Phenotypic plasticity of *Sarotherodon galilaeus* (Linnaeus, 1978) obtained from the Aiba, Eko-Ende and Asejire Reservoirs in Southwestern Nigeria

Oladimeji, T. E.¹* Oyewale, O. T¹. and Afolabi, O.²

¹Department of Zoology, Obafemi Awolowo University, Ile-Ife, Nigeria; ²Department of Biological Sciences, University of Africa, Toru-Orua, Bayelsa, Nigeria *Corresponding author: Tofunmi E. Oladimeji. toladimeji@oauife.edu.ng

Received: 17 January, 2025 Revised: 08 May, 2025 Accepted: 10 June, 2025 Keywords: Differentiation, Phenotypic

plasticity, Meristics, Morphometrics, Sarotherodon galilaeus



©2025 Zoological Society of Nigeria



This is an Open Access article distributed under the terms of Creative Commons Attribution License 4.0 (CC BY-NC-SA

Introduction

The construction of reservoirs for the generation of hydropower, irrigation support, and water supply for domestic use has constituted a major disturbance to aquatic ecosystems globally. It has resulted in the formation of distinct aquatic habitats, altering the ecological and genetic traits of fish populations (Downing *et al* 2006; Santos and Araújo, 2015; Winemiller *et al* 2016). Reservoirs often present unique environmental gradients, such as water temperature, pH, dissolved oxygen, and trophic conditions, which can drive phenotypic plasticity among fish populations (Okada *et al* 2005; Agostinho *et al* 2007).

Phenotypic plasticity is the ability of a single genotype to produce different morphological or behavioural traits in response to varying ecological conditions. This flexibility enables populations to adapt rapidly and survive when faced with new environmental challenges (Ghalambor *et al* 2007). Understanding how fish populations adapt to these conditions can provide information on their resilience, genetic diversity, and management needs. Phenotypic differences among populations could be either adaptive or neutral. Adaptive phenotypic differences are linked to genetic factors, thus having speciation potential (Schluter and Rieseberg, 2022). In contrast, neutral phenotypic differences are

Abstract

Fish often exhibit phenotypic plasticity by adapting their morphological traits to changing environments. In this study, the phenotypic plasticity of Sarotherodon galilaeus from three reservoirs (Aiba, Eko-Ende, and Asejire) in Southwestern Nigeria was assessed by evaluating their morphometric and meristic characters. Twenty-five morphometric measurements and six meristic counts were recorded in fifty samples from each reservoir. Morphometric measurements were standardised as a function of standard length, eliminating bias attributed to size. The meristic counts were not standardised because they are discrete and less influenced by size. One-way ANOVA was used to analyse morphometric and meristic data to test for significant differences between groups. The meristic and standardised morphometric datasets were further analysed using Canonical Variate Analysis (CVA) on R (candisc package). Significant differences (p<0.05) occurred within and between groups for 23 parameters among populations. The CVA plot revealed clear morphological differentiation among the three populations at 95% confidence ellipses, but the meristic data could not delineate the populations. Therefore, the three populations of S. galilaeus exhibited a significant degree of phenotypic divergence based on their morphometric traits, likely driven by geographic isolation and local adaptation to the unique environmental conditions of each reservoir.

> purely environmentally induced and short-lived, lacking speciation potential but still carrying significant implications for improved fisheries management (Mojekwu and Anumudu 2015).

> Sarotherodon galilaeus (Linnaeus 1978) (commonly known as Mango tilapia) is an important freshwater fish species for artisanal fisheries and aquaculture in Nigeria. It has a wide distribution both in tropical and subtropical regions of the world, including Africa, the Middle East, Europe, and some parts of Asia. Its regions of natural occurrence include Africa and the Middle East, while its regions of introduction include Europe and some Asian countries such as Japan and China, mainly for aquaculture purposes (Froese and Pauly 2014). Sarotherodon galilaeus is economically important in aquaculture and fisheries due to its adaptability to diverse environmental conditions and its significant contribution to food security in many developing countries (FAO, 2022).

> Morphometric and meristic analyses are essential tools for studying fish populations as they help elucidate population structure and phenotypic plasticity (Chapman *et al* 2000; Naspleda *et al* 2012). They are also valuable tools for taxonomic studies and for exploring evolutionary relationships among groups while providing useful insights into fish ecology and behaviour (Mojekwu and Anumudu, 2015). Morphometrics is the

Oladimeji, T.E. Oyewale, O.T. and Afolabi O. (2025). Phenotypic plasticity of *Sarotherodon galilaeus* (Linnaeus, 1978) obtained from the Aiba, Eko-Ende, and Asejire Reservoirs in Southwestern Nigeria. *The Zoologist 26*. http://dx.doi.org/10.4314/tzool.v26i1.5 measurement of shape and size-related traits such as total length, body depth, and caudal peduncle, while meristics involves serial countable traits such as fins, rays, and scales. Analysis of morphometric and meristic data using various univariate and multivariate methods is a common approach for assessing population differentiation patterns (Aguirre *et al* 2013; Ola-Oladimeji *et al* 2017). These methods are useful for detecting subtle phenotypic variations caused by environmental factors or genetic isolation, especially in fish populations (Albertson and Kocher 2005; Oladimeji *et al* 2015).

