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MORPHOMETRIC CHARACTERIZATION AND CONDITION FACTOR OF THREE STRAINS OF TILAPIA *Sarotherodon galilaeus* (LINNAEUS, 1758), AN AQUACULTURE CANDIDATE SPECIES IN BENIN

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ABSTRACT

The morphometric characteristics are dependable tools used to characterize and identify fish species especially in the field, where more detailed diagnostic tools are not available. This study was carried out to determine the morphological variation and the condition factor of *Sarotherodon galilaeus* strains from Ahozon, Hlan and Togbadji lakes in Southern Benin. *Sarotherodon galilaeus* samples were collected from traditional fisheries at the three ecosystems, identified and weighed. Twenty-four morphometric traits were measured using the caliper and the condition factor were determined for the three strains. A Principal Component Analysis (PCA) was carried out to determine the relationship between the three populations of *S. galilaeus*. The results show that the mean values of the fish size (TL) ranged from 9.82cm (Ahozon Lake) to 17.98cm (Togbadji Lake). The condition factors were 2.34, 2.40 and 2.97 in Hlan, Ahozon and Togbadji Lakes, respectively, showing that fish from Lake Togbadji have bigger size and better environmental conditions. The analysis of variance showed significant differences between the mean values of Total Length (TL), Standard Length (SL), Head Length (HL), Body Depth (BD) and Dorsal Fin Base Length (DFBL) of fish in Lake Togbadji and other water bodies. Length-weight relationships showed an allometric growth of *S. galilaeus* populations from the three lakes ("b" values 2.92, 3.16 and 3.55 in Hlan, Ahozon and Togbadji lakes, respectively). The PCA revealed an overlap among *S. galilaeus* individuals from Ahozon and Hlan Lakes, discriminating the population from Togbadji Lake. This suggests that *S. galilaeus* populations from Lake Togbadji are a separate strain with specific characteristics. Further investigations on genetic variability could help to understand the genetic diversity of the three populations of *S. galilaeus* in order to promote the species in Beninese aquaculture industry.

Key words: *Sarotherodon galilaeus*, morphometrics, Condition factor, Strain, Southern Benin

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INTRODUCTION

Sarotherodon galilaeus (Linnaeus, 1758) is a freshwater cichlid fish with economic and commercial importance that is found in most of the Beninese freshwater ecosystems. The species has been abundantly recorded in Lake Hlan [1], Lake Toho [2], man-made Lake of Ahozon [3] and Oueme, Mono and Pendjari rivers [4, 5, 6]. It is well established in these ecosystems with good population parameters especially in Ahozon, Hlan and Togbadji lakes [7, 8, 9]. Despite its abundance and establishment in natural ecosystems, the species is yet to be domesticated and introduced into the Beninese aquaculture industry. Meanwhile, investigations in Ghana and Egypt reported that the species can grow well in ponds and floating cages, where experiments showed no differential growth between male and female individuals [10, 11]. Owusu-Frimpong *et al.* [12] established that the *S. galilaeus* presents high breeding and growth performances and its culture both in cages and ponds can generate similar profit like the culture of *Oreochromis niloticus* in the same conditions.

In recent years, Benin government adopted a new strategy to develop aquaculture and boost fish production. One of the recommendations is to investigate the aquaculture potential of other indigenous fish species (*Tilapia* sp., *Chrysichtys* sp.) while working to improve the existing ones (*Oreochromis niloticus*, *Clarias* sp.) [13]. Based on the performances of *S. galilaeus* in terms of growth and breeding the specie appears to be a good candidate for aquaculture in Benin [10,11]. In general, the process for fish species domestication includes baseline studies on its biology and ecology and experimental trials to understand the optimal conditions for its growth and requirements in captivity [14]. These preliminary studies are important for assessing the ecological characteristics including morphometry and growth and feeding strategies of its stocks in natural ecosystems. Indeed, the morphometric differences among stocks of a species are recognized to be important while evaluating population structure and forming a basis for identifying stocks [15]. Advancements in morphometrics have used powerful tools for testing and displaying differences in shape, isolating shape from size variation, and identifying stocks of species with unique morphological characteristics, enabling better management of the species.

Many investigations have been carried out to assess the morphometric characteristic of *S. galilaeus* in Benin. The authors provided useful information on population parameters and length-weight relationships of the species in different lakes in Southern Benin [9, 11,16, 17]. However, the various studies were scattered, covering only single aquatic ecosystems. Timely and comprehensive studies of the species morphometry, taking into account multiple ecosystems are scarce. Therefore, the present research is carried out to determine the morphometric

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characteristics of *S. galilaeus* populations from the Hlan, Ahozon and Togbadji lakes, three freshwater ecosystems in Southern Benin, aiming to assess the morphological diversity of the species. It intends to provide useful information for sustainable management of *S. galilaeus* in Southern Benin lakes.

MATERIALS AND METHODS

Study area

Specimens of *S. galilaeus* have been collected from the Hlan, Ahozon and Togbadji Lakes in the southern region of Benin (Figure 1). Due to their geographic location, the lakes experience a sub equatorial climate with four seasons namely: (1) a long rainy season from mid-March to mid-July, (2) a short dry season from mid-July to mid-September, (3) a short rainy season from mid-September to mid-November, and (4) a long dry season from mid-November to mid-March [18].

