (2020), *C. nigrodigitatus* ranks as the third most significant species for commercial fishing in the Cross River Estuary. It exhibits perennial occurrence with maximal density during the rainy season. *Chrysichthys* fisheries employ a large number of people in the teeming riverine settlements of Nigeria thus improving the standard of people's socioeconomic life (Ama-Abasi *et al.,* 2017). The species has recently entered the global market, providing Nigeria with a source of foreign exchange profits (Suberu *et al.,* 2015).

Phenotypic flexibility is the capacity of a genotype to create different phenotypes as a response to varying environmental conditions (Murta, 2000). Morphometric features can exhibit high flexibility in response to diverse ecological factors, such as availability of food (benthic-pelagic feeding continuum), competition for resources, presence of predators, water flow, salinity, temperature, etc. (Kristjánsson, 2002). Fish are more susceptible to ecologically induced morphological variations than any other vertebrates, thus exhibiting phenotypic diversities both within and between populations. (Allendorf *et al.,* 1987; Wimberger, 1992). Significant variations in morphological characteristics among populations are a clear indication of phenotypic diversity. Various authors have documented intraspecific morphological variations within fish populations of numerous species across different environmental gradients, including water chemistry, depth, substrate type, flow patterns, prey composition, and predation risk. (Solomon *et al.,* 2015; Oladimeji *et al.,* 2015; Ukenye *et al*., 2015; Cabasan *et al.,* 2017; Oladimeji and Olaosebikan, 2017; Oladimeji *et al;* 2023; Zhao *et al*., 2023). Variations in morphometric and meristic traits can also suggest differences in growth rates, survival capacities, and metabolic processes among fish populations, facilitating the differentiation of widely distributed species (Lawson, 2010). It has been reported that the most popular approach to characterize fish stocks is to analyze phenotypic changes in morphometric or meristic features (Dwivedi *et al.,* 2013). In this study, different water bodies in Southwestern Nigeria which represent divergent habitats, were used to establish phenotypic diversity in *C. nigrodigitatus* populations with a view to providing information that will guide the identification of genetic stocks among the populations and enhance their sustainable management.

MATERIALS AND METHODS

Description of Study Area

The three water bodies used for this study are Asejire Reservoir, Epe Lagoon, and Igbokoda River.

Asejire Reservoir

Asejire Reservoir was formed by impounding the River Osun in Oyo State, southwest Nigeria in the late 1960s. Asejire reservoir is located between longitudes 004° 08'00" E – 004° 13'33" E and latitudes 07° 21'45" N - 7° 36'25" N. It is a Y-shaped, 19.5 km long, man-made reservoir located about 30 km East of Ibadan, Southwest Nigeria (Ayoade *et al*., 2006). It has a catchment area of 7,800 $km^{2,}$ an impounded area of 2,342 hectares, and a maximum flood elevation of 152.4 m. The reservoir holds about 80 million liters of water daily, of which 80 percent is used for home consumption.

Epe Lagoon

The Epe Lagoon is located in Lagos State within latitudes 06°31'89' N and 06°33´70´ N and longitudes 003°31´91´E and 004°03´71´E. Its surface area is around 243 km^3, and its maximum depth is approximately 2.8 m (Edokpayi *et al*., 2008). In the north, east, and west, it shares borders with some municipalities, and in the south, the Gulf of Guinea. A sizable fishery in Lagos State is supported by the lagoon (Edokpayi *et al*., 2008). The main river that empties into the lagoon is the Osun River. It is surrounded by two lagoons: the freshwater Lekki Lagoon to the east and the brackish Lagos Lagoon to the south.

Igbokoda River

Igbokoda River is located between latitudes 5°57'30 to 6°20'0N and longitude 4°33'30 to 5°3'0E in Ilaje Local Government Area of Ondo State, Southwest, Nigeria. (Bankole *et al*., 2020). Igbokoda serves as the headquarters of Ilaje Local Government in Ondo State, Nigeria, situated within the coastal region of the Dahomey Basin. Communities such as Ilowo, Ilepete, Aiyetoro, and Awoye are riverine settlements. Igbokoda River varies in elevation from around 1 meter below sea level to 15 meters above sea level. The lowland tropical rainforest habitat of Ondo State has distinct wet and dry seasons. The mean monthly temperature in the southern region is 27°C, with a mean relative humidity of more than 75%. The study area is traversed by numerous tributaries, rivers, and streams, some of which are directly or indirectly connected to the Atlantic Ocean. The samples were taken specifically from the Awoye riverine settlement of the Igbokoda River.