Measurements of morphometric and meristic characters are used to assess morphological diversities in fish populations because these tools are sensitive to environmental changes and remain fundamentally reliable (Fryer and Iles 1972). Studies have shown that tilapia populations often exhibit phenotypic plasticity in response to varying environmental conditions, such as water quality, habitat type, predator pressure, resource availability, and hydrological conditions (Arbour and López-Fernández, 2013; Burress, 2015; Oladimeji and Olaosebikan, 2017; Gilbert *et al* 2020; Oladimeji *et al* 2023).

Reservoirs in south-western Nigeria, for example, represent distinct ecological systems with unique environmental pressures. However, little is known about how environmental differences between these reservoirs influence the morphological characteristics of the fishes. Existing studies on *S. galilaeus* have largely focused on

its ecology (Olopade *et al* 2014; Adeosun 2016; Gbaguidi *et al* 2016; Ouedraogo *et al* 2024), genetic analysis (Borovski *et al* 2019; Luo *et al* 2021; Fiteha *et al* 2023), with few emphasising population-level morphological characterisation (Oladimeji *et al* 2020; Akindele and Fagbuaro 2022).

Characterising population-specific morphological variations in S. galilaeus can provide insight into their adaptations to varying environmental conditions, which is crucial to understanding evolutionary processes and local adaptations. It will also help to identify distinct populations or morphotypes that may eventually become subspecies requiring conservation efforts. Taking into account the prevailing environmental stressors in most water bodies, such as habitat degradation, climate change, and anthropogenic activities, preserving diversity within the species is critical for maintaining ecosystem resilience and fishery sustainability. This study, therefore, was aimed to assess the phenotypic plasticity of S. galilaeus in three different reservoirs in Nigeria using morphometric measurements and meristic counts.

Materials and methods

Description of the study area

Three different reservoirs in Southwest Nigeria, viz. Aiba, Eko Ende, and Asejire Reservoirs were used for the study (Figure 1).



Figure 1. Map of Nigeria showing locations of Aiba, Eko-Ende, and Asejire Reservoirs

Aiba Reservoir, also known as the Iwo Water Corporation, is located in Iwo, Osun State, Nigeria. The reservoir was built with the primary purpose of providing potable water to residents of Iwo and its surrounding communities (Ogunbode *et al* 2019). It lies between longitudes 004° 11' and 004° 13' and latitudes 07° 38' and 07° 39' of the equator. The reservoir, one of the oldest in southwestern Nigeria, was created on 1st June 1957. It has a storage capacity of 1.91 billion cubic meters and is supplied with fresh water from a catchment area of 54.39 square kilometres. Aiba Reservoir is 11.58 meters high,

stretches 455.2 meters in length, and has an average depth of 0.75 meters.

Eko Ende Reservoir is located between latitudes 7°44' and 7°57'N, and longitudes 4°26' and 4°41'E, in the Irepodun Local Government Area of Osun State, Nigeria. The reservoir was formed by impoundment of the Otin River, which was dammed in 1973. It has a storage capacity of 5.5 million cubic meters and an elevation ranging from 35m to over 400m above sea level. The reservoir was built to supply potable water to the communities of Oba, Eko-Ende, Okuku, Ikirun Eko-

Ajala and Iragbiji. The reservoir has a mean annual rainfall of approximately 1400mm, the wet season extends from March to October, with torrential rains and thunderstorms characterising its beginning and end (Adediji and Ajibade 2008).

Asejire Reservoir is located in Oyo State, Nigeria, approximately 30 kilometres east of Ibadan. It was formed by the impoundment of the Osun River in 1972 and is located between latitudes 07°21'48"N to 07°26'84"N 004°07'17"E and longitudes to 004°08'925"E. The reservoir has a catchment area of approximately 23.42 square kilometres (2,342 hectares), with a normal pool elevation of 150 meters and a maximum flood elevation of 152.4 meters. Its surface area spans about 24 square kilometres. The reservoir supplies water to the Asejire and Osegere water treatment plants in Ibadan, with a capacity of about 80 million litres per day, 80% of which is allocated for domestic use. Asejire Reservoir was originally constructed to supply water for domestic and industrial purposes, but has also become a hub for fishing activities (Asibor 2008).

