



Morphometric Variations of Nile Tilapia (*Oreochromis niloticus*) (Linnaeus, 1758) (Perciformes, Cichlidae) Collected from Three Rift Valley Lakes in Ethiopia

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Abstract

The pattern of morphometric differentiation among three populations of Tilapia (*Oreochromis niloticus*) sited in Koka, Ziway, and Langano lakes in the Ethiopian rift valley was examined. Morphometric differentiation was examined, compared and quantified by the use of twelve different body measurements in 391 specimens to generate baseline information for conservation and product improvement plans. The result revealed that comparisons of mean values of morphometric measurements in the three studied tilapia populations statistically significant differences ($P < 0.05$). The Fulton's condition factor (K) of *Oreochromis niloticus* samples collected from Lakes Koka, Ziway, and Langano was 1.48, 1.2, and 0.66, respectively. The Discriminant Function Analysis performed on seven variables led to a correct classification in 90.5 % of cases. Differences observed between samples in this study indicated that there is important morphometric variation between the studied tilapia populations. Plotting the two significant canonical discriminant functions separated the Lake Langano population from the other two.

INTRODUCTION

Tilapia is the second most cultured fish species in the world next to carp (Zhou *et al.*, 2015). It is considered as the ideal fish species for aquaculture mainly due to its rapid growth, high fecundity, ability to resist poor water quality, and good performance under sub-optimal nutritional conditions (Hassanien *et al.* 2011; Hasan and Tamam, 2019; Hasan *et al.*, 2019).

In Ethiopia, Tilapia is an important commercial fish species, distributed in all the rift valley lakes and some other high land lakes and rivers (Mengesha, 2015; Golubtsov and Mina, 2003). It contributes more than 50% of the total landings of fish

caught per year in Ethiopia (Tesfaye and Wolff, 2014) and is considered the most edible fish species (Janko, 2015). The aquatic genetic resources management considers several activities that should be performed in every water body depending on the fish species and nature of the geographic locations. The identification of threats and morphological and/or molecular characterizations come first when conservation is proposed.

Morphological variation is a necessity for taxonomic identity, population differentiation, and genetic diversity assessment for the effective management of fisheries resources. Its

existence among populations indicates that there might be genetic or/and non-genetic (environmental) factors and their interactions resulting in a unique population structure in each water body. According to Naeem and Salam (2005), morphometric and meristic studies of animals are part of the vigorous tools for measuring the discreteness of the same species.

Characterization of *O. niloticus* based on morphometric and meristic variables have also been reported elsewhere (Mert and Cicek, 2010; Yakubu and Okunsebor, 2011; Nazrul *et al.*, 2011; Samaradivakara *et al.*, 2012; Hockaday *et al.*, 2000; Espinosa-Lemus *et al.*, 2009; Hassanien *et al.*, 2011; Naeem *et al.*, 2011). Research work on the morphometric characterization of fish in Ethiopia is not very common. This study is therefore planned to quantify and compare the possible morphometric variations between *O. niloticus* populations from three rift valley lakes in Ethiopia. It also aimed to generate baseline information for further product improvement and conservation plans.

METHODOLOGY

Place and Time

This research was conducted for a month at the three main rift valley lakes

(Koka, Ziway and Langano) of Ethiopia in 2019/ 2020. Lake Koka (Latitude 08°24'0" N, Longitude 39°35'0" E) is formed as a result of damming of the Awash River for hydropower in the late 1960s. The surface area of the lake is 250 km² with a maximum and mean depth of 14 m and 9 m, respectively (LFDP, 1997). It is located at an altitude of 1,590 m above sea level.

The region around Lake Koka has a total average annual rainfall of about 630 mm and an average surface water temperature of 19 °C (averaged for the period between 1998 and 2009) (Mesfin, 2009). Lake Ziway is a freshwater lake. It is 31 km long and 20 km wide and has a surface area of 440 km² and a maximum depth of 9 m (Awulachew *et al.*, 2007). Lake Ziway is situated between 7°51' to 8°07' N and 38°43' to 38°56' E with an altitude of 1636 m above sea level (Merga *et al.*, 2020). Lake Langano is situated at 037°55.423 N, 05°94.541 E, with an altitude of 1110 m (Hirut *et al.*, 2019). It has a surface area of 230 km² and a maximum depth of 46 m. It contains reddish-brown water attributable to the quantity of iron-containing silt compounds (Talling and Talling, 1965; Wood and Talling 1988). The study areas were mapped with ArcGIS and given in Figure 1.

