PHENOTYPIC VARIABILITY REVEALED DIFFERENTIALLY HETEROGENEOUS TRAITS IN LONGNECK CROAKER, *Pseudotolithus typus* (Bleeker, 1863), ACROSS EPE AND LAGOS LAGOONS, NIGERIA

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ABSTRACT

The adaptive phenotypic flexibility, descriptive and discreteness characteristics of *Pseudotolithus typus* obtained from Epe and Lagos lagoons in southwestern Nigeria were investigated to ensure precise identification, management and conservation of the species. Six meristic counts and 15 morphometric measurements were collected from mature *Pseudotolithus typus* obtained from Epe and Lagos Lagoons. Data on phenotypic and heterogeneous attributes were analysed using descriptive statistics, linear regression, and Discriminant Factor Analysis (DFA). Meristic values ranged from 2.00±0.00 (Eye) - 30.80±1.16 (Dorsal-Fin-Rays) and 2.00±0.00 (Eye) - 31.03±0.76 (Dorsal-Fin-Rays) in Epe and Lagos lagoons, respectively. Dorsal Spine Count had a higher variation at Epe (Coefficient of Variation, CV=5.58%) than Lagos lagoon (CV=4.65%). Morphometric values ranged from 4.25±0.51 (Orbital Length) - 28.77±1.54 (Head Length) in Epe Lagoon; and 3.52±0.22 (Pectoral Fin Width) - 28.35±1.75 (Body Depth) in Lagos Lagoon. Caudal Peduncle Length (CV=34.02%) and Mouth Height (CV= 12.44%) had the highest variation in Epe and Lagos Lagoons; respectively. Generally, 56.25% and 37.50% of the attributes had CV>10% in Epe and Lagos Lagoons. Cross-validation of group membership revealed 95.0% (entire), 93.3% (Epe) and 96.7% (Lagos) correctness of the *apriori* groupings. *Pseudotolithus typus* population demonstrated taxonomic sanctity, but differentially flexible phenotypes across Epe and Lagos lagoons. This indicates the adaptive potential and survivability of the species in multiple lagoon environments.

Keywords: Phenotypic structure, Morphologic variability, Croaker fish, Lagoon ecosystems

INTRODUCTION

Pseudotolithus species are among the commercial croakers that inhabit the mud bottom of coastal waters, from shoreline to estuaries and lagoons. Croakers are important food fish in Nigeria, constituting about 40% of the total fish landing on the Nigerian coast (Gaffer, 1994). However, Croakers are threatened by mass mortality in Nigerian coastal waters, with *Pseudotolithus elongatus* being the most abundant, followed by *P. typus* and *P. senegalensis* (IUCN redlist) (Olopade and Dienye, 2023).

Pseudotolithus typus is a good source of protein, and lean in fat content. The species is rich in Omega 3, with Eeicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA) being the most abundant fatty acids (Njinkoue *et al*., 2016). The edible parts and bones are rich in potassium and calcium, while the sodium to potassium ratio and omega 3 fatty acids make it fit for consumption and a preventer of cardiovascular diseases. *Pseudotolithus typus* is distributed across the West African coasts and harvested in commercial quantities in Sierra Leone, Benin Republic, Cameroun and Nigeria (Anyanwu and

Kusemiju 1990; Ossoukpe, *et al.,* 2013; Jang *et al*., 2021; Adjigbe *et al.*, 2023). *Pseudotolithus typus* is widely distributed in estuaries of Nigeria, where it is generally classified as an omnivore or predator (Nta *et al*., 2020; Awotunde, 2021). It utilizes various kinds of food resources available in its habitat (Bachok *et al.*, 2004). Hence, the species is being considered for aquaculture, where wild sources would be the resource bank to be leveraged on in the supply of stock for aquaculture development. However, management and conservation of the species through aquaculture would require a deep understanding of its survival strategy in various habitats and taxonomic sanctity for sustainable identification, utilization and improvement. Moreso, diverse taxonomic units of the species could be utilized as production compartments in aquaculture. Furthermore, understanding the phenotypic plasticity and taxonomic entities within and across species and populations is essential when considering the impacts of climate change and heightened anthropogenic activities on the survival of the species in its range of distribution.