Fish Sampling and collection of biological data

Samples of S. galilaeus were randomly collected from the landings of commercial fishermen from Aiba and Eko Ende Reservoirs in Osun State, and Asejire Reservoir in Oyo State, Nigeria, between December 2023 and April 2024. Fifty samples were collected from each reservoir, totalling 150. The samples were brought to the laboratory in an ice chest and identified using keys prepared by Paugy et al (2003). Twenty-five morphometric measurements according to Dunz and Schliewen (2010) were recorded on each fish using a standard meter rule and digital vernier callipers (NEIKO 01407a). These measurements included Total Length (TL), Standard Length (SL), Head Length (HL), Body Depth (BD), Snout Length (SNL), Eye Diameter (ED), Cheek Depth (CHD), 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), Preorbital Distance (POD), Caudal Peduncle Length (CPL), Caudal Peduncle Depth (CPD), Lower Jaw Width (LJW), Pectoral Spine Length (PSL), Pre-Anal Distance (PAD), and Distance of lower Jaw to Pelvic Fin (PELD). Six meristic characters were counted and recorded including: number of scales on the lateral line, dorsal spine, dorsal ray, gill rakers, anal fin ray, and anal fin spine.

Variable transformations and statistical analyses

The morphometric measurements of each fish were transformed using the function of its standard length according to Reist (1985) as follows:

$$Mn = \left(\frac{Mo}{SL}\right)\%$$

Where:

Mn is the new measurement Mo is the original measurement, and SL is the standard length.

This was done primarily to remove the bias that size differences can introduce into the morphometric data. The standardised morphometric measurements were further converted to common logarithms to stabilise variance and improve the normality of the data. The meristic data were not standardised because meristic traits are fixed early in development and are not influenced by an increase in size (Masood *et al* 2015a). The meristic data and size-adjusted morphometric data were analysed using Canonical Variate Analysis (CVA) on R (Candisc package). One-way Analysis of Variance (ANOVA) was used to test for the variation in morphometric and meristic characters among the three fish populations. This was conducted on SPSS version 22.

Results

Mean values of morphometric and meristic characters of S galilaeus from the three reservoirs are presented in Tables 1 and 2, respectively. One-way Analysis of Variance revealed significant differences (p < 0.05)within and between groups for twenty out of the twentyfour size-corrected morphometric measurements and two meristic traits in the three populations of S. galilaeus. The morphometric characters that exhibited significant differences were total length, head length, body depth, snout length, eye length, anal fin length, length of last dorsal spine, length of the third anal spine, pelvic fin length, pre-dorsal distance, upper lip length, lower jaw length, lower lip length, pectoral fin length, preorbital distance, caudal peduncle length, caudal peduncle depth, lower jaw width, pectoral spine length, and pre anal distance. This reveals a high level of heterogeneity in the populations. Also, two of the six recorded meristic traits, specifically the number of scales on the lateral line and gill rakers, showed significant differences between the three populations.

The CVA plot revealed a clear separation among the three populations along the first two canonical axes (CV1 and CV2) at 95% confidence ellipses (Figure 2). The biplot of the coefficients of the linear discriminants (LD1 and LD2) from the CVA displayed the weight of each morphometric character and its contribution to the separation of groups along the first two canonical axes (Figure 3). Traits with high positive loadings on the CV1 included DFL (21.17), AFL (17.10), PELD (17.28), and ED (10.51), while traits with high negative loadings were TL (-48.95), HL (-16.21), LJL (-21.20), DSL (-17.12), PecFL (-17.09). On the CV2, traits with high positive loadings included PAD (27.37), PecFL (15.44), ED (13.84), PSL (9.06), and PDD (8.59) while those with high negative loadings included DFL (-29.59), LJL (-19.34), and ChD (10.19). The CVA plot of the meristic counts revealed a considerable level of homogeneity, as the meristic characters largely overlapped among the three populations (Figure 4).

32 The Zoologist, 26:29-36, June, 2025

| Fable 1: Morphomet | ric characters | (mean) | of Sarotherodon | galilaeus |
|---------------------------|----------------|--------|-----------------|-----------|
|---------------------------|----------------|--------|-----------------|-----------|