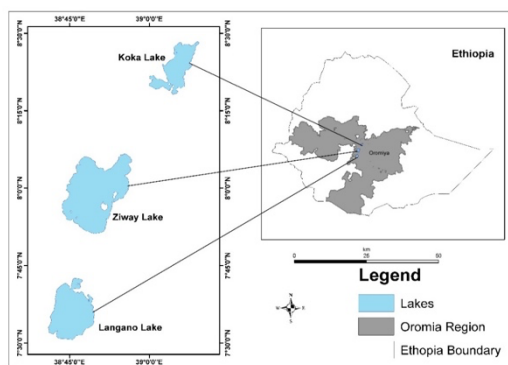


Figure 1. Map of the study.

Research Materials

The tools used in this research were scale (cm) and digital balance (g). The materials used in this research were 391

O. niloticus fish samples obtained from fishermen at landing sites along the lakes (Ziway, Langano, and Koka).

Research Design

This study was conducted by taking 12 different body measurements of tilapia fish samples (*O. niloticus*) collected from the three main rift valley lakes of Ethiopia.

Work Procedure

Sample Collections and Measurements of Morphometric Variables

O. niloticus fish samples were obtained from fishermen at landing sites along the lakes (Ziway, Langano, and Koka). A total of 391 specimens of *O. niloticus* (Figure 2) were obtained and

taken to the nearby laboratory of the Batu Fish and Other Aquatic Life Research Centre for morphometric analyses.

A total of 12 morphometric characters were measured using a centimeter scale to the nearest centimeter and body weights were measured using a digital balance to the nearest gram. The morphometric measurements were Total length (TL), Standard Length (SL), Body depth (BD), Pre-orbital length (POL), Pre-pectoral length (PPCL), Pre-pelvic length (PPLL), Pre-dorsal length (PDL), Pre-anal length (PAL), Caudal height (CH), Head length (HL), Eye Diameter (ED), Bodyweight (W).