Lake Hlan is located between 6° 56 '35.05"N and 2° 19' 57.32" E in Toffo District, Department of Atlantic, 80 km from the Atlantic coast. It is within the catchment area of the Hlan River and is supplied with water by small streams flowing in the area such as Samion, Da, Hoho, Hlan and Koto. The lake is connected to the Ouémé and Sô rivers allowing fish to migrate from the rivers to flooded areas of the lake for breeding. The man-made lake of Ahozon is located at Pahou in the South Western of the Country between 06˚ 22 '52"N ; 002˚ 10' 34"E. The lake originated from sand dredging activities and receives, every wet season, a huge amount of running waters. Annual mean rainfall can reach 1307.3 mm and the ambient temperatures vary between 25 °C and 33.6 °C [19] and [20]. The lake is within a swampy soil in the coastal zone which currently undergoes some sand-dredging activities. Togbadji Lake is located between 6°43'0" N, 1° 40' 60" E in the Couffo Department and covers an area of 5.5 km^2. The lake is fed by the Mono River each year during the flooding period. The annual rainfall varies from 544 to 1 376 mm, and temperatures range between 20.6 and 33.5 °C with an average of 28 °C [21].

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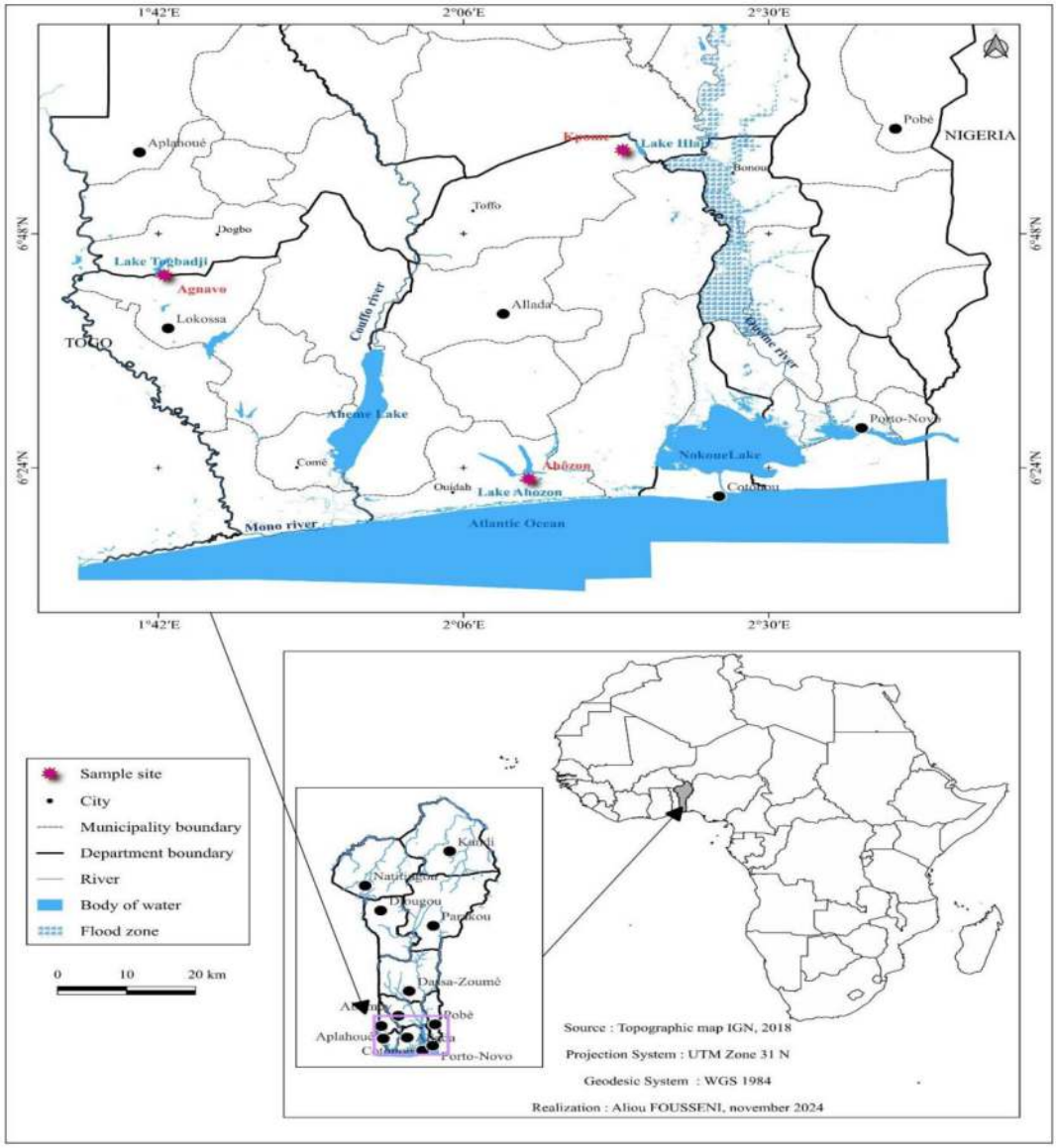

Figure 1 : **Geographical map of Benin, showing the location of the study area (Ahozon, Ahémé and Togadji Lakes)**

Fish samples collection

Kpome, Ahozon and Agnavo were selected for fish sample collections in Hlan, Ahozon and Togbadji lakes, respectively. Fish samples were collected once from traditional fisheries at the different sampling sites. Overall, 59, 64 and 50 adult male and female specimens of *S. galilaeus* were sampled respectively from Hlan, Ahozon and Togbadji lakes, iced in cooler containers and transported to the Fisheries Research Laboratory at the National Institute for Agricultural Research of Benin (INRAB) for morphometric analysis. Fish were identified using fish identification guides of [22, 23].