Migration could result in an increased range of distribution allowing a species to be encountered across various habitats. This kind of response is often essential for fish to survive environmental threats. However, migratory processes are enhanced by the capacity of a genotype to produce several phenotypes, depending on the environment (Forsman, 2015; Lind *et al.*, 2015). This phenomenon is considered an evolutionary strategy to better adapt to environment fluctuations (Peck *et al*., 2013). Consequently, the degree of variation could specify the kind of changes a species might have experienced in the past; the current situation; and the probability of sustenance in the future (Robinson and Parsons, 2002). An assessment of traits that reflect phenotypic variation is essential in the determination of population structure of exploited species, and for fishery management (Waples and Naish, 2009). In addition, understanding a population's phenotypic plasticity is largely needful in the selection of wild stocks, used in hatchery programs (Wang, 2020).

Phenotypic plasticity is the ability of one genotype to produce different phenotypes depending on environmental conditions (Nonaka *et al.*, 2015). Adaptive phenotypic plasticity is the ability of a genotype to express phenotypes for improved ecological performance, when exposed to different local environments (Robinson and Dukas, 1999; Dewitt and Scheiner, 2004; Ghalambor *et al*., 2007). Plasticity, genetic assimilation and cryptic genetic variation may contribute to adaptive radiations (Schneider and Meyer, 2017). The population's phenotypic structure could signal the trend of adaptiveness or flexibility in varied habitats and the key morphologic players in this regard.

One of the simple, cheap and effective traditional methods used for assessing population phenotypic plasticity is through morphometric variability studies. Such studies have the propensity to expose the flexibility of species morphometric traits, which could infer possible adaptive strength under changing environmental conditions. Molecular genetic markers are powerful tools used for detecting the genetic uniqueness of individuals, populations or species and are needed for the assessment of the genetic diversity of fish species (Avise, 1994; Askari and Shabani, 2013).

Morphometric and meristic data are used to delineate and understand the critical adaptive traits of species' phenotypes. This information will help in management and conservation of such species in changing ecosystems. This study assessed the morphologic structure (meristic and morphometric) of *P. typus* populations in Lagos and Epe lagoons in Nigeria. It also determined the flexibility/variability of the morphologic traits of the species and identified the phenotypic discreteness of the populations, based on the morphologic characters.

MATERIALS AND METHODS

Description of Study Areas

The study was conducted in Lagos and Epe lagoons located in Southwestern Nigeria. The Lagos lagoon lies between Latitude 6° 26' – 6° 37' N and Longitude 3° 23' - 4° 20' E. The water body flows through Lagos metropolis; with a surface area of approximately 6,354.7 km^2. It is more than 50 km long and 3 to 13 km wide. It is separated from the Atlantic Ocean by a long sand spit and flanked by swampy margins on the side (Badejo *et al.*, 2014).

Except for the Commodore channel, the Lagos lagoon is fairly shallow, not plied by ocean-going ships, but by smaller barges and boats and it empties into the Atlantic Ocean via Lagos harbour (Figure 1). The Epe lagoon is sandwiched between the Lekki lagoon (freshwater) in the east and the Lagos lagoon (estuary water) in the west. It lies between latitudes 6^{o} 23' and 6^{o} 41' N and longitude 2^{o} 2' E and 3^{o} 42' E. It is a brackish water environment with a mix of seawater from the Gulf of Guinea (Atlantic Ocean) and freshwater from river Oshun (Figure 1). It has a surface area greater than 243 km^2 and a depth range of 1 – 6 m. *Pseudotolithus typus* is one of the common catches of fisherfolks in the Epe and Lagos lagoons.