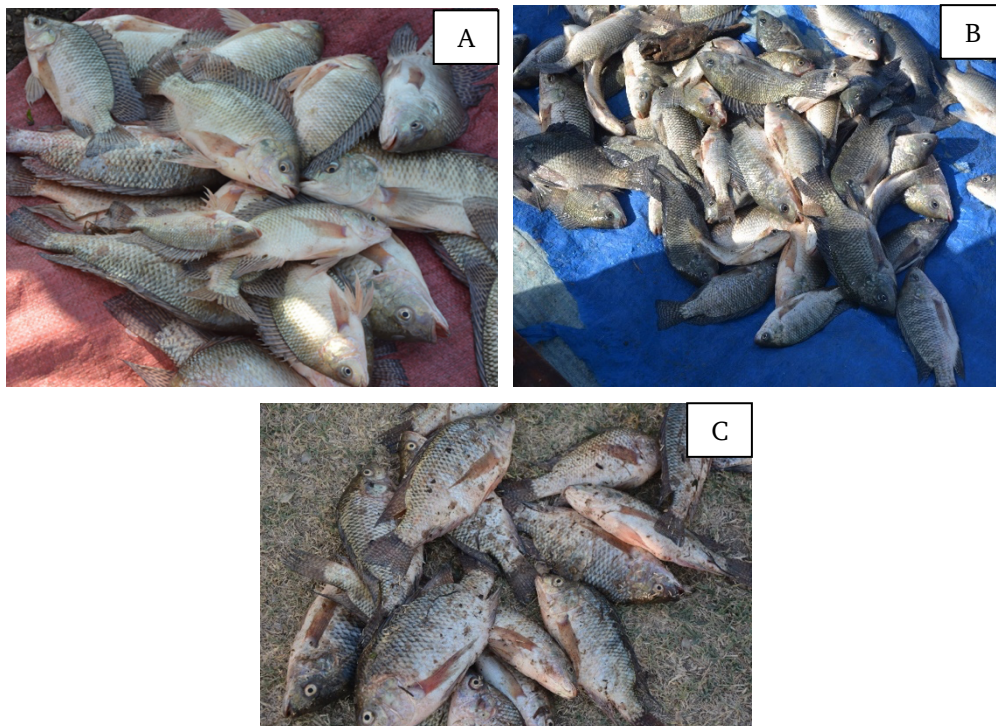


Figure 2. Photos of *O. niloticus* from the study areas (A = Koka, B = Langano, C= Ziway).

Data Analysis

All statistical analyses were performed using SPSS Version 23 and Microsoft excel. All morphometric measurements were divided by standard length (SL) of each fish to correct size-dependent variation in morphometric characters (Elliott and Hurley, 1995) before conducting any further statistical analysis. The samples were categorized into three groups/populations based on

the water body they were caught vis., group I Ziway population (N=130), group II Koka population (N=132), and group III Langano population (N=129) for convenience of interpretation.

An equation in the form of $W = aL^b$ (which was transformed to the logarithm of the form $\text{Log } W = \text{Log } a + b\text{Log } L$), where W is the bodyweight of fish in grams, L is the total length in centimeters, 'a' is the intercept and 'b' is the slope of the regression line was used to calculate the

relationship between length (L) and weight (W) of fish (Wootton, 1990) in each population. The relationship between the length (L) and weight (W) of a fish is usually expressed by the equation $W=aL^b$, where 'a' is the intercept and 'b' is the allometry coefficient.

Values of the exponent 'b' provide information on fish growth. When 'b' = 3, increase in weight is isometric. When the value of 'b' is other than 3, the weight increase is allometric (positive if 'b' >3, negative if 'b' <3). This is a useful tool that provides important information concerning the structure and function of fish populations (Anderson, 1996).

The correlation coefficients between transformed variables and standard length were calculated to check if the data transformation was effective in removing

the effect of size in the data. The Fulton Condition factor (K) was also calculated for each population using the formula $K=W/L^3 \times 100$ (Bagenal and Tesch, 1978): where K is the condition factor, W is the bodyweight of fish in grams, and L is the total length in centimeters. Data obtained were subjected to factor analysis using Discriminant Function Analysis (DFA) and a distribution graph was generated using SPSS Version 23.

RESULTS AND DISCUSSION

Morphometric Characters

The descriptive data of all measured morphometric characters (after divided by standard length) comprising mean values, standard deviations, and coefficient of variation (CV) are presented in Table 1.

Table 1. Descriptive data of *O. niloticus* sampled from Lakes Ziway, Langano, and Koka.

Morpho- metric Characters	Koka Reservoir (N=132)			Lake Ziway (N=130)			Lake Langano (N=129)			All data		
	Mean	SD	CV %	Mean	SD	CV %	Mean	SD	CV %	Mean	SD	CV %
SL (cm)												
TL (cm)	1.31	0.028	2.19	1.32	0.0586	4.41	1.36	3.65	2.67	1.33	0.048	3.62
	39	84		72	0		58	0		51	39	
PDL (cm)	0.37	0.021	5.67	.367	0.0214	5.84	0.39	2.49	6.27	0.37	0.026	6.87
	20	09		8	7		80	5		90	06	
HL (cm)	0.32	0.013	4.15	.329	0.0164	4.98	0.34	2.00	5.86	0.33	0.018	5.47
	51	51		5	2		22	5		23	18	
POL (cm)	0.09	0.021	22.82	.090	0.0135	14.9	0.09	0.89	9.74	0.09	0.015	16.36
	32	27		8	3		14	0		21	07	
PPL (cm)	0.31	0.026	8.55	.320	0.0188	5.89	0.33	1.99	5.88	0.32	0.024	7.57
	30	76		0	4		84	1		39	51	
PPLL (cm)	0.38	0.020	5.36	.392	0.0211	5.39	0.41	2.12	5.14	0.39	0.024	6.14
	36	57		1	2		43	8		66	34	
PAL (cm)	0.73	0.029	4.06	.755	0.0328	4.34	0.74	2.82	3.78	0.74	0.030	4.14
	80	98		5	3		52	0		57	89	
BD (cm)	0.44	0.021	4.82	.442	0.0260	5.89	0.41	2.66	6.44	0.43	0.027	6.44
	08	26		6	5		31	0		21	84	
ED (cm)	0.08	0.011	14.45	.079	0.0092	11.61	0.08	1.14	13.43	0.08	0.010	13.23
	04	62		2	0		53	6		16	81	
CH (cm)	0.18	0.024	13.57	.180	0.0236	13.13	0.17	2.76	15.73	0.17	0.025	14.09
	13	60		2	6		60	8		90	22	
W (g)	11.3	2.625	23.18	9.76	3.7215	38.12	6.42	159.	24.77	9.18	3.450	37.56
	258	20		22	5		42	126		84	93	