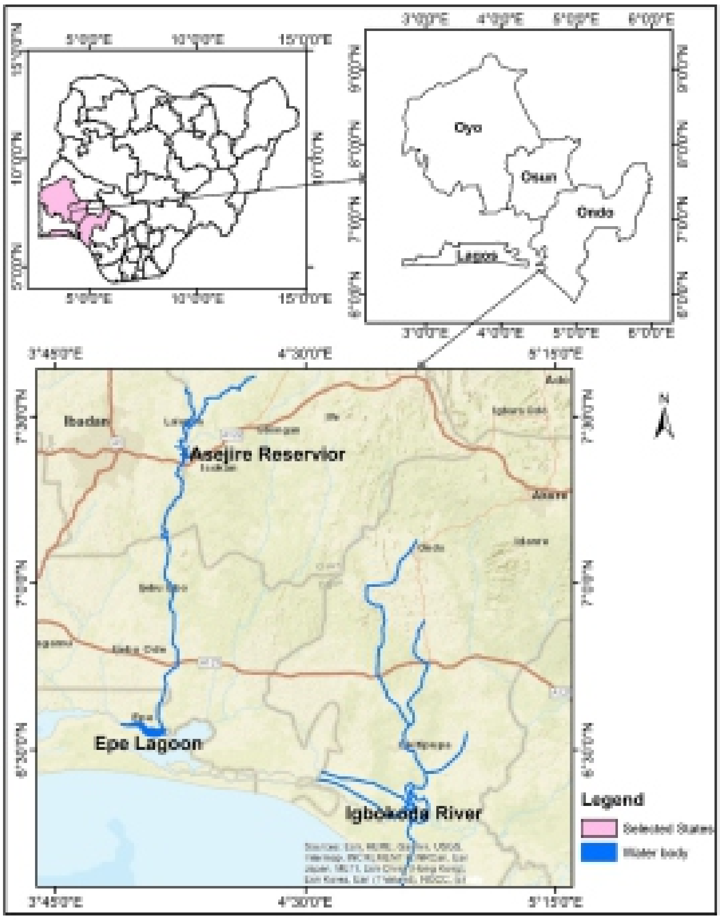

Figure 1: Map of the study areas.

Fish Sampling

A total of 150 specimens of *C. nigrodigitatus* were collected from the Asejire Reservoir, Epe Lagoon, and Igbokoda River in Oyo, Lagos, and Ondo States, respectively, between February 2023 and March 2024, with fifty samples taken from each waterbody. The samples were obtained from the catch of commercial fishermen, after which they were iced and brought to the laboratory for analysis. The identification keys developed by Paugy *et al.* (2003) were used to identify the fish samples.

Morphometric and Meristic Studies

Thirty morphometric characters which include total length (TL), standard length (SL), head length (HL), head width (HW), muzzle length (ML), eye diameter (ED), anal fin length (AFL), the interorbital distance (ID), the first dorsal fin length (DFL1), and the second dorsal fin length (DFL2), pre-dorsal length 1 (PrDL1), pre-dorsal 2 length (PrDL2), pre-anal length (prAl), pre-pectoral length (PrPcL), pre-pelvic (PrPe), dorsal pectoral length (DPL), dorsal pectoral length 2 (DPcL2), pelvic anal length; (PeAl), pectoral anal length (PcAL), pelvic pectoral length (PePcL), operculum eye distance (OED), dorsal anal length 1 (DAL1), dorsal anal length 2 (DAL2), dorsal pelvic length 1 (DPeL), dorsal pelvic length 2 (DPeL2), body height (BH), pectoral fin length (PcFL), pelvic fin length (PeFL), dorsal spine length (DSL), pectoral spine length (PcSL) were measured on each fish using digital vernier calipers (DCLA-0605 0-6). Four meristic counts, which are dorsal fin spine, pectoral fin ray, soft dorsal fin ray, and pectoral ray spine, were also recorded on each fish.