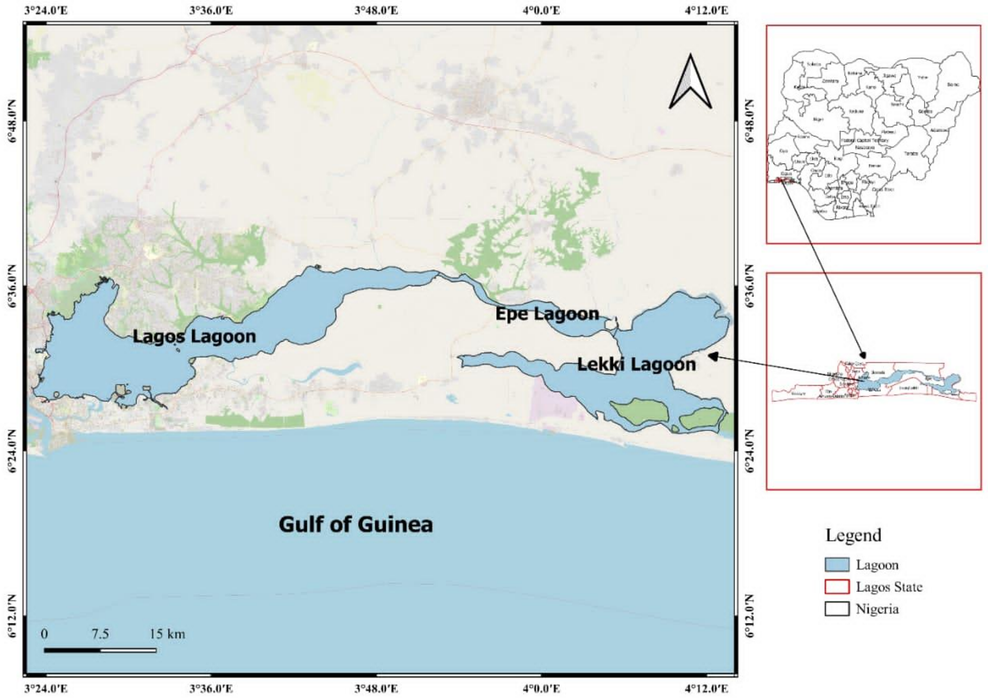

Figure 1. Map showing Lagos and Epe Lagoons (inset: Maps of Nigeria and Lagos State)

Sample Collection

Thirty uniformly sized samples of mature *Pseudotolithus typus* were collected from fisher folks at the main landing sites of Epe and Lagos lagoons, from August to October, 2021. Specimens were transported in iced containers from the landing sites to the Laboratory at the Department of Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Nigeria. The samples were collected following convenience sampling method described by Martin *et al.* (2016) and Espinosa-Lemus *et al.*, (2009). Specimens were collected from fisher folks without consideration of the specific fishing gear and fishing ground, until 30 specimens were obtained from each location.

Measurements of Morphometric and Meristic Attributes

Morphometric and meristic characterization followed the methods of Gunawickrama (2007) and Oyebola (2015). Hence, fifteen morphometric and six meristic attributes were assessed on the 60 samples (Table 1). A count of six meristic attributes was carried out while the morphometric measurements were taken using a measuring board, measuring tape and calipers graduated in millimeters. All length measurements (morphometric) were taken between identical points along the anterior to the posterior axes of each fish, whereas body depth was taken perpendicularly between the identified points taken at the base of the attributes. Each morphometric attribute was standardized by dividing the value by the standard length of the fish sampled and multiplying by 100%, and denoted as phenotypic value.

Flexibility/Heterogeneity of Morphometric and Meristic Attributes of *Pseudotolithus typus*

The flexibility of the morphometric and meristic attributes was determined by estimating the Coefficient of Variation (CV) of meristic and standardized values of morphometric attributes (inferred phenotypic values). The CV was derived by dividing values of standard deviation by the mean value of each attribute, then multiplying by 100 (%). The CV>10% and statistically derived multiple modes were taken as indicative of significant variability/flexibility/heterogeneity in each attribute (Mayr, 1969). This implies a level of significant flexibility in response to environmental challenges. The proportion of such heterogeneous attributes was taken to be indicative of the heterogeneity/phenotypic structure of the population.

Phenotypic descriptors and discreteness of *Pseudotolithus typus* from Epe and Lagos Lagoons

Data from all the measured phenotypic attributes were utilized for the determination of phenotypic descriptors and subsequent analysis of the canonical discreteness of sampled groups from Epe and Lagos lagoons. This followed a stepwise discriminate analysis process using relevant statistical tools (Gunawickrama, 2007).

Table 1a. Description of morphometric attributes of *Pseudotolithus typus* from Epe and Lagos Lagoons, Nigeria