Among the morphometric characters, weight (W), TL, and PAL showed high values in all the populations. The age of fish was not considered in the

analysis as there was a high similarity in total and standard length. Besides, the coefficient of variation of these variables

was less than 4%, which indicated that the age of the sampled fish was very similar.

According to Yakubu and Okunsebor (2011), the size of fish is more important than its age, mainly because several factors in taxonomy, ecology, and physiology are more size-dependent than age-dependent. In this study, there was no significant difference between morphometric variables between males and females in all the sampled populations, so the effect of sex was not considered further in the analysis.

In the same way as this result, sex demonstrated a negligible effect on

morphometric variables (Turan *et al.*, 2005). Because of the very high genetic correlation between the expressions of body traits in the two sexes, Nguyen *et al.* (2007) also concluded that there was no need to treat trait expressions in the two sexes as different traits.

The result also showed a very high value of the coefficient of variation (between 23% and 38%) of body weight among the fish samples of the three populations. The mean values of all the recorded phenotypic variables were checked if they vary significantly in each population (Table 2).

Table 2. Means* ± S.D. of morphometric variables of three *O. niloticus* populations.

Variables	Koka Reservoir	Lake Ziway	Lake Langano
TL	1.3137 ^a ± 0.02885	1.3267 ^b ± 0.05862	1.3656 ^c ± 0.03660
PDL	0.3718 ^a ± 0.02074	0.3674 ^a ± 0.02134	0.3980 ^b ± 0.02483
HL	0.3253 ^a ± 0.01321	0.3293 ^a ± 0.01628	0.3426 ^b ± 0.01983
POL	0.0937 ^a ± 0.02096	0.0912 ^a ± 0.01279	0.0912 ^a ± 0.00857
PPCL	0.3133 ^a ± 0.02691	0.3201 ^b ± 0.01863	0.3385 ^c ± 0.01984
PPLL	0.3836 ^a ± 0.02001	0.3921 ^b ± 0.02108	0.4143 ^c ± 0.02089
PAL	0.7380 ^a ± 0.02973	0.7554 ^b ± 0.03288	0.7438 ^a ± 0.02746
BD	0.4401 ^a ± 0.02102	0.4428 ^a ± 0.02601	0.4132 ^c ± 0.02619
ED	0.0805 ^a ± 0.01116	0.0792 ^a ± 0.00861	0.0852 ^c ± 0.01154
CH	0.1807 ^a ± 0.02432	0.1805 ^a ± 0.02323	0.1757 ^a ± 0.02781
W	11.3252 ^a ± 2.62533	9.7617 ^b ± 3.72141	6.4243 ^c ± 1.59111

Note: Means in the same row followed by different letters are significantly different (P < 0.05).