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Fish sample processing and data analysis

Twenty-four (24) morphometric measurements were recorded on each fish specimen (Figure 2). An ichtyometer was used to measure the total length (TL) and standard lengths (SL). For the smaller elements like eye diameter, body depth, least peduncle length, and so on the caliper was used. The data collected were entered in a Microsoft Excel sheet. Shapiro-Wilks test was used to test normality of the data. The means of the principal values were calculated in an Excel using cross-dynamic table function. Size structure and Fulton's condition factor K were determined for the different populations of *S. galilaeus.* The condition factor which indicates the well-being of the fish in the lakes were calculated using the following formula :

$$\mathbf{K = 100\ W/TL^3} \qquad (1)$$

where **K** is the condition Factor, **W** is the weight of the fish (g) and **TL** is the total length of the fish (cm).

The means values of the morphometric traits were calculated and the relationships between the principal morphometric traits determined. One-way Analysis of Variance (ANOVA) was performed on the data to assess the variation among the mean values of the morphometric characteristics of the three populations. Finally, size-corrected morphometric data were analyzed by a multivariate method using Principal Component Analysis (PCA). Factor loadings based on Eigenvalues from Principal Component Analysis (PCA) were used to determine the morphometric character with the highest variation that can discriminate the three populations. The statistical analyses were performed using R programming software version 4.3.2 (R Core Team 2023)

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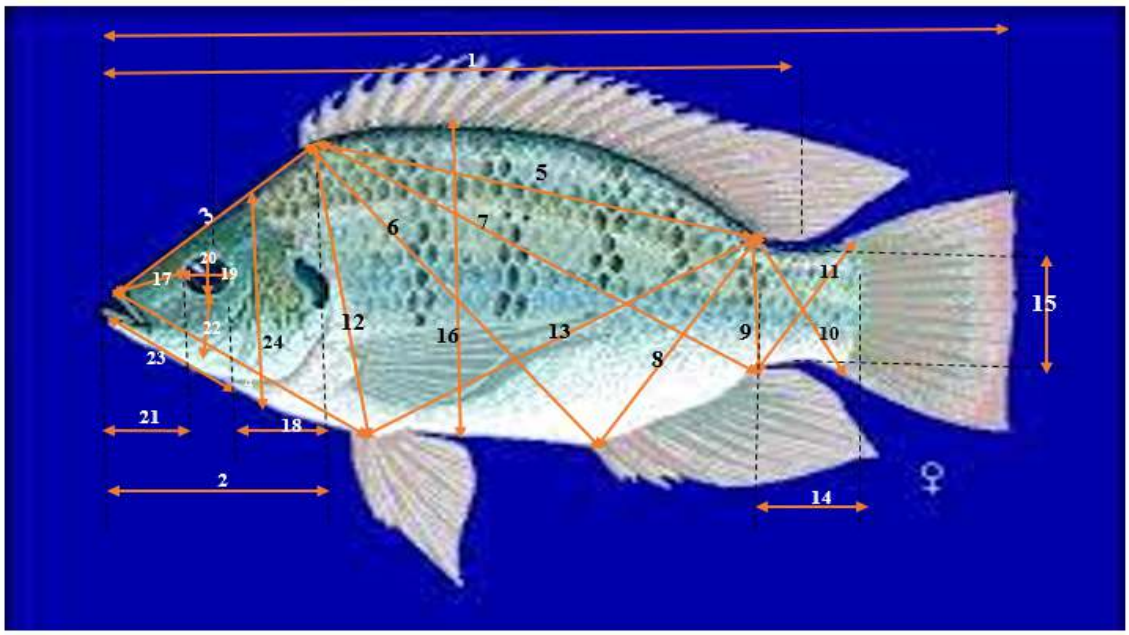

Figure 2 : Morphometric measurements on *S. galilaeus* specimen

1- Standard length (SL), 2- Head length (HL), 3- Snout to dorsal-fin origin (SNDOR), 4- Snout to pelvic-fin origin (SnPEL), 5- Dorsal-fin base length (DFBL), 6- Anterior dorsal to anterior anal (ADAA), 7- Anterior dorsal to posterior anal (ADPA), 8- Posterior dorsal to anterior anal (PDAA), 9- Posterior dorsal to posterior anal (PDPA), 10- Posterior dorsal to ventral caudal (PDVC), 11- Posterior anal to dorsal caudal (PADC), 12- Anterior dorsal to pelvic-fin origin (ADP2), 13- Posterior dorsal to pelvic-fin origin (PDP2), 14- Caudal-peduncle length (CPL), 15- Least caudal-peduncle depth (LCPD), 16- Body depth (BD), 17- Snout length (SnL), 18- Postorbital head length (POHL), 19- Horizontal eye diameter (HED), 20- Vertical eye diameter (VED), 21- Preorbital length (PRE), 22- Cheek depth (CD), 23- Lower-jaw length (LJL) and 24- Head depth (HD)

RESULTS AND DISCUSSION

Size structure and condition factor of S. galilaeus populations from Ahozon, Hlan and Togbadji lakes in Benin

Overall, the total length of fish varies according to the ecosystems from 6.40 cm (Ahozon) to 23.50 cm (Togbadji) (Table 1). The average size of fish in Lake Togbadji Lake was 17.98+/- 3.20 cm with maximum values of 23.50 cm. Fish in the other two lakes had smaller sizes with TL mean values of 9.82+/-2.86 cm and 11.70+/-3.50 cm in Ahozon and Hlan lakes, respectively. The ANOVA performed on TL showed that *S. galilaeus* fish in Togbadji Lake have bigger size compared to those from Ahozon and Hlan lakes (p=6.009e-05). The mean weight of the fish was 30.18g +/-31.65, 46.28g +/-35.01 and 195.45g +/-108.22 respectively for Ahozon, Hlan and Togbadji Lakes.