S/N	Attributes	Abbreviation	Description
1	Total Length	TL	Distance between the tip of the snout to the tip of caudal fin.
2	Standard Length	SL	Distance between the tip of snout to the base of the caudal fin.
3	Body Depth	BD	The maximum distance between the dorsal fin and the ventral position of the fish, measured perpendicularly.
4	Head Length	HL	Distance from the upper lip to the posterior end of the opercula membrane.
5	Orbital Length	OL	The distance across the end of the two orbitals.
6	Pectoral Fin Length	PFL	The distance from the base to the tip of the pectoral fin.
7	Pectoral Fin Width	PFW	The perpendicular distance of the pectoral fin taken at the widest margin.
8	Caudal Fin Length	CFL	The distance from the base of the caudal fin to the tip.
9	Caudal Fin Width	CFW	The distance from the stretched lobes of the caudal fin taken at the widest margin.
10	Caudal Peduncle Length	CPL	The base of the last anal fin ray to the middle of the caudal fin fold.
11	Caudal Peduncle Height	CPH	The perpendicular distance of the deepest portion of the caudal peduncle.
12	Caudal Peduncle Width	CPW	The distance between the stretched lobes of the caudal fin fold.
13	Mouth Width	MW	The distance between the angles of the open mouth.
14	Mouth height	MH	The distance between the top and base of the open mouth.
15	Eye’s Relative Height	ERH	The distance between the upper and lower rims of the eye in the longitudinal axis.

Table 1b. Description of meristic attributes of *Pseudotolithus typus* from Epe and Lagos Lagoon, Nigeria

S/N	Attributes	Abbreviation	Description
1	Count of Dorsal Fin Spine	NDFS	The number of the dorsal fin spine.
2	Count of Dorsal Fin Rays	NDFR	Total number of dorsal fin soft rays.
3	Count of Anal Fin Rays	NAFR	Total number of anal fin soft rays.
4	Count of Caudal Fin Rays	NCFR	Total number of caudal fin soft rays.
5	Count of Pectoral Fin Rays	PFR	Total number of pectoral fin rays.
6	Count of Pelvic Fin Rays	PelvicFR	Total number of pelvic fin rays.

Data Analysis

Meristic and morphometric data were subjected to univariate analysis such as percentages, mean, and mode. Values from Epe and Lagos lagoons were compared using student t-test. To minimize size-related dissimilarity, all morphometric variables were adjusted using the allometric approach, as proposed by Elliott *et al.* (1995) in Eqn 1:

$$M_{adj} = M \left(\frac{L_s}{L_o}\right) b \ldots\ldots\ldots\ldots. (1)$$

Where; M is the original measurement, M_{adj} is the size-corrected measurement, L_s is the overall mean of standard length for all samples in each analysis, L_o is the standard length, and b is the slope of the regression of log M on log L_o, using all fish from each group.

The size-corrected morphometric data were further subjected to stepwise multivariate factor analysis. The coefficient of simple linear regression was utilized to determine significant descriptors (P<0.05) among the morphometric attributes, prediction equation and model summary. Discriminate Function Analysis (DFA) was used to compute the correctly classified percentage of fish samples in Epe and Lagos lagoons. The probable errors of the classification functions were calculated through cross-validation to infer the canonical discreteness of the groups. All analysis were carried out on SPSS (version 20.0).

RESULTS

Meristic Values and Variability in the *Pseudotolithus typus* from Epe and Lagos Lagoons

Meristic attributes ranged from 2.00±0.00 (Eye) to 30.80±1.16 cm (Dorsal Fin Rays) in Epe, and 2.00±0.00 (Eye) to 31.03±0.76 (Dorsal Fin Rays) in Lagos lagoon (Table 2). The coefficient of variations of all meristic attributes were <10% and ranged from 3.22 (CFR) to 5.58 (Dorsal Spine) and 2.45 cm (Dorsal Fin rays) to 4.65 (Dorsal Spine) in Epe and Lagos lagoons, respectively. Multiple modes and CV>10% did not occur in any meristic attribute in the populations (Table 2).

Morphometric Values and Variability in the *Pseudotolithus typus* from Epe and Lagos Lagoons

Morphometric attributes varied from 4.25±0.51 (OL) to 28.77±1.54 (HL) in Epe, and 3.52±0.22 (PFW) to 28.35±1.75 (BD) in Lagos lagoon (Table 3). Approximately, 69.32% and 46.15% of the morphometric attributes showed significant heterogeneity (CV>10%) in Epe and Lagos, lagoons, respectively. In Epe, CV>10% occurred in OL, ERH, PFL, CFL, MW, MH, PFW, CPL, and CPW. The PFW (10.56%) was the lowest, while CPL (34.02%) was the highest. In Lagos, CV>10% occurred in OL, ERH, PFL, CFL, MW and MH with PFL (10.02%) being the lowest and MH (12.44) being the highest. Multiple mode occurred in 61.54% and 53.85% of attributes in Epe and Lagos populations, respectively. Multiple mode occurred in OL, CPH, MW, MH, PFL, CPL, BD, and HH in Epe lagoon. Similarly, multiple modes occurred in OL, CPH, MW, MH, HL, ERH, and CFL in Lagos lagoon. Hence, Epe population had significantly higher values for HL, HH, OL, PFL, PFW, CFL, CPH, and CPW, while values were higher in BD, ERH, CPL, and MW for Lagos lagoon population (Table 3).