The same result showing the impact of environmental variations on the morphometric and meristic differences of fish was reported by other authors (Akinrotimi *et al.*, 2018; Alkinson and Sibly, 1997; Eyo, 2003; Fagbuaro, 2015; González *et al.*, 2016; Jin *et al.*, 2007; Kara *et al.*, 2011; Liao *et al.*, 2006; Scheiner, 1993). A very high morphological plasticity in fish can be caused by environmental conditions such as food abundance and temperature (Beacham, 1990; Eyo, 2003; Scheiner, 1993). According to Ezeafulukwe *et al.* (2015), morphological plasticity due to environmental variability is commonly found among many fish species, predominantly in freshwater fish species.

After data standardization according to Elliott and Hurley (1995), body weight (W) showed a very high value of the coefficient of variation (between 23% and

38%). There was a significant ($p < 0.05$) difference in weight among the fish samples collected from the three water bodies. Samples from Lake Koka displayed a higher mean value (11.3258 ± 2.62520 gm). The ratio of POL/SL also showed a high value (22%) of coefficients of variation. Moreover, ratios of ED/SL and CH/SL showed roughly a coefficient of variation between 10 and 15%. All other morphometric characters showed a coefficient of variation lower than 10%.

All the coefficients of variation of different morphometric characters were significantly (P < 0.05) different between populations. The mean W/SL ratio was 9.19. The mean ratios of TL/SL and PAL/SL represented 1.33 and 0.74, respectively. The ratios of TL/SL, PDL/SL, HL/SL, PPCL/SL, PPLL/SL, PAL/SL, and BD/SL showed a coefficient of variation lower than 10%; ratios POL/SL, ED/SL,

and CH/SL showed a coefficient of variation between 10 and 20%, while the ratio of W/SL showed a coefficient of variation greater than 20%.

Among populations, the W/SL and POL/SL in Koka reservoir and PAL/SL and BD/SL in Lake Ziway were significantly ($P < 0.05$) higher. The ratios TL/SL, PDL/SL, HL/SL, PPCL/SL, PPLL/SL, and ED/SL were significantly ($P < 0.05$) higher in the Lake Langan population. Based on these relationships, fish from Lake Langan were significantly ($P < 0.05$) more profound at the cranial level than Lakes Koka and Ziway populations that are profound at the caudal level, which is in line with the work of Turan *et al.* (2006) who reported that differences between populations of Tilapiine species were reflected mostly in head measurement.

In the same manner, a significant variation in the eye diameter, dorsal fin ray, caudal peduncle depth, and left gill raker of *Sarotherodon galileus* from three man-made lakes (Oyewunmi *et al.*, 2014), body depth and caudal peduncle length as the discriminating characters in *Sarotherodon melanotheron* from three different Creeks in River State (Akinrotimi *et al.*, 2018) and the head length, body depth, and caudal peduncle width are reported by Ezeafulukwe *et al.* (2015) to be discriminating characters between *Coptodon zilli* from the wild and that of the ponds. The head length, total length, body weight, standard length, and pre-pelvic distance as the discriminating characters in *Coptodon zilli* from three major dams in Southwestern Nigeria was reported by Fagbuaro (2015).

Morphometric measurements can be used for species identification, hence a

univariate analysis of twelve measurements expressed as percentages of the standard length of fish was performed. Most of the morphometric mean values of *O. niloticus* from the three populations were significantly ($P < 0.05$) different from each other. Fish from Lake Koka was heavier (weight) than those coming from both Ziway and Langan lakes, and the difference is significant ($P < 0.05$). Furthermore, TL, PPCL, and PPLL were also significantly ($P < 0.05$) different in each population. Besides, the Langan population is significantly ($P < 0.05$) different on PDL, HL, BD, and ED from the other two populations.

The fish samples collected from Lake Ziway are significantly ($P < 0.05$) different from Koka and Langan only in PAL. However, there is no significant difference in POL and CH between the three populations. This result is in line with the research results of Samaradivankara *et al.*, (2012) who delineated Tilapia samples from Reservoirs in Sri Lanka into four groups using morphological methods.

Length-Weight Relationship

The length-weight relationship of the collected fish samples was calculated based on the logarithmic transformation of the data. The parameter 'b' of the fish studied ranged from a minimum of 3.07 to a maximum of 3.1686, with a mean value of 3.11. The regression slope of all three populations was greater than 3 indicating that the fish had positive allometric growth. The length-weight relationship equations and their parameters were given in Table 3.