| Morphometric | Reservoirs | | | |
|----------------------------------|------------------|------------------|------------------|--|
| characters | Aiba | Eko-Ende | Asejire | |
| Total Length* | 15.75 ± 1.06 | 14.47 ± 1.23 | 13.77 ± 1.15 | |
| Standard Length | 12.64 ± 0.84 | 11.68 ± 1.02 | 11.40 ± 0.91 | |
| Pre-anal Distance* | 8.63 ± 0.81 | 8.14 ± 0.80 | 7.55 ± 0.65 | |
| Dorsal Fin Length* | 7.11 ± 0.58 | 6.53 ± 0.66 | 6.41 ± 0.59 | |
| Body Depth* | 5.27 ± 0.35 | 4.43 ± 0.64 | 4.73 ± 0.47 | |
| Distance Lower Jaw to Pelvic Fin | 5.11 ± 0.31 | 4.76 ± 0.40 | 4.60 ± 0.43 | |
| Pre-dorsal Distance | 4.79 ± 0.32 | 4.44 ± 0.37 | 4.15 ± 0.34 | |
| Pectoral Fin Length* | 4.67 ± 0.34 | 4.41 ± 0.42 | 3.77 ± 0.34 | |
| Head Length* | 4.05 ± 0.30 | 3.72 ± 0.31 | 3.48 ± 0.28 | |
| Pelvic Fin Length* | 3.74 ± 0.45 | 3.41 ± 0.40 | 2.99 ± 0.38 | |
| Anal Fin Length* | 2.30 ± 0.18 | 2.18 ± 0.22 | 2.20 ± 0.24 | |
| Length of Last Dorsal Spine* | 2.24 ± 0.18 | 2.03 ± 0.19 | 1.84 ± 0.16 | |
| Pelvic Spine Length* | 2.04 ± 0.16 | 1.92 ± 0.17 | 1.67 ± 0.19 | |
| Caudal Peduncle Length* | 2.01 ± 0.18 | 1.95 ± 0.20 | 1.81 ± 0.24 | |
| Length of Third Anal Spine* | 1.98 ± 0.15 | 1.92 ± 0.31 | 1.64 ± 0.18 | |
| Caudal Peduncle Depth* | 1.89 ± 0.19 | 1.82 ± 0.19 | 1.74 ± 0.18 | |
| Snout Length* | 1.60 ± 0.19 | 1.36 ± 0.13 | 1.32 ± 0.15 | |
| Lower Jaw Length* | 1.44 ± 0.15 | 1.08 ± 0.09 | 0.99 ± 0.08 | |
| Cheek Depth | 1.38 ± 0.14 | 1.23 ± 0.13 | 1.21 ± 0.12 | |
| Pre-orbital Distance* | 1.33 ± 0.15 | 1.19 ± 0.13 | 1.14 ± 0.14 | |
| Upper Lip Length* | 1.21 ± 0.13 | 1.02 ± 0.09 | 0.97 ± 0.09 | |
| Lower Jaw Width* | 1.14 ± 0.13 | 0.98 ± 0.08 | 0.91 ± 0.08 | |
| Lower Lip Length* | 1.11 ± 0.11 | 1.02 ± 0.08 | 0.90 ± 0.14 | |
| Lower Lip Width | 1.08 ± 0.13 | 1.01 ± 0.08 | 1.01 ± 0.12 | |
| Eye Diameter* | 1.07 ± 0.08 | 1.03 ± 0.06 | 0.93 0.07 | |

*Indicates characters that are significantly different (p<0.05) between the populations

Table 2: Meristic counts (mean) of Sarotherodon galilaeus

| Meristic counts | Reservoirs | | | |
|-----------------------------------|------------------|------------------|------------------|--|
| | Aiba | Eko-Ende | Asejire | |
| Number of Scales on Lateral Line* | 29.96 ± 1.16 | 29.78 ± 1.02 | 27.82 ± 0.77 | |
| Dorsal Fin Spine | 16.14 ± 0.41 | 16 ± 0.35 | 16.02 ± 0.52 | |
| Dorsal Fin Ray | 11.94 ± 0.37 | 12.06 ± 0.31 | 11.96 ± 0.20 | |
| Gill Rakers* | 24.84 ± 1.15 | 24.82 ± 1.21 | 23.48 ± 1.05 | |
| Anal Fin Ray | 10.18 ± 0.39 | 10.36 ± 0.49 | 10.16 ± 0.37 | |
| Anal Fin Spine | 3.00 ± 0.00 | 3.00 ± 0.00 | 3.00 ± 0.00 | |

*Indicates traits that are significantly different (p≤0.05) between the populations



Figure 2. Canonical variate analysis plot based on morphometric measurements of *S. galilaeus*, indicating the differentiation pattern among the populations.



Figure 3. A biplot showing the relative contributions of each morphometric variable in discriminating the populations.