Predicted Morphometric Attributes in *Pseudotolithus typus* from Epe and Lagos Lagoons

Regression analysis (Tables 4, 5, 6) produced $R^2 = 0.97$ and $R = 0.99$ at $P = 0.00$, as weight (WT) regressed significantly with total length at beta = 28.27 for Epe population. The regression equation is presented below:

$$SL = 28.27 + 0.27TL - 0.16BD - 0.17HL + 0.01HH + 0.07OL - 0.12ERH - 0.10PFL + 0.05PFW - 0.02CFL + 0.01CPL - 0.26CPH - 0.04CPW - 0.09MW - 0.08MH + 0.02WT \quad \ldots\ldots\ldots\ldots (2)$$

For the Lagos population (Tables 7, 8, 9), the morphometric parameters regressed at $R^2 = 0.94$ and $R = 0.97$ and $P = 0.00$, as standard length significantly regressed with total length, with the regression equation:

$$SL = 33.45 + 0.29TL - 0.04BD - 0.26HL - 0.26HH - 0.20OL + 0.39ERH - 0.04PFL - 0.37PFW + 0.04CPL - 0.10CFL - 0.27CPH - 0.36CPW - 0.21MW - 0.16MH + 0.01WT \quad \ldots\ldots\ldots\ldots (3)$$

Morphometric Discreteness of *Pseudotolithus typus* from Epe and Lagos Lagoons

Discriminate analysis (Table 10) showed Epe and Lagos lagoon populations had *apriori* predicted group membership of 100%. However, cross-validation revealed 93.3% and 96.7% correctness of the *apriori* classification for Epe and Lagos groups, as well as, 95.0% correctness for the entire *P. typus* group.

DISCUSSION

Conventionally, the environment modifies the expression of genetic potentials and this ultimately reflects in the structure of phenotypes of such population. In this case, meristic attributes are more conserved and seldom change significantly, except in mutilation and/or genetic-mediated changes. On the other hand, morphological characters are prone to environmental influences and may not always corroborate with genetic variation of the species (Cadrin and Friedland 1999). Morphometric attributes could vary significantly in response to environmental challenges; the extent being influenced by the type of environmental pressure being confronted and the intrinsic potential of the population to adaptively respond through

Table 2. Mean and Coefficient of Variation of the Meristic Attributes of *Pseudotolithus typus* from Epe and Lagos Lagoons, southwestern Nigeria

	Epe		Lagos		
Phenotype	**Mean±SD**	**CV (%)**	**Mean±SD**	**CV (%)**	**P value**
Dorsal Spine	10.03±0.56	5.58	10.33±0.48	4.65	P > 0.05
Dorsal Fin	30.80±1.16	3.77	31.03±0.76	2.45	P > 0.05
AFR	8.20±0.41	5.00	8.00±0.00	N	N
CFR	17.40±0.56	3.22	17.33±0.61	3.52	P > 0.05
PFR	16.70±0.92	5.51	16.90±0.71	4.20	P > 0.05
Pelvic FR	5.07±0.25	4.93	5.00±0.00	N	N
Eye	2.00±0.00	N	2.00±0.00	N	N

Values were not significantly different at p<0.05. N: means not computed.
N indicates cannot be computed because the standard deviations is 0. AFR - Anal fin rays count, CFR - Caudal fin rays count, PFR - Pectoral fin rays count, Pelvic FR- Pelvic fin rays count, Eye - Eye count.