Table 3. Length-weight relationship equations and their parameters.

Population	Equation	'b'	Coefficient of Determination (r^2)
Koka	$\text{Log } W = 3.1686 \text{Log } TL - 2.0088$	3.1686	0.9563
Ziway	$\text{Log } W = 3.097 \text{Log } TL - 1.9161$	3.097	0.8733
Langan	$\text{Log } W = 3.0738 \text{Log } TL - 1.9507$	3.0738	0.9643

The length-weight relationship of the samples of *O. niloticus* was calculated based on the logarithmic transformation

of the data. It provides important information concerning the structure and function of fish populations. In the current

study, the length and weight relationship of *O. niloticus* were high ($r^2 = 0.9563$, $r^2 = 0.8733$, and $r^2 = 0.9643$ at Lakes Koka, Ziway, and Langano, respectively). It was significant at the 0.01 level and indicated that the bodyweight of this species increases as the total length increase. The same high r^2 value was also reported for other fish species in different water bodies (Dalu *et al.*, 2013; Ndiaye *et al.*, 2015; Saha *et al.*, 2019).

According to Kleanthidis *et al.* (1999), the concept of cube law hypothetically suggested that the value of 'b' for an ideal fish needs to be 3.0, which represents an isometric growth. In this study, the value of regression coefficient 'b' of the fish samples from Lakes Koka, Ziway, and Langano was 3.1686, 3.097, and 3.0738, respectively with no fish population exhibiting an isometric ($b=3$) relative growth, which doesn't maintain their specific body shape throughout their life. Fish undergoing positive allometric growth is an indication of the stoutness of the body with an increase in length. *O. niloticus* at all three lakes had a positive allometric growth pattern as the value of regression coefficient 'b' was greater than 3 for all.

Thus, the weight of the fish was higher as compared to the cube of its length. The estimated length-weight coefficient (b) value of *O. niloticus* in this study is within the range of 'b' values in tropical fishes ($b=2.5-3.5$) (Pauly and Gayanilo, 1997) and almost the same as the 'b' value reported before for Lake Ziway ($b=3.11$) (Tadesse, 1997), and Lake Koka ($b= 3.0541$). A 'b' value of 3.026 for *O. niloticus*, which is within the same range as this result, was also reported by Kosai *et al.* (2014). The variation in the value of 'b' happens due to season, habitat, gonad maturity, sex, diet, stomach fullness, health, preservation techniques, and annual differences in environmental conditions (Bagenal and Tesch, 1978; Froese, 2006).

The Fulton's Condition Factor (K)

The Fulton's condition factor expresses the degree of the wellbeing of fishes in their habitat. In this study, it was calculated to be 1.48, 1.2, and 0.66 for a fish population of Lake Koka, Lake Ziway, and Lake Langano, respectively.

Fulton's condition factor (K) is defined as the wellbeing of fish and is strongly influenced by both biotic and abiotic environmental conditions. It can be used as an index to assess the status of the aquatic ecosystem in which fish lives (Nazeef and Abubakar, 2013). In the current study, Fulton's condition factor (K) of *O. niloticus* samples collected from Lakes Koka, Ziway, and Langano were 1.48, 1.2, and 0.66, respectively.

The lake Langano population showed the least value of condition factor indicating the possible existence of continuous environmental pressure, and/or less presence of phytoplankton and zooplankton, which are the most important food in the fish diet in the lake.

A condition factor of the same fish species in Lake Langano was reported as 1.67 (Tadesse, 1999). The relatively high condition factor in Lakes Koka and Ziway might be caused by the environmental differences that exist between these water bodies and Lake Langano. Fulton's condition factor for the same species in different water bodies in Ethiopia was reported: Lake Abaya, 1.43 (Berhan, 2016), Lake Hayq, 1.81 (Tessema *et al.* 2019), Lake Tana, 2.29 (Tadesse, 1999), Lake Chamo, 2.23 (Teferi and Admassu, 2002). A higher value of condition factor is correlated with high energy content, adequate food availability (high phytoplankton and zooplankton), reproductive potential, and favorable environmental conditions (Paukert and Rogers, 2004).