Key: TL: total length, HL: head length, DSL: dorsal spine length, PecFL: pectoral fin length, PAD: Pre-anal distance, PFL: pectoral fin length, PSL: pelvic spine length, PDD: pre-dorsal distance, ASL: Anal spine length, EyL: eye length, AFL: anal fin length, PELD: distance lower jaw to pelvic fin, LLW: lower lip width, ChD: cheek depth, DFL: dorsal fin length, BD: body depth, ULL: upper lip length, LJL: lower jaw length,



Figure 4. Canonical variate analysis plot based on meristic counts of *S. galilaeus* showing large overlap among the populations

Discussion

In this study, CVA revealed clear morphological divergence among *S. galilaeus* populations from Aiba, Eko Ende, and Asejire Reservoirs. The spatial separation and minimal overlap at 95% confidence ellipses for each population indicate that the observed morphological differences are statistically significant. Each population formed a distinct cluster, showing that the morphometric traits effectively discriminated among the three populations. The separation along the first canonical axis (CV1), which accounted for the greatest proportion of

variance, was strongly influenced by total length dorsal fin length, anal fin length, lower jaw length, and pectoral fin length. This suggests that these traits are the major drivers of interpopulation divergence among the three populations. The separation along the second axis (CV2) was primarily driven by traits such as pre-anal distance, pectoral fin length, and eye length. The strong contributions of these traits, which are mostly related to locomotion and feeding, indicate phenotypic plasticity in response to localised environmental conditions, such as food availability, prey-predator relationships, and habitat structure. Wainwright and Richard (1995) noted that mouth morphology is closely linked to dietary specialisation and foraging strategies in teleost fishes.

Morphological divergence resulting from adaptive responses to different environmental pressures has been widely reported in cichlid fishes and other freshwater species (Wimberger 1992; Kassam *et al* 2003; Akindele and Fagbuaro 2022). Moreover, the three populations examined in this study are from reservoirs that were impounded at different times in the past. River impoundment constitutes a major disturbance to aquatic ecosystems, causing fundamental changes in flow regimes, which in turn alter the movement of migratory species, especially fish (Dynesius 1994; Nilsson *et al* 2005; Downing *et al* 2006; Santos and Araújo 2015). The construction of dams alters riverine connectivity, leading to the isolation of fish populations (Pompeu and Zambaldi 2020).

The pattern of morphological differentiation observed in this study highlights the presence of a strong barrier to gene flow resulting from the presence of dams, which may have impacted the migratory routes of the fishes. The distinct clustering observed here corroborates findings that phenotypic traits can be significantly shaped by geographic isolation and habitat variation, both of which are prevalent in reservoir systems. Similar patterns have been reported in other African freshwater systems, where fish populations isolated by hydrological barriers exhibit significant morphological divergence (Franssen 2011; Foster *et al* 2014; Oladimeji and Olaosebikan 2017).

The significant differences observed among the three populations in most of the morphological traits examined suggest that a high level of morphological heterogeneity exists in the populations. This corresponds to the report of Fagbuaro *et al* (2015), who noted significant differences in the morphometric and meristic characters of *S. galilaeus* sampled from three reservoirs (Ado-Ekiti, Egbe and Ero) in Ekiti State, Nigeria. The findings of this study contradict those of Oladimeji *et al* (2020), who reported significant morphological homogeneity among *S. galilaeus* populations from the Opa, Ero, and Asejire Reservoirs in Southwest Nigeria, attributing this similarity to the comparable climatic conditions across the three reservoirs.

In this study, the meristic traits examined did not reveal any significant differentiation among the three populations. This is expected because most meristic traits are fixed early in development and they do not respond to environmental changes (Murta 2000; Oladimeji *et al* 2015).

Usually, morphological variations can result from plasticity in response to the environment or from genetic polymorphisms (Sommer 2020). Morphological variables that are under selection ultimately lead to adaptive phenotypes and can promote the evolution of a new species (Schluter and Rieseberg 2022). When supported by genetic data, morphological differentiation can provide early evidence of population structure, which is crucial for the sustainable management of stocks (Valladares *et al* 2024).

Therefore, it is important to investigate whether the morphological differences observed in this study are genetically related or short-term, environmentally induced. Further studies involving high-resolution genetic markers such as microsatellites and SNPS are recommended to elucidate the genetic structure of the *S. galilaeus* populations.

The observed morphological divergence in this study underscores the importance of incorporating phenotypic data in fish stock assessments and conservation planning.

Conclusion

The study revealed phenotypic plasticity by establishing clear morphological differentiation among *S. galilaeus* populations from Asejire, Eko Ende, and Aiba Reservoirs. The population-specific morphological differences revealed in this study could assist relevant stakeholders in making informed decisions for developing location-specific strategies for the sustainable utilisation and conservation of *S. galilaeus*.

Conflict of interest

The authors declare that there are no conflicts of interest.