Table 3. Mean and Coefficient of Variation of Morphometric Attributes of *Pseudotolithus typus* from Epe and Lagos Lagoons

	Epe		Lagos		
Phenotype	**Mean±SD**	**CV (%)**	**Mean±SD**	**CV (%)**	**P value**
BD	26.16±1.73	6.61a	28.35±1.75	6.17	P <0.05
HL	28.77±1.54	5.35	27.81±0.94	3.38a	P <0.05
HH	23.75±1.95	8.21a	20.74±1.15	5.54	P < 0.05
OL	4.25±0.51	12.0a	3.72±0.41	11.02a	P < 0.05
ERH	5.68±0.61	10.74	5.77±0.65	11.27a	P < 0.05
PFL	24.06±2.75	11.43a	20.25±2.03	10.02	P < 0.05
PFW	5.40±5.70	10.56	3.52±0.22	6.25	P < 0.05
CFL	16.72±4.38	26.20	14.27±0.84	10.16a	P < 0.05
CPL	14.61±4.97	34.02a	20.44±1.32	6.46	P < 0.05
CPH	8.83±0.57	6.46a	7.72±0.69	8.94a	P <0.05
CPW	7.79±0.88	11.30	6.96±0.48	6.90	P < 0.05
MW	7.44±1.04	13.98a	7.85±0.92	11.72a	P <0.05
MH	8.45±1.65	19.53a	8.44±1.05	12.44a	P < 0.05

a = Multiple modes; Body depth (BD), Head length (HL), Head height (HH), Orbital length (OL), Relative eye height (ERH), Pectoral fin length (PFL), Pectoral fin width (PFW), Caudal fin height (CFL), Caudal peduncle length (CPL), Caudal peduncle width (CPW), Mouth width (MW), Mouth height (MH).

Table 4. Model Summary of Linear Regression of the Phenotypic Descriptors of Morphometric Attributes of *Pseudotolithus typus* from Epe Lagoon (N=30)

Model	R	R Square	Adjusted R Square	S.E.
1	0.986[a]	0.972	0.941	0.483

a. Predictors: (Constant) WT, MH, ERH, CPW, CFL, BD, MW, PFW, OL, HL, CPH, CPL, HH, PFL and TL

Table 5. ANOVA of Linear Regression of the Phenotypic Descriptors of Morphometric Attributes of *Pseudotolithus typus* from Epe Lagoon (N=30)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	112.12	15	7.48	31.99	0.00[b]
	Residual	3.27	14	0.23		
	Total	115.39	29			

a. Dependent Variable: SL

b. Predictors: (Constant) WT, MH, ERH, CPW, CFL, BD, MW, PFW, OL, HL, CPH, CPL, HH, PFL and TL

Table 6. Coefficient of Regression for the Morphometric Attributes of *Pseudotolithus typus* from Epe Lagoon (N=30)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	28.27	4.54		6.23	0.00
	TL	0.27	0.16	0.27	1.64	0.12
	BD	-0.16	0.10	-0.14	-1.5	0.13
	HL	-0.17	0.11	-0.13	-1.62	0.13
	HH	0.01	0.10	0.01	0.07	0.95
	OL	0.07	0.35	0.02	0.20	0.84
	ERH	-0.12	0.32	-0.04	-0.36	0.73
	PFL	-0.10	0.08	-.014	-1.25	0.23
	PFW	0.05	0.03	0.14	1.75	0.10
	CFL	-0.02	0.04	-0.05	-0.67	0.51
	CPL	0.01	0.04	0.03	0.25	0.81
	CPH	-0.26	0.28	-0.07	-0.90	0.38
	CPW	-0.04	0.18	-0.02	-0.23	0.83
	MW	-0.09	0.14	-0.05	-0.61	0.55
	MH	-0.08	0.07	-0.07	-1.09	0.30
	WT	**0.02**	**0.01**	**0.44**	**3.37**	**0.01**

Dependent Variable: Standard length (SL)

Table 7. Model Summary of Linear Regression of the Phenotypic Descriptors of Morphometric Attributes of *Pseudotolithus typus* from Lagos Lagoon (N=30)

Model	R	R Square	Adjusted R Square	S.E.
1	0.97[a]	0.94	0.88	0.37

a. Predictors: (Constant) WT, MW, CPW, BD, PFW, CPH, OL, MH, HL, CPL, TL, PFL, ERH, HH and CFL

Table 8. ANOVA of Linear Regression of the Phenotypic Descriptors of Morphometric Attributes of *Pseudotolithus typus* from Lagos Lagoon (N=30)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.23	15	2.15	15.14	0.00[b]
	Residual	1.95	14	0.14		
	Total	34.18	29			

a. Dependent Variable: SL

b. Predictors: (Constant) WT, MW, CPW, BD, PFW, CPH, OL, MH, HL, CPL, TL, PFL, ERH, HH and CFL