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The size structure of the fish from the three lakes is shown in Figure 3. Overall, fish measuring less than 10cm are the most represented in the *S. galilaeus* samples, accounting for more than 35.10% of the fish collected; followed by fish belonging to class 12-16cm with 28.25% of the fish. In Togbadji lake, all the fish are above 12cm and more than 40% of the fish collected are bigger than 18cm. Besides, all the fish from Ahozon lake are smaller and more than 66.25% of them are less than 12cm. Finally, fish from Hlan Lake are of medium size with the majority of individuals measuring between 12cm and 18.4cm.

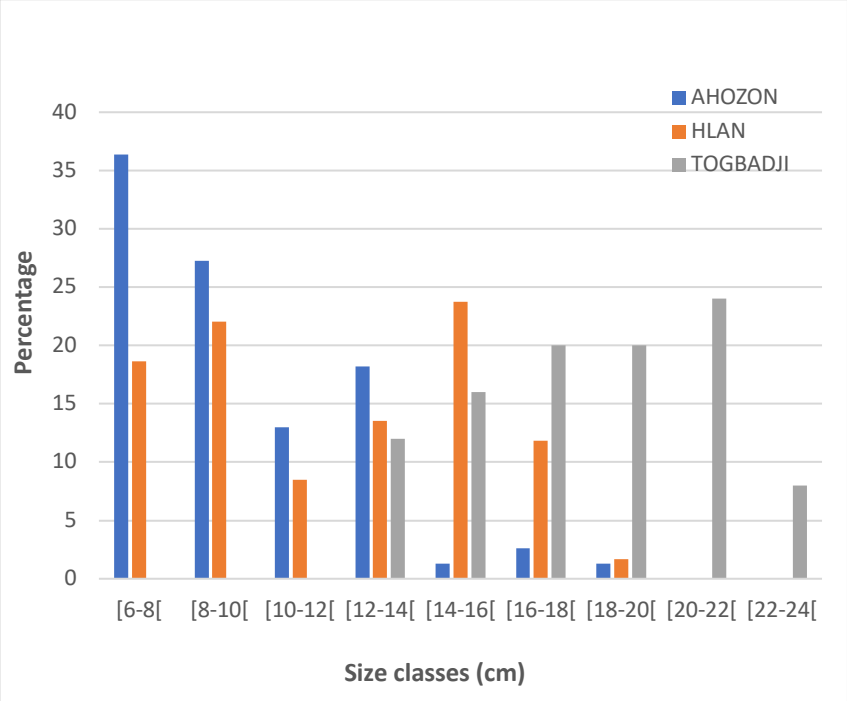

Figure 3 : **Size structure of *S. galilaeus* populations from Ahozon, Hlan and Togbadji lakes**

The findings recorded for fish size in this study are similar to the observations of [9] who reported a total length of 6.1-22.6cm in Togbadji lakes, one of the lakes investigated during the study. In Ahozon Lake, about 66.25% of the fish are smaller than 12cm. The presence of small size specimens in the fish sample collected during this study could result from the degradation of the lake caused by agricultural activities in the catchment area of the lake and the sampling period. According to [25], sand dredging, salt production and other anthropogenic activities can disturb the aquatic ecosystems resulting in a reduction of food availability, and therefore, the growth of the fish. The maximum weight of fish recorded in Togbadji Lake is 359.35g. These values are higher than the 260.0 g recorded by [9] in the same lake. The difference could result from the fact that fish samples were collected during the dry season between January and March whereas [9] sampled throughout the year including the rainy season when breeding activity is high in the fish.

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The condition factor K calculated for *S. galilaeus* in the three lakes (Table 2) shows that the fish is in a good condition in all the ecosystems. Lake Togbadji is the ecosystem providing the most optimal conditions for the fish with the condition factor K close to 3. In other Lakes, the condition factor is lower with K values of 2.40 and 2.34 in Ahozon and Hlan respectively. The Analysis of variance performed on the condition factor k shows significant difference between fish from Togbadji lake and other lakes ($p=6.009 \times 10^{-05}$).

Overall, the results of this study suggest that the three lakes offer *S. galilaeus* good environmental and feeding conditions to display its growth as reported by Gbaguidi *et al* [3]. In general, the condition factor of *S. galilaeus* in the three ecosystems is lower than 3. Fish from Togbadji Lake displayed better conditions than others. This condition factor, combined with the bigger size of the fish and the allometric growth of the fish shows that the three lakes offer good conditions for the development of the fish. This could be explained by the low exploitation rate of the fish in the lake as it was reported low fishing pressure and better water quality which are important elements necessary for the growth of fish before capture [9, 26].

Morphometric variability of *S. galilaeus* populations in Ahozon, Hlan and Togbadji lakes

The mean values of morphometric characters vary from one lake to another (Table 4). In general, the values recorded for the morphometric traits of *S. galilaeus* populations in Togbadji Lake are higher than those from Hlan Lake. Fish from Ahozon lake have lower morphometric parameters.

The ANOVA performed on the data showed that there is a significant difference between the morpho-metric characteristics of *S. galilaeus* in Togbadji Lake and the other ecosystems. The characters with the highest values in Togbadji Lake include TL, SL, HL, BD, DFBL, ADAA, PDP2 and ADP.