Statistical Analysis

Descriptive and inferential statistics were carried out on the morphometric and meristic data. One-way analysis of variance (ANOVA) was performed on the morphometric and meristic data to test the variation for each character across the three fish populations using IBM SPSS 26. The morphometric and meristic data were analyzed separately by multivariate analyses because morphometric traits are continuous measurements while meristic traits are discontinuous. Each morphometric measurement was normalized to the fish's size (standard length, SL) to eliminate size-related bias. This was achieved by expressing each measurement as a percentage of the standard length as follows:

$Mn = \left(\frac{Mo}{SL}\right)\%$ (Reist, 1985). where:
Mo is the original measurement, and
SL is the standard length.
The standard length was thereafter removed from further analysis. The normalized morphometric measurements were converted to common logarithms, as logarithmic transformations tend to more closely approximate linearity and normality compared to the original values. These values were then used for multivariate analysis using Principal Component Analysis (PCA) and cluster analysis on PAST software 3.2 (Hammer *et al*., 2001).

RESULT

One-way analysis of variance (ANOVA) indicated significant differences ($p < 0.05$) within and between groups for 18 out of the 33 morphometric and meristic parameters, revealing a considerable level of heterogeneity in the populations. The parameters that differed significantly ($p < 0.05$) across the three locations are muzzle length, eye diameter, interorbital distance, pre-pelvic length, dorsal pectoral length 1, dorsal pectoral length 2, pre-dorsal length 2, pre-anal length, pre-pectoral length, dorsal fin length 1, dorsal fin length 2, dorsal anal length 1, dorsal anal length 2, dorsal pelvic length 2. Others are pectoral spine length, pectoral fin ray, dorsal spine length, and pectoral ray spine. Principal Component Analysis of the 29 morphometric measurements of *C. nigrodigitatus* from the three locations of study revealed overlapping data between *C. nigrodigitatus* populations from Asejire reservoir and Epe lagoon while the Igbokoda river population formed a separate cluster (Figure 2). The dendrogram also revealed a similar pattern as the Igbokoda river population of *C. nigrodigitatus* formed a separate cluster while the Epe Lagoon and Asejire reservoir populations had overlapping clusters (figure 3). Factor loading based on PCA indicated that dorsal spine length was the morphometric trait most responsible for variation among the three studied populations of *C. nigrodigitatus* (loading 0.9996) (Figure 4).

The PCA diagram of the four meristic counts recorded on the *C. nigrodigitatus* populations revealed homogeneity of meristic characters among the three populations (Figure 5). Factor loadings based on the PCA revealed that the pectoral ray spine was the most variable meristic trait among the three populations (Figure 6). The dendrogram also revealed homogeneity of the meristic data across the three populations as there was no definite pattern of differentiation (Figure 7).

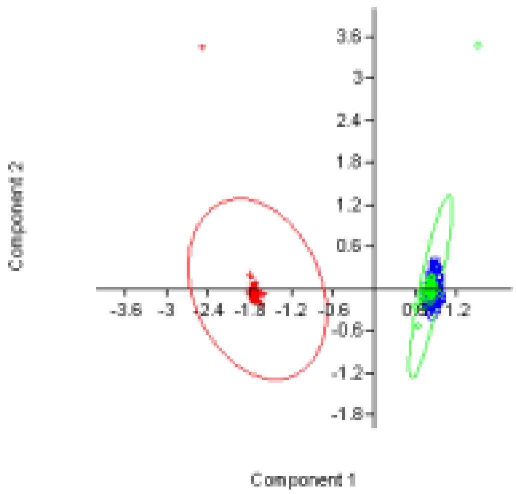

Figure 2: Principal Component Analyses of 29 morphometric measurements of *C. nigrodigitatus* showing the overlap of data between populations from Asejire Reservoir (blue), and Epe Lagoon (green). Igbokoda River (red) formed a separate cluster.