Table 9. Coefficient of Regression for the Morphometric Attributes of *Pseudotolithus typus* from Lagos Lagoon (N=30)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	33.45	5.25		6.38	0.00
	TL	**0.29**	**0.10**	**0.34**	**2.93**	**0.01**
	BD	-0.04	0.07	-0.06	-0.58	0.57
	HL	-0.26	0.14	-0.22	-1.89	0.08
	HH	-0.26	0.17	-0.28	-1.60	0.13
	OL	-0.20	0.32	-0.08	-0.62	0.54
	ERH	0.39	0.23	0.23	1.72	0.11
	PFL	-0.01	0.08	-0.03	-0.16	0.88
	PFW	-0.37	0.48	-0.08	-0.77	0.46
	CPL	0.04	0.14	0.03	0.29	0.78
	CFL	-0.10	0.15	-0.12	-0.65	0.53
	CPH	0.27	0.19	0.17	1.39	0.19
	CPW	-0.36	0.28	-0.16	-1.27	0.23
	MW	-0.21	0.15	-0.18	-1.40	0.18
	MH	-0.16	0.10	-0.16	-1.59	0.14
	WT	0.01	0.01	0.20	1.63	0.13

Dependent Variable: Standard length (SL)

Table 10. Canonical Discriminant Classification for *Pseudotolithus typus* from Epe and Lagos Lagoons

		Source	Predicted Group Membership		Total
			Epe	Lagos	
Original	Count	Epe	30	0	30
		Lagos	0	30	30
	%	Epe	100	0.0	100.0
		Lagos	0	100.0	100.0
Cross-validated[b]	Count	Epe	28	2	30
		Lagos	1	29	30
	%	Epe	93.3	6.7	100.0
		Lagos	3.3	96.7	100.0

a. 100% of original grouped cases correctly classified

b. Cross-validation is done only for those cases in the analysis. Each case is classified by the functions derived from all cases other than that case.

c. 95.0% of cross-validated grouped cases correctly classified.

the flexibility of their morphometric attributes. The findings revealed that while the meristic attributes were similar, the morphometric attributes significantly differed across the population, despite similar mean values.

There were many heterogeneous morphometric sites across the two locations. This trend of variation in heterogeneity of morphometric traits may have been contributed mostly by the high differences in the CV and the occurrence of multiple modes rather than the differences in the mean values. Specifically, the CV>10% occurred in 69.32% and 46.15% of morphometric attributes in Epe and Lagos lagoons, respectively. In the same vein, multiple modes occurred in 61.54% and 53.85% of the attributes in the Epe and Lagos lagoon populations, respectively. This infers that *P. typus* was highly heterogeneous/flexible in its morphometric attributes across the habitats. This adaptive flexibility could be responsible for its survivability in the habitats.

Phenotypic variability is expected to be similar within species while habitat differences could trigger differential phenotypic responses and subsequent phenotypic variability within a species. In the current study, the trend of plastic/heterogeneous attributes varied across *P. typus* populations in Epe and Lagos lagoons, with different attributes varying in the habitats despite being the same species. The CPL was most varied (34.02%) in Epe; while MH (12.44) had the highest variation in Lagos, indicating differential morphological responses of same species at these habitats. This trend could imply that the environmental condition at the habitats were likely different, hence the most varied attributes were the most expressed. This could also be linked to the nature of the prevailing environmental challenge in the habitats, to which all attributes may have responded with their plastic capabilities, with the most affected attributes showing the greatest coefficient of variability in each habitat.

Significant variation in Mouth Height (MH) could be a response to variation in availability and size of prey, an indication of nutritional issues in Lagos lagoon. It should be noted that at similar mean values, though CV was greatest in MH among analysed morphometrics in Lagos Lagoon, the CV of MH in Epe was higher (19.53%) than Lagos Lagoon (12.44%) and the value across the habitats were multi-modal. This implies both locations probably had food variation related issues with the most challenging situation at the Epe Lagoon. *Pseudotolithus typus* is generally classified as an omnivore or predator feeding mainly on aquatic insects, fish and plant debris (Awotunde, 2021). Anyanwu, and Kusemiju (1990) reported crustacean, molluscs and diverse fish species in the stomach of the species in Lagos. Bachok *et al*. (2004) reported *Pseudotolithus typus* could utilize various kinds of food resources in their habitat and the inherent ability of the species to expand their food items (Awotunde, 2021). Hence, *P. typus* can diversify its food; an adaptive trait for coping with varied food conditions. Fishes are capable of changing their gut morphology in response to available food resources and demonstrate high degree of plasticity (Awotunde, 2021). The significant variation in the MH would possibly coexist with variation of the gut morphology in *P. typus* in response to food conditions across the habitats. Although not included as a variant in the current study, the species would also have flexible gut morphology to cope with diverse food items across habitats.