The relationships between the different morphometric traits were analyzed to assess the morphology of the fish in the three populations. These different values are presented in Table 5. Overall, the head represents 26.45%, 25.44% and 28.71% of the fish's total length respectively in Ahozon, Hlan and Togbadji lakes. The fish body depth in Hlan Lake (34.31% of the TL) is lower than those in Ahozon and Togbadji Lakes (35.41% of TL and 35.57% of the TL respectively). These relationships have shown that, in general, *S. galilaeus* specimens from Togbadji Lake are wider than those from Ahozon and Hlan Lakes with the head occupying more proportion of the fish body.

The results of Principal Component Analysis performed using the morphometric data of the three populations of *S. galilaeus* (Ahozon, Hlan and Togbadji) are presented in Figures 4 to 8. The Figures 4 showed that the variability of the data is explained

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by the first 7 components with PC1 and PC2 accounting for 78.5% and 3.9% of the variability respectively. As the cumulative variance explained by these two components is greater than 80%, PC1 and PC2 have been used for the analysis.

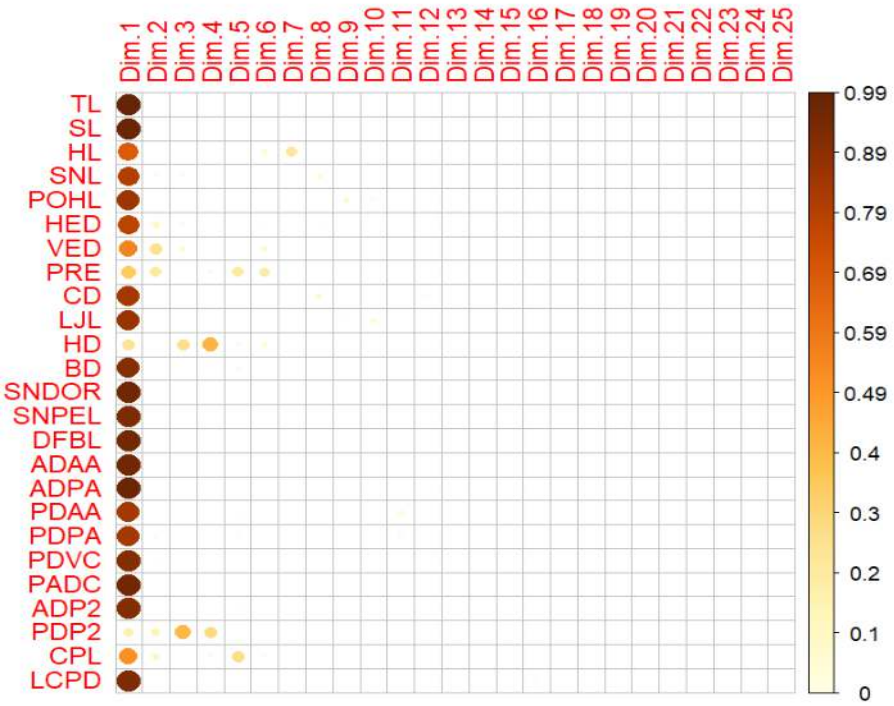

Figure 4 : Magnitude of the morphometric variables in the PC1 and PC2

Considered individually, the components PC1 and PC2 explained the variables with different magnitudes. The PC1 explained more than 78% of the total variance and took into account 21 variables including TL, SL, ADPA, SNDOR, PADC, etc. Apart from PRE, HD, PDP2 and CPL, the PC2 expressed the variation of only five variables including eye diameter (VED et HED), the caudal peduncle length (CPL), the preorbital length (PRE) and the posterior dorsal to pelvic fin Length (PDP2).

The PCA performed using the morphometric characters showed an overlap among *S. galilaeus* individuals from Ahozon, Hlan and Togbadji lakes (Figure 5). The overlap is more evident between fish from Ahozon and Hlan lakes where morphometric traits of individuals have shown to be similar in the two ecosystems (Figure 6). However, there is a slight dispersion of some individuals from Togbadji Lake which are characterized by high values of morphometric traits. Overall, the PCA performed on the morphometric traits discriminates the *S. galilaeus* populations of Togbadji Lake from Ahozon and Hlan populations which have similar characteristics.