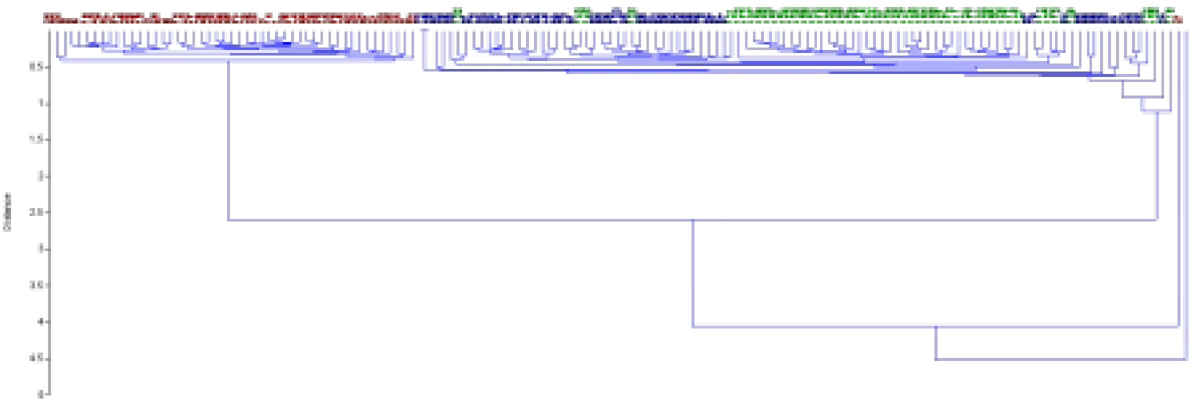

Figure 3: Dendrogram illustrating the overlap of data between the *C. nigrodigitatus* populations from Asejire Reservoir (blue) and Epe Lagoon (green), while the Igbokoda River (red) forms a distinct cluster.

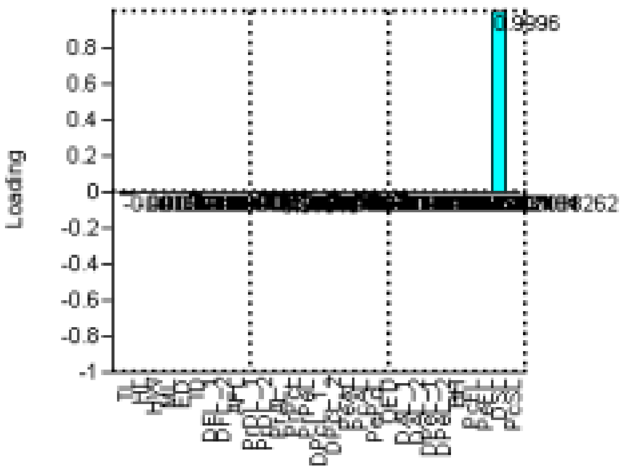

Figure 4: The morphometric characters of *C. nigrodigitatus* and their loadings on PC1 of the principal component analysis indicating dorsal spine length as the morphometric character that varied the most among the three populations of *C. nigrodigitatus.*

Keys: total length (TL), head length (HL), head width (HW), muzzle length (ML), eye diameter (ED), the anal fin length (AFL), the interorbital distance (ID), the first dorsal fin length (DFL1), second dorsal fin length (DFL2), pre-dorsal length 1 (PrDL1), pre-dorsal length 2 (PrDL2), pre-anal length (prAl), pre-pectoral length (PrPcL), pre-pelvic (PrPeL), dorsal pectoral length (DPL), dorsal pectoral length 2 (DPcL2), pelvic anal length (PeAL), pectoral anal length (PcAL), pelvic pectoral length (PePcL), operculum eye distance (OED), dorsal 1anal length (DAL1), dorsal 2anal length (DAL2), dorsal pelvic length 1(DpeL 1), dorsal pelvic length 2 (DPeL2), body height (BH), pectoral fin length (PeFL), pelvic fin length (PcFL), dorsal spine 1length (DSL1), pectoral spine length (PeSL)