References

- Adediji, A. and Ajibade, L.T. 2008. The change detection of major dams in Osun State, Nigeria, using Remote Sensing (RS) and GIS Techniques. J. Geogr. Reg. Plann. 1: 110-115. https://doi.org/10.5897/JGRP.9000136.
- Adeosun, F.I. 2016. An investigation into the food and feeding ecology of *Sarotherodon galilaeus* in Oyan Lake, Ogun State, Nigeria. *Nig. J. Anim. Sci. 18(2)*: 364-369.
- Agostinho, A.A., Gomes, L.C. and Pelicice, F.M. 2007. Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil. (Ecology and management of fisheries resources in reservoirs in Brazil). Maringá, EDUEM, 501p.
- Aguirre, W.E., Shervette, V.R., Navarrete, R., Calle, P. and Agorastos, S. 2013. Morphological and genetic divergence of *Hoplias microlepis* (Characiformes: Erythrinidae) in rivers and artificial impoundments of Western Ecuador. *Copeia*. 2: 312-323. https://doi.org/10.1643/CI-12-083.
- Akindele, T.A. and Fagbuaro, O. 2022. The morphometric characteristics and meristic traits of and condition factor of *Sarotherodon galilaeus* from three major reservoirs of Ekiti State, Nigeria. *Asian J. Adv. Res.* 5(1): 1-11.
- Albertson, R. C., and Kocher, T. D. 2005. Genetic architecture sets limits on transgressive segregation in hybrid cichlid fishes. *Evolution*. 59:686-690. https://doi.org/10.1111/j.0014-3820.2005.tb01027.x.
- Arbour, J.H. and López-Fernández, H. 2013. Ecological variation in South American geophagine cichlids arose during an early burst of adaptive morphological and functional evolution. *Proc. R. Soc. B: Biol. Sci.* 280(1763). https://doi.org/10.1098/rspb.2013.0849.

- Asibor, N.O. 2008. Utilization and ecological impacts of Asejire Reservoir. *Nig. J. Environ. Manage.* 21(2): 87-94.
- Borovski, T., Tadmor-Levi, R., Shapiro, J., Rubinstein, G., Agyakwah, S.K., Hulata, G. and David, L. 2018. Historical and recent reductions in genetic variation of the Sarotherodon galilaeus population in the Sea of Galilee. Conserv. Genet. 19:1323-1333. https://doi.org/10.1007/s10592-018-1102-7.
- Burress, E.D. 2015. Cichlid fishes as models of ecological diversification: patterns, mechanisms, and consequences. *Hydrobiologia*. 748: 7-27.
- Chapman, L.G., Galis, F. and Shinn, J. 2000. Phenotypic plasticity and the possible role of genetic assimilation: Hypoxia-induced trade-offs in the morphological traits of an African cichlid. *Ecol Lett.* 3(5): 387-393. *http://dx.doi.org/10.1046/j.1461-0248.2000.00160.x.*
- Downing, J.A., Prairie, Y.T., Cole, J.J., Duarte, C.M., Tranvik, L.J., Striegl, R.G., McDowell, W.H., Kortelainen, P., Caraco, N.F., Melack, J.M. and Middelburg, J.J. 2006. The global abundance and size distribution of lakes, ponds, and impoundments. *Limnol. Oceanogr.* 51: 2388-2397. https://doi.org/10.4319/lo.2006.51.5.2388.
- Dunz, A. and Schliewen, U.K. 2010. Description of a Tilapia (Coptodon) species flock of Lake Ejagham (Cameroon), (Perciformes, Cichlidae). *Spixiana*. *33*(*2*): 251-280.
- Dynesius, M. and Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science*. 226: 753-761. https://doi.org/:10. 1126/science.266.5186.753
- Fagbuaro, O., Oso, J.A., Oyegbile, O.M. and Akinyemi, O. 2015. Biometric characteristics of *Sarotherodon* galilaeus from three man-made lakes in Ekiti State, Southwest Nigeria. J. Biol. 3(2): 15-21.
- Food and Agriculture Organization of the United Nations (FAO) 2022. The state of world fisheries and aquaculture 2022. Towards blue transformation. Rome, FAO.
- Foster, K., Bower, L. M. and Piller, K. R. 2014. Getting in shape: Habitat-based morphological divergence for two sympatric fishes. *Biol. J. Linn. Soc.* 114(1). *https://doi.org/10.1111/bij.12413.*
- Fiteha, Y.G., Rashed, M.A., Ali, R.A.M. and Magdy, M. 2023. Characterization and phylogenetic analysis of the complete mitochondrial genome of Mango Tilapia (*Sarotherodon galilaeus:* Cichlidae). *Mol. Biol. Rep.* 50:3945–3950. https://doi.org/10.1007/s11033-023-08288-6.
- Franssen, N. 2011. Anthropogenic habitat alteration induces rapid morphological divergence in a native stream fish. *Evol. Appl.* 4(6): 791-804. *https://doi.org/10.1111/j.1752-4571.2011.00200.x*.
- Froese, R. and Pauly, D. (eds.) 2014. "Sarotherodon galilaeus." FishBase.
- Fryer, G. and Iles, T.D. 1972. The Cichlid Fish of the Great Lakes of Africa. Oliver and Boyd, Edinburgh. 641 pp.
- Gbaguidi, H., Adite, A. and Sossoukpe, E. 2016. Feeding ecology and establishment of the naturally-colonized freshwater cichlid, *Sarotherodon galilaeus* (Pisces:

Actinopterigii: Perciformes) from a man-made lake, South-Benin, West Africa. *Nat. Res.* 7: 337-355. https://doi.org/10.4236/nr.2016.76030.

- Ghalambor, C.K., McKay, J.K., Carroll, S.P. and Reznick, D.N. 2007. Adaptive versus non-adaptive phenotypic plasticity and the potential for contemporary adaptation in new environments. *Funct. Ecol.* 21(3): 394-407. https://doi.org/10.1111/j.1365-2435.2007.01283.x
- Gilbert, M.C., Akama, A., Fernandes, C.C. and Albertson, R.C. 2020. Rapid morphological change in multiple cichlid ecotypes following the damming of a major clearwater river in Brazil. *Evol. Appl.* 13(10):2754-2771. https://doi.org/10.1111/eva.13080.
- Kassam, D. D., Adams, D. C., Ambali, A. J. D. and Yamaoka, K. 2003. Body shape variation in relation to resource partitioning within cichlid trophic guilds coexisting along the rocky shores of Lake Malawi. *Anim. Biol. 53(1)*: 59-70.
- Luo, C., Yang, P. and Wang, S. 2021. The complete mitochondrial genome of Sarotherodon galilaeus (Linnaeus, 1758) (Perciformes: Cichlidae) and its phylogenetic placement. Mitochondrial DNA B 6(3): 920-921. https://doi.org/10.1080/23802359.2021.1888327.
- Mojekwu, T.O. and Anumudu, C.I. 2015. Advanced techniques for morphometric analysis in fish. J. Aquacul. Res. Dev. 6: 354. https://doi.org/10.4172/2155-9546.1000354.
- Masood, Z., Rafique, N., Saddozai, S., Achakzai, W., Farooq, R., Jamil, N., Razzaq, W., Iqbal, F., Khawar, M., Din, N. and Bano, N. 2015b. Comparative survey of some morphometric and meristic differentiation among the male and female fishes of the four mullet species of family Mugilidae from Karachi Coast, *Pakistan. J. Appl. Env. Biol. Sci. 5(11)*: 140-150.
- Murta, A.G. 2000. Morphological variation of horse mackerel (*Trachurus trachurus*) in the Iberian and North African Atlantic: implications for stock identification. *ICES J. Mar. Sci.* 57(4): 1240-1248. https://doi.org/10.1006/jmsc.2000.0810.
- Naspleda, J., Vila-Gispert, A., Fox, M.G., Zamora, L. and Ruiz-Navarro, A. 2012. Morphological variation between non-native lake- and stream-dwelling pumpkin seed Lepomis gibbosus in the Iberian Peninsula. J. Fish Biol. 81(6):1915-35. https://doi.org/10.1111/j.1095-8649.2012.03416.x.
- Nilsson, C. Reidy C.A. Dynesius, M., Revenga, C. 2005. Fragmentation and flow regulation of the World's large river systems. *Science* 308: 405–408. https://doi:10.1126/science.1107887
- Ogunbode, T.O., Akande, J.A., Ogungbile, P.O. and Odekunle, O. 2019. Sustainability and resilience of Aiba Dam Reservoir in Iwo, Nigeria. J. Appl. Environ. Manage. 23(10): 1937-1942. https://doi.org/10.4314/jasem.v23i11.5.
- Okada, E.K., Agostinho, A.A. and Gomes, L.C. 2005. Spatial and temporal gradients in artisanal fisheries of a large neotropical reservoir, the Itaipu Reservoir, Brazil. *Can. J. Fish. Aquat. Sci.* 62: 714-724. https://doi.org/10.1139/f05-015.