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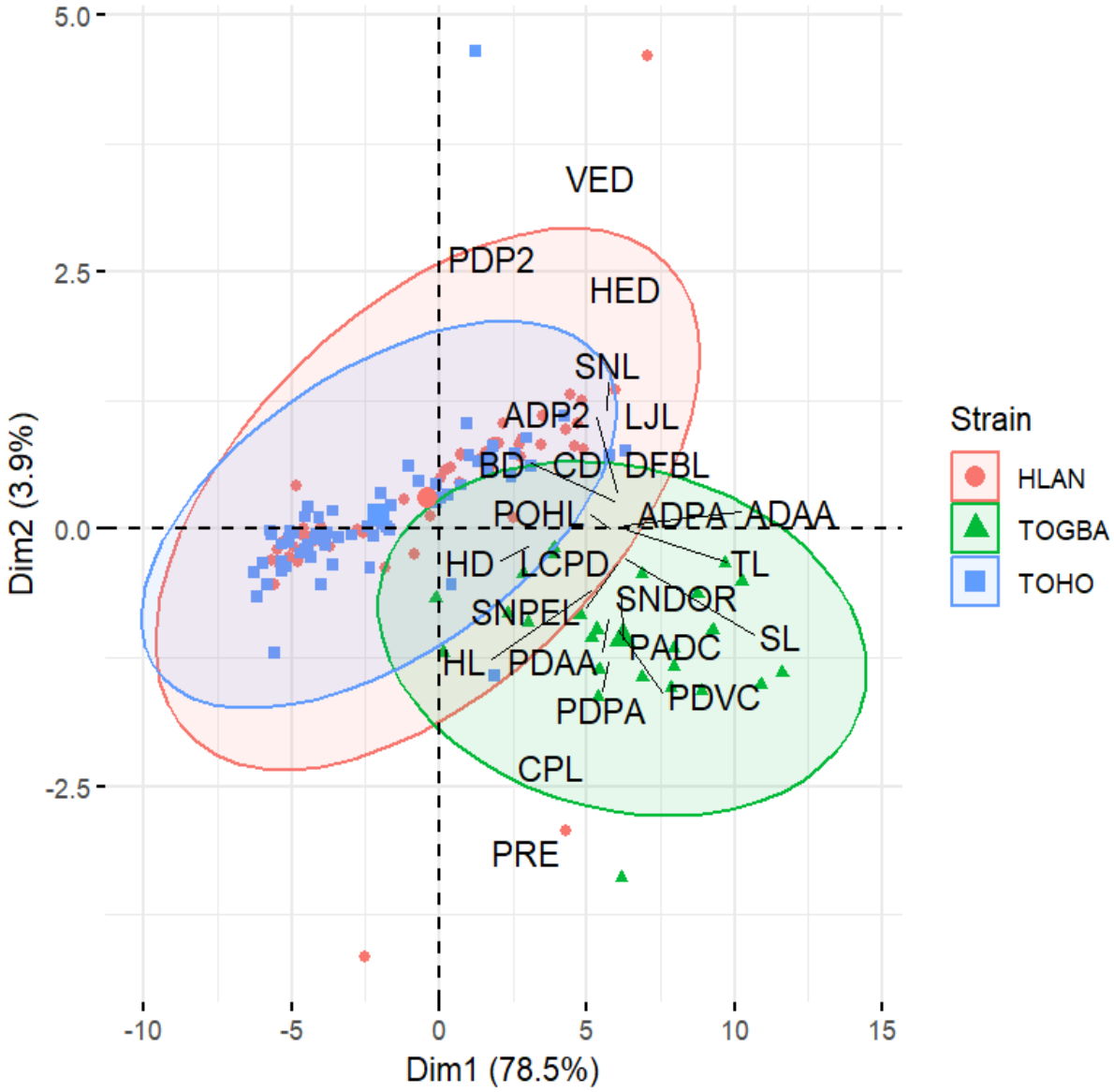

Figure 5: **PCA showing the overlap among *S. galilaeus* populations from Ahozon, Hlan and Togbadji Lakes**

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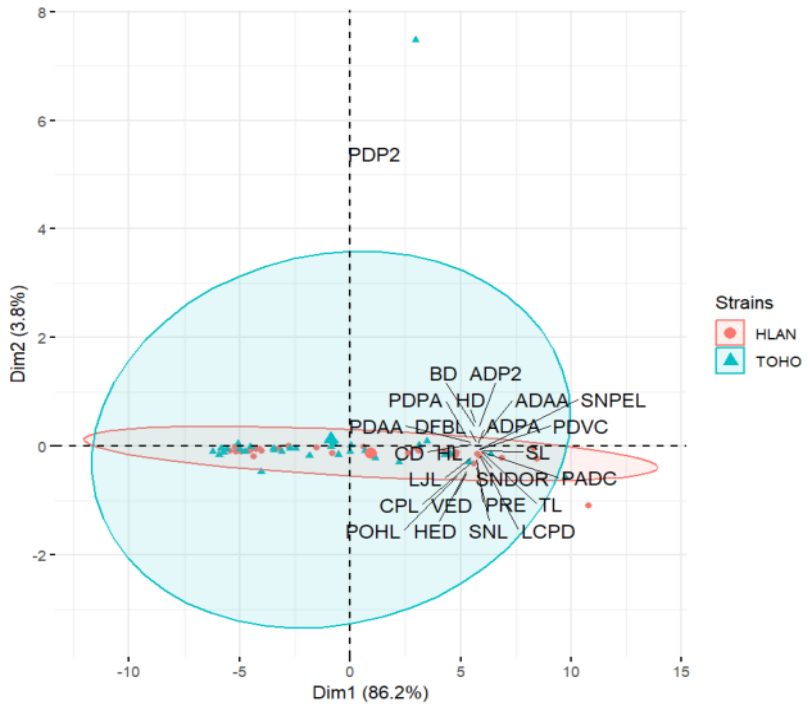

Figure 6: PCA of morphometric data of *S. galilaeus* from Hlan and Ahozon lakes showing the overlap among the individuals