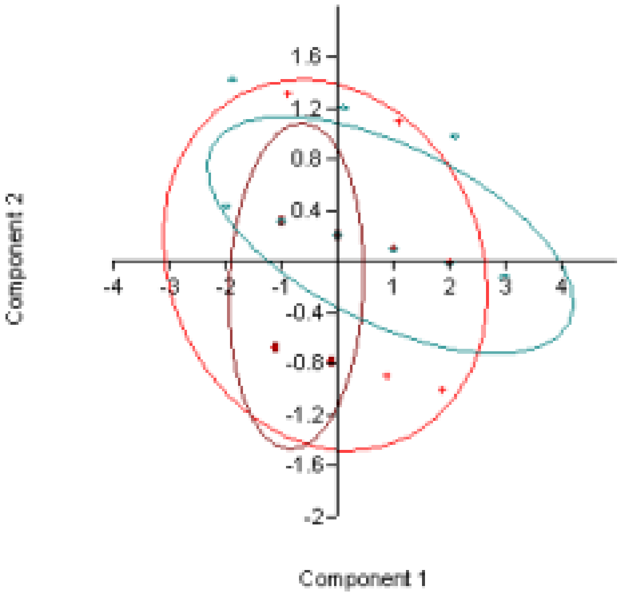

Figure 5: Principal Component Analyses based on four meristic counts of *C. nigrodigitatus* from Asejire Reservoir (purple), Epe Lagoon (green), and Igbokoda (red), showing homogeneity of characters.

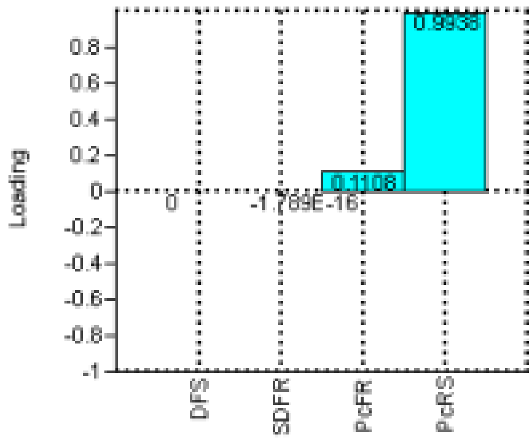

Figure 6: The meristic counts of *C. nigrodigitatus* and their corresponding loadings on PC1 of the principal component analysis showing the pectoral ray spine as the meristic character most significantly influencing variation among the studied populations.

Keys: DFS= Dorsal fin spine, SDFR= Dorsal fin ray, PcFR= pectoral fin ray and PcRS= Pectoral ray spine

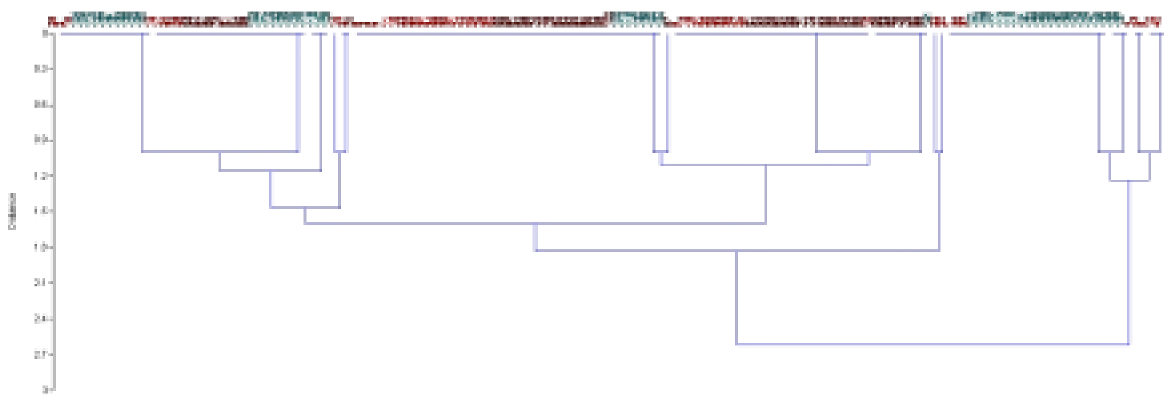

Figure 7: Dendrogram showing homogeneity of meristic data among *C. nigrodigitatus* populations from Asejire Reservoir (Purple), Epe Lagoon (Green), and Igbokoda River (Red).