Relationships Between Morphometric Variables

The correlation coefficients between transformed morphometric traits and standard length were calculated for all

individuals in the three populations (Table 4) to check if the data transformation was effective in removing the effect of size. The

pairwise comparisons revealed significant positive as well as negative correlations between the morphometric variables.

Table 4. Correlations between morphometric variables of *O. niloticus*.

	TL	PDL	HL	POL	PPCL	PPLL	PAL	BD	ED	CH	W
TL	1										
PDL	0.408** 0.000	1									
HL	0.399** 0.000	0.618**	1								
POL	0.021 0.680	0.147** 0.004	0.241** 0.000	1							
PPCL	0.367** 0.000	0.395** 0.000	0.507** 0.000	0.164** 0.001	1						
PPLL	0.439** 0.000	0.367** 0.000	0.380** 0.000	0.044 0.383	0.556** 0.000	1					
PAL	0.316** 0.000	0.066 0.194	0.187** 0.000	-0.018 0.726	0.231** 0.000	0.319** 0.000	1				
BD	0.068 0.179	-0.101* 0.047	-0.122* 0.016	0.115* 0.023	-0.099 0.050	-0.135** 0.007	0.211** 0.000	1			
ED	0.326** 0.000	0.452** 0.000	0.530** 0.000	0.132** 0.009	0.287** 0.000	0.158** 0.002	0.110* 0.029	-0.048 0.341	1		
CH	0.037 0.467	0.071 0.164	0.083 0.100	0.119* 0.019	0.009 0.864	-0.064 0.206	0.010 0.848	0.169** 0.001	0.094 0.064	1	
W	- 0.451** 0.000	- 0.395** 0.000	- 0.390** 0.000	0.021 0.674	-0.418** 0.000	-0.417** 0.000	-0.153** 0.002	0.269** 0.000	-0.450** 0.000	0.119* 0.019	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Discriminant Function Analysis

In this study, seven characters were selected by stepwise DFA on morphometric data from three *O. niloticus* stocks. The characters selected on fish were total length (TL), pre-dorsal length

(PDL), pre-pelvic length (PPLL), pre-anal length (PAL), body depth (BD), eye diameter (ED), and weight (W). The analysis of the morphometric variables produced two significant discriminant functions (Table 5).

Table 5. Standardized canonical discriminant function coefficients for morphometric traits (Log transformed) of three Nile Tilapia populations.

Traits	Functions	
	1	2
TL	-1.182	1.096
PDL	-.833	1.227
PPLL	-1.046	.172
PAL	1.014	-1.273
BD	1.370	-.215
ED	.232	.578
W	1.083	-.760
Eigenvalue	1.765 ^a	.186 ^a
% of variance	90.5	9.5
Cumulative %	90.5	100

a. First 2 canonical discriminant functions were used in the analysis.

The first function accounted for 90.5% of the variance and the second function 9.5% in the data. The larger the Eigenvalue, the more of the variance in the dependent variable is explained by that function. The bivariate plot of the two canonical functions separated the Lake Langano population (a negative sector) from the Lakes Koka and Ziway populations (a positive sector) (Figure 3).

The canonical discriminant function 1 and canonical discriminant function 2

were plotted to allow visual examination of the distribution of each sample along the CF axis that showed a clear between-sample differentiation (Figure 3). In the discriminant space, the Lake Langano samples were mostly isolated from all other samples. According to the canonical discriminant function coefficients obtained for morphometric data, the most influential variables for function 1 were PAL, BD, ED, and W.