- Oladimeji, T.E. and Olaosebikan, T.O. 2017. Morphological variability of *Tilapia zillii* (Gervais, 1848) from selected reservoirs in southwestern, Nigeria. *Ife J. Sci.* 19(1): 15-25 *https://dx.doi.org/10.4314/ijs.v19i1.3.*
- Oladimeji, T.E., Adewole, H.A., Olagunju, S.D. and Ogunribido, A.O. 2023. Impoundment impact on the morphology of *Brycinus macrolepidotus* (Characiformes: Alestidae) populations in the Osun River, Nigeria. *Gene. Biodivers. J.* 7(2):130-140. *https://doi.org/10.46325/gabj.v7i2.324*
- Oladimeji, T.E., Awodiran, M.O. and Ola-Oladimeji, F.A. 2020. Morphological characterisation of *Sarotherodon galilaeus* in three reservoirs in Southwest Nigeria. *Ife J. Sci.* 41(5): 1021-1029. https://dx.doi.org/10.4314/ijs.v22i3.7.
- Oladimeji, T.E., Awodiran, M.O. and Komolafe, O.O. 2015. Genetic differentiation studies among natural populations of *Tilapia zillii*. *Not. Sci. Biol.* 7(4): 423-429. *https://doi.org/10.15835/nsb749649*.
- Ola-Oladimeji, F.A., Oso, J.A., Oladimeji, T.E., Idowu, E.O., Adeleke, K. And Urihe, F.O. 2017. Phenotypic diversities of four populations of *Clarias gariepinus* (Siluriformes, Clariidae) obtained from Ogun and Ondo State waterbodies in South-Western Nigeria *Vestn.* Zoo. 51(4): 285–294, https://doi.org/10.1515/vzoo-2017-0034.
- Olopade, O.A., Taiwo, I.A., Emeka, C.R. 2014. Studies on some biological aspects of *Sarotherodon galilaeus* in Oyan dam, Nigeria. *Acad. J. Agric. Res.* 2(3): 093-099. http://dx.doi.org/10.15413/ajar.2013.0156.
- Ouedraogo, R.B., Sanogo, S. and Compaoré, I. 2024. Assessing the exploitation status of *Sarotherodon galilaeus* (Linnaeus, 1758) in Samendéni Reservoir, Burkina Faso. *Egypt. J. Aquat. Biol. Fish. 28(1)*: 1509 -1535.
- Paugy, D., Leveque, C. and Teugels, G.G. 2003. The fresh and brackish water fishes of West Africa, Volume I and II. IRD Editions. Publications scientifiques. Du museum. 457 and 815pp.
- Pompeu, P.S. and Zambaldi, L. 2020. Evaluation of River Fragmentation and Implications for the Conservation of Migratory Fish in Southeastern Brazil. *Environ. Manage.* 65(5): 702-709.

http://doi.org/10.1007/s00267-020-01266-9. PMid:32086549.

- Reist, J.D. 1985. An Empirical Evaluation of Several Univariate Methods that Adjust for Size Variation in Morphometric Data. *Can. J. Zool.* 63: 1429-1439. *https://doi.org/10.1139/z85-213.*
- Santos, A.B. and Araújo, F.G. 2015. Evidence of morphological differences between Astyanax bimaculatus (Actinopterygii: Characidae) from reaches above and below dams on a tropical river. Environ. Biol. Fishes. 98: 183-191. https://doi.org/10.1007/s10641-014-0248-5.
- Schluter, D. and Rieseberg, L.H. 2022. Three problems in the genetics of speciation by selection. *Proc. Natl. Acad. Sci. USA. 119(30)*: e2122153119 *https://orcid.org/0000-0003-1683-7836.*
- Sommer, R.J. 2020. Phenotypic Plasticity: From Theory and Genetics to Current and Future Challenges. *Genetics.* 215(1): 1-13. https://doi.org/10.1534/genetics.120.303163.
- Valladares, M.A., Fabres, A.A., Sánchez-Rodríguez, F., Collado, G.A. and Mendez, M. A. 2024. Population structure and microscale morphological differentiation in a freshwater snail from the Chilean Altiplano. BMC Ecol. Evol. 24(5). https://doi.org/10.1186/s12862-023-02196-w.
- Wainwright, P.C. and B.A. Richard. 1995. Predicting patterns of prey use from morphology of fishes. *Environ. Biol. Fishes.* 44: 97-113.
- Wimberger, P. H. 1992. Plasticity of fish body shape. The effects of diet, development, family and age in two species of *Geophagus* (Pisces: Cichlidae), *Biol. J. Linn. Soc.* 45(3): 197-218. https://doi.org/10.1111/j.1095-8312.1992.tb00640.x.
- Winemiller, K.O., McIntyre, P.B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., Baird, I.G., Darwall, W, Lujan, N.K. [...], and L. Sáenz 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong: Basin-scale planning is needed to minimize impacts in mega-diverse rivers. *Science* 351: 128-129. *https://10.1126/science.aac7082*.

ORCID

Tofunmi E. Oladimeji: https://orcid.org/0000-0002-4852-7018