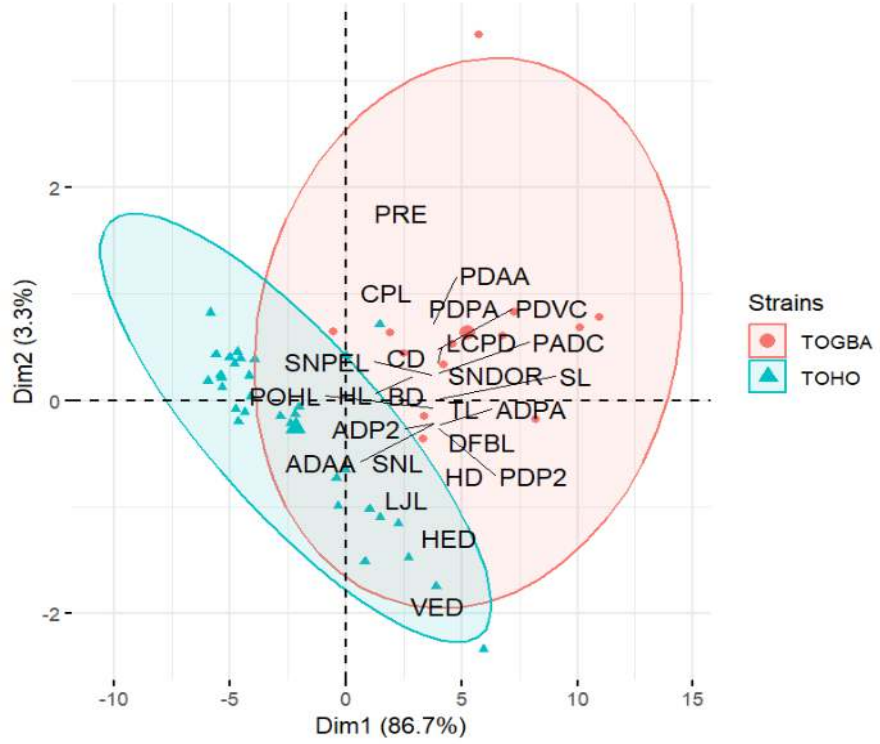

Figure 7: PCA of morphometric data of *S. galilaeus* from Togbadji and Ahozon lakes

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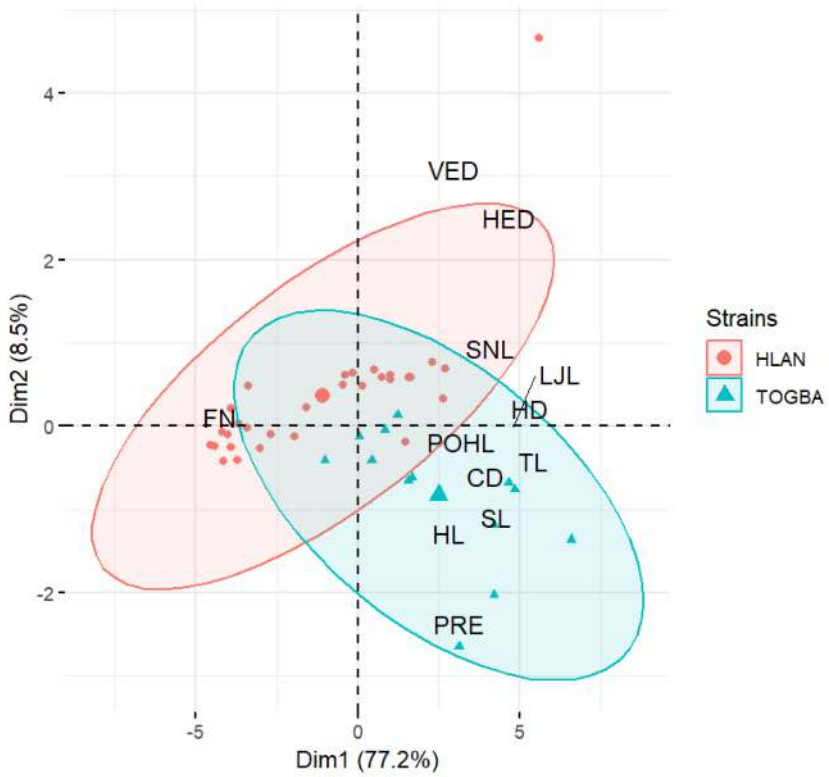

Figure 8: PCA of morphometric data of *S. galilaeus* from Togbadji and Hlan lakes

The investigations revealed a great variation of the morphometric characters of *S. galilaeus* from the three lakes. The mean values of the morphometric measurements show that fish from Togbadji Lake are morphologically different from other populations. That result is supported by the principal component analysis which revealed an overlap between fish populations from Hlan and Ahozon lakes whereas in Togbadji Lake, although some individuals have similar morphology with the other two populations, the majority of fish are separated. The main characters responsible for this differentiation of *S. galilaeus* populations in Togbadji lake include total and standard length, Caudal peduncle length, Snout to dorsal fin length and posterior dorsal to anterior anal fin length among others. Morphometric measurements are considered dependable tools and are used to characterize and identify fish species because they are sensitive to environmental changes and can be applied on the field where more detailed diagnostic tools are not available [27] .

The contribution of morphometric traits to the separation of the different populations of tilapia fish has been already mentioned in several studies. Indeed, the BW, BD, TL, SL, PRA, DPF and PRD contributed to discriminate *S. galilaeus* populations of Al Sabaloga from those from Sinnar and Kosti reservoirs in Sudan [25]. The same observations were made in Benin by Fagnon *et al.* [26] who concluded that 26 out of 28 morphometric characters are the key elements that differentiated significantly

Sarotherodon melanotheron populations from fresh and brackish waters in southern Benin (Nokoue Lake, Aheme lake, Coastal lagoon, Toho Lake, Porto-Novo lagoon and SUCOBE reservoir). In Nigeria, investigations showed a wide overlap of data among the morphometric measurements of *S. galilaeus* from the Opa, Asejire and Ero reservoirs [27]. This is in line with the findings of the present study showing that fish from different environments have different morphology. The three ecosystems considered in this study belong to different agro-climatic zones with different climatic characteristics and hydrologic regimes which could affect the morphology of the fish.