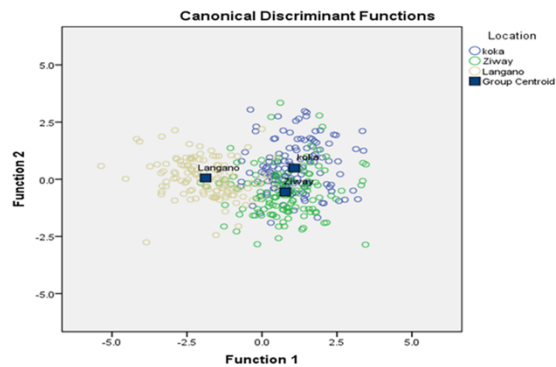


Figure 3. Scatter plot of the two canonical discriminant functions from analysis of morphometric traits for Nile Tilapia stocks.

The overall random assignment of individuals into their original group was high (72.9%) (Table 6). The proportion of individuals correctly classified into their

original group, i.e., Lake Langano, Lake Koka, and Lake Ziway was 88.4%, 66.4%, and 66.2%, respectively.

Table 6. Direct and percentage of grouped cases correctly classified into their original population.

		Classification Results ^a				
		Location	Predicted Group Membership			Total
			Koka	Ziway	Langano	
Original	Count	Koka	85	43	4	132
		Ziway	33	86	11	130
		Langano	3	12	114	129
	%	Koka	64.4	32.6	3.0	100.0
		Ziway	25.4	66.2	8.5	100.0
		Langano	2.3	9.3	88.4	100.0

a. 72.9% of original grouped cases correctly classified.

The pairwise comparisons of transformed morphometric traits and standard length revealed significant positive as well as negative correlations. The result showed that the size effect was almost eliminated in the populations during analysis for instance expressed by the negative correlation of weight and the

total length, which shows the impact of size on the morphometric variables are perfectly minimized by dividing all the variables by standard length. The morphometric relationships among different body parts of the fish can be used to determine possible differences between

separated populations of the same species (Austin *et al.*, 2008).

The Langanu fish morphological measurements have highly deviated from the samples from the other two lakes. This high deviation might be related to the difference in the water chemistry, zooplankton and phytoplankton composition, diversity, etc., of Lake Langanu from the other two that affected the fish morphometry. This is in line with what Turan *et al.* (2006) reported whereby habitat influenced the morphology of fish. According to Kara *et al.* (2011), morphological differentiation between fish populations in different localities/ habitats may not be related to genetic differentiation alone but by the inclusion of the environmental factors or their interactions. Hutchings (2004) demonstrated that phenotypic plasticity arises when the same genotype produces different phenotypes in different environments.

Morphological differentiation patterns among populations can indicate how diverse a population is. The Discriminant Function Analyses indicated that morphometric differentiation between the three samples was mainly due to differences in TL, PDL, PPLL, and ED which were significantly ($P < 0.05$) higher in the Lake Langanu population, and PAL, BD, and W that were higher in the populations of Lakes Koka and Ziway. These morphometric variations may reflect differential habitat use. The Lake Langanu population showed significantly ($P < 0.05$) higher head length which is in line with a report by Gatz (1979) where relative head length was reported to be related to prey size.

According to Matthews (1988), eye diameter may reflect differences in turbidity. Moore (1950) described increases in cutaneous sense organs to compensate for reduced eye diameter in cyprinids adapted to turbid streams in North America. The eye diameter, which is significantly ($P < 0.05$) higher for the Lake Langanu population was may be related to the relatively less turbid Lake Langanu,

Secchi depth 28.5cm (Tadesse, 1999) as compared to for instance Lake Ziway, where turbidity is increasing noting Secchi depth as shallow as 17 to 20 cm (Lemma and Desta, 2016; Abera *et al.*, 2018).

Geographical locations determine the type of abiotic components capable of modifying the fish morphology. For instance, elevation difference was reported to be correlated with body sizes (Alkinson and Sibly, 1997; Jin *et al.*, 2007) and head sizes (Liao *et al.*, 2006). Though it is not so big, there is an altitude variation among the three lakes (see study areas).

CONCLUSION

This study delineated *O. niloticus* samples from three rift valley lakes in Ethiopia based on morphometric measurements. The result revealed that the samples from Lake Langanu were significantly different from samples of the other two lakes. Biotic and abiotic factors, genetics, and their interactions are believed to be the main cause of the observed morphometric variations.

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