DISCUSSION

Fish exhibit greater variation in morphological characteristics both within and between populations compared to any other group of vertebrates (Zamudio *et al.*, 2016). This study utilized measurements of morphometric characters and meristic counts to explore the phenotypic diversities among three distinct populations of *Chrysichthys nigrodigitatus*. These morphological tools are reliable for characterizing fish species, particularly in field studies, as they are responsive to environmental changes (Akindele and Fagbuaro, 2022). Morphological differences among species populations are mostly attributed to environmental factors. These factors can include differences in habitat, food availability, water temperature, and predation pressure, etc. Over time, natural selection can favour individuals with traits that are best suited to their specific environment, leading to the development of distinct morphological characteristics (Gotthard and Nylin, 1995). In this study, statistically significant differences ($p<0.05$) were recorded in eighteen (18) out of the twenty-nine (29) size-corrected morphometric measurements. Also, two of the four meristic counts showed significant differences among the three populations, underscoring the existence of morphological differences among the three populations, which could be attributed to variations in environmental factors.

The present findings align with the result of Adilieje *et al.* (2020), who reported significant differences ($p<0.05$) in 19 out of 23 morphometric traits examined among *C. nigrodigitatus* populations from the middle and lower Cross River. Principal component analysis and cluster analysis revealed that the *Chrysichthys nigrodigitatus* populations from Asejire reservoir and Epe lagoon are morphologically similar, whereas the Igbokoda/Awoye River population is morphologically different. The similarity in morphology between the *C. nigrodigitatus* populations from Asejire reservoir and Epe lagoon could be due to similar environmental conditions, or recent gene flow between the populations (Isa, 2019). The morphological discreteness exhibited by the Igbokoda population relative to the other two populations (Asejire Reservoir and Epe Lagoon) could be attributed to differences in environmental conditions, geographic isolation, or different environmental pressures (Naish and Hard, 2008). Asejire Reservoir and Epe Lagoon are freshwater habitats, while Igbokoda River (Awoye community) is a marine habitat. This is similar to the findings of Ajado *et al.* (2005), who reported that the morphological variability observed in *C. nigrodigitatus* sampled from Lagos, Badagry, and Lekki lagoons were related to ecological differences, implying that ecological pressures may influence the development of population-specific morphological traits.

Similarly, Crozier and Hutchings, (2014) accentuated environmental conditions such as food availability, water temperature, and salinity levels as factors significantly contributing to high morphological plasticity in fish populations. This emphasizes the importance of ecological influences on phenotypic diversity. The pattern of phenotypic variability observed among the studied *C. nigrodigitatus* populations also suggests a direct correlation between morphological differentiation and geographic distance, implying that spatial isolation acts as a barrier to migration (gene flow) between populations (Khayyami *et al*., 2015). Oladimeji and Olaosebikan (2017) similarly reported three phenotypically separable populations of *Tilapia zillii* (Gervais, 1848) in three southwestern states of Nigeria based on geographical distance and differences in environmental conditions. Zhao *et al.* (2023) also reported morphological differences in different geographical populations of the golden pompano in China.

Principal Component Analysis and cluster analysis have been used by various researchers as a multivariate approach to investigate variations among fish populations (Willis *et al*., 2005; Ola-Oladimeji *et al*., 2016, Oladimeji and Olaosebikan, 2017; Zhao *et al.,* 2023). In this study, Principal Component analysis of the meristic characters did not reveal any definite pattern of differentiation among the three populations of *C. nigrodigitatus* studied. Typically, morphometric characters show significantly greater differences among groups than meristic traits because morphometric characters are responsive to environmental changes, whereas meristic traits are established early in development and remain fixed (Allendorf *et al*., 1987). The factor loadings on PC1 of the principal component analysis revealed that the dorsal spine length and the pectoral ray spine are the respective morphometric and meristic characters most significantly influencing variation among the studied *C. nigrodigitatus* populations. This highlights the importance of these specific characters in distinguishing among the three populations studied, underscoring the role of morphometric and meristic characters in intraspecific morphological differentiation studies. Understanding these relationships can provide valuable insights into the evolutionary and ecological dynamics that shape population structures.

CONCLUSION

The morphological analysis of *C. nigrodigitatus* populations from Asejire reservoir, Epe Lagoon, and Igbokoda River, revealed a reasonable degree of phenotypic diversity among the three populations, indicating that the Igbokoda River population of *C. nigrodigitatus* is phenotypically separable from the other two populations.

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CONFLICT OF INTEREST

The authors declare that no known conflicts of interest are associated with this manuscript.

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