The relationships between the principal morphometric traits (TL, BD and HL and the ED, SNL and HL) established in this research highlighted that the fish head occupied a smaller proportion of the fish body in Hlan Lake than in other lakes. Also, it revealed that fish are thinner in the same lake, supporting the negative allometric growth obtained for the species. These observations could be explained by the environmental conditions of the lake and potentially, the genetic make-up of the species in that ecosystem.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The investigations on the morphometric characteristics of *Sarotherodon galilaeus* populations in Ahozon, Hlan and Togbadji Lakes provided useful information on the ecology of the species. Fish from Togbadji Lake appears bigger and in better condition compared to the other populations. This translate the good environmental conditions of Lake Togbadji. The PCA revealed two distinct fish groups from the study: “Ahozon-Hlan” group with similar characteristics and “Togbadji” group with higher values. The genetic characterization and evaluation of genetic parameters of the different populations could help to understand the genetic variability and performance of the three strains in order to promote the species into the Beninese aquaculture industry.

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Contribution of the authors

Aliou Fousseni is the principal author of the research. He designed the research methodology, spearheaded the field work for data collection, developed the draft and did the editings of the manuscript.

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Dr Wilson Jere edited the research plan and together with ***Emmanuel O. Oje***, he carried out the statistical analysis of the data and did the revision of the manuscript.
Delano Zocli assisted in fish sampling and morphometric data collection.
Dr Luc Gangbe supervised the data collection in the field and participated in the development of the manuscript.
Mexford Mulumpwa, ***Antoine Chikou*** and ***Vincent Joseph Mama*** contributed to the editing of the research protocol and the manuscript of the article.

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Table 1: **Mean values of Total Length (TL) and Weight (W) of *S. galilaeus* from Ahozon, Hlan and Togbadji Lakes**

Lake	Total Length (cm)				Weight (g)			
	Mean	Stand. Dev	Min.	Max.	Mean	Stand. Dev	Min.	Max.
Ahozon	9.82	2.86	6.40	19.00	30.18	31.65	6.33	201.25
HLAN	11.70	3.50	6.80	18.40	46.28	35.01	7.33	135.01
Togbadji	17.98**	3.20	12.30	23.50	195.45**	108.22	35.55	359.35

***Values significantly different*

Table 2: Condition factor of S. galilaeus in Ahozon, Hlan and Togbadji lakes

Lakes	Mean	Min.	Max.	Écartype
Ahozon	2.403	1.270	2.972	0.277
HLAN	2.336	1.360	3.070	0.283
TOGBADJI	2.970**	1.910	4.038	0.580
Total	**2.465**	**1.270**	**4.038**	**0.402**

***Values significantly different*

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Table 3: Mean values of morphometric traits of Sarotherodon galilaeus in Ahozon, Hlan and Togbadji Lakes

Morph. Traits	AHOZON	HLAN	TOGBA	Total général
TL	10.20	11.87	17.98a	12.18
SL	7.75	8.97	14.20a	9.33
HL	2.70	3.02	5.20a	3.25
SNL	0.87	1.09	1.36	1.04
PRE	0.85	1.16	2.15	1.19
HD	2.98	3.54	5.83	3.68
BD	3.61	4.05	6.34a	4.25
SNDOR	3.08	3.41	5.61	3.64
DFBL	4.77	5.36	8.11a	5.57
CPL	0.91	1.05	2.08	1.16
SNPEL	3.26	3.66	5.78	3.85
VED	1.01	1.15	1.15	1.09
HED	1.00	1.12	1.34	1.11
POHL	1.10	1.23	2.11	1.32
CD	1.03	1.34	1.83	1.29
LJL	1.58	1.75	2.48	1.80
ADAA	4.89	5.58	8.38a	5.76
ADPA	5.17	6.06	9.26	6.22
PDAA	2.59	3.16	4.89	3.21
PDPA	1.45	1.66	3.02	1.80
PDVC	1.38	1.59	3.24	1.78
PADC	1.45	1.70	3.06	1.82
ADP2	3.58	3.98	6.06a	4.16
PDP2	5.52	5.34	8.02a	5.87
LCPD	1.10	1.28	2.29a	1.37

a- For a particular morphometric trait, values with the letter "a" are significantly different

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ANOVA Outputs

```
Strains Scores
    1. HLAN - 0.4857197
    2. HLAN -1.6408000
    3. HLAN - 0.5018454
    4. HLAN - 0.3826399
    5. HLAN - 0.4540149
    6. HLAN - 0.4045859
> model<-lm(Scores~Strains,data=df1)
> anova(model)
Analysis of Variance Table

Response: Scores
Df Sum Sq Mean Sq F value    Pr(>F)
Strains 2 19.554 9.7772 10.401 6.009e-05 ***
Residuals 145 136.300 0.9400

Signif. codes :  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 4: Relationships between morphometric traits of S. galilaeus from Ahozon, Hlan and Togbadji Lake in southern Benin

LAKES	HL/TL		ED/HL		SNL/HL		BD/TL	
	Mean	Écartype	Mean	Écartype	Mean	Écartype	Mean	Écartype
AHOZON	0.2645	0.0304	0.1015	0.0123	0.3199	0.0533	0.3541	0.0434
HLAN	0.2544	0.0216	0.0981	0.0126	0.3543	0.0790	0.3431	0.0476
TOGBADJI	0.2871	0.1051	0.0706	0.0101	0.2804	0.0749	0.3557	0.0293

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