The caudal peduncle is a morphologic attribute linked to maneuvering and possibly indicating variation in hydrodynamic conditions (Oyebola, 2015). The higher variation in caudal peduncle length at Epe lagoon suggests relatively more hydrodynamics than at Lagos lagoon. The fish species possibly require more maneuvering using the caudal peduncle in Epe Lagoon; indicating a key area for management and conservation of fisheries in this Lagoon.

The *P. typus* from Epe and Lagos lagoons demonstrated heterogeneity (CV>10%) in OL, ERH, PFL, CFL, MW and MH indicating these attributes are under significant environmental variation in both habitats. In addition to the earlier listed heterogeneous morphologic attributes, the Epe population was also heterogeneous in pectoral fin width (PFW), caudal peduncle length (CPL) and caudal peduncle width (CPW) indicating possible significant pressure probing the morphologic responses in these attributes in the habitat. These three heterogeneous attributes are also linked to swimming maneuver in which the pectoral fin is usually utilized for steering in coordination with the caudal peduncle and subsequent movement of the caudal fin.

According to McHenry and Lauder (2006), locomotors in fish may disproportionately increase in span owing to hydrodynamic changes. Hence, variation in the three locomotion-related traits revealed that variation in functional traits for movement could be one of the main survival strategies of the species against fluctuations in water condition of the hydrodynamic environment. Significant variation in locomotion related traits was also demonstrated in African catfish, *Clarias gariepinus* in a hydrodynamic water condition with implications on sub-species (Oyebola, 2015). Similar to the variation in locomotion traits in the hydrodynamic habitat, the Epe population is possibly being pressured to maneuver unstable swimming patterns in response to possible variations in the habitat's hydrodynamic conditions. The situation possibly persists in Epe and Lagos lagoons; however, the environmental pressure would be deeper in Epe compared to the Lagos Lagoon. Specifically, the Epe population was more heterogeneous in HL, HH, OL, PFL, PFW, CFL, CPH and CPW, while variability values were higher only in BD, ERH, CPL, and MW in Lagos, indicating the Epe population is more environmentally pressured. Interestingly, *P. typus* demonstrated adaptive phenotypic flexibility in both cases. This attribute may highlight the adaptive nature that has allowed the relative availability of the species in habitats while its close relative (*P. senegalensis)* is currently threatened.

Measurements on morphometric characters are useful for predicting organismal response to environmental variation (Santos *et al.*, 2011). Traditionally, the strength of predictive taxonomic characters is consistent or stable, despite varied conditions. The availability of predictive morphometric traits may be difficult in morphologically heterogeneous population structures, where frequency of significant predictive attributes would be low. In agreement with this, only weight and total length significantly predicted the regression equations for the respective Epe and Lagos Lagoon populations. This is in congruence with the trend of occurrence of high morphologic heterogeneity/plasticity of the population.

Nonaka *et al.* (2015) reported that morphologic plasticity promotes reproductive isolation and ultimately, speciation in populations that forage on two or more resources. Morphologic plasticity contributes to early stages of speciation, prior to genetic divergence, by facilitating fast phenotypic divergence.

In this study, discriminant factor analysis supported 95%, 96.7% and 93.3% correctness of the taxonomic sanctity of the entire, Epe and Lagos populations at cross-validation. This indicate that although a high level of phenotypic heterogeneity/plasticity and divergence occurred, the concept of new species or speciation can be ruled out. The extent of the expressed plasticity has not resulted in the formation of a new species. Therefore, the Epe and Lagos lagoon populations are possibly residing in different habitats, and their morphologies are responding differently, possibly due to the prevailing differential environmental conditions. The phenotypic variability of the population and their spatial differences have not induced significant taxonomic divergence to create a new species. However, the *P. typus* demonstrated the capability of flexibility to possibly cope in different lagoon systems.

CONCLUSION

The morphometric and meristic data revealed taxonomic sanctity for *Pseudotolithus typus* across the Epe and Lagos Lagoons. The population had highly flexible attributes within and across habitats indicating adaptive tendencies to survive in lagoon habitats. The morphological flexibility is probably its adaptive trait for survival and the identified morphologic predictors could be useful for their delineation across the lagoons.

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