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Morphological and meristic characterization of the African bonytongue, *Heterotis niloticus* (Cuvier, 1829), from Lake Hlan and Sô River, Southern Benin, West Africa: The need for habitat protection and species conservation

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Abstract
The African bonytongue, *Heterotis niloticus* (Pisces: Osteoglossiformes: Osteoglossidae) is one of the largest omnivorous fish species of high commercial and economic value in African freshwater fisheries and in semi- intensive and extensive aquaculture systems. *Heterotis* specimens were sampled in the Lake Hlan - Sô River (South-Benin) system in order to investigate the morphological and taxonomic characterization of this threatened species under overfishing and various environmental degradations, and to detect whether the population is morphologically and taxonomically separable. The population exhibited significant (P<0.05) morphological relationships with positive slopes varying between 0.39 and 2.97 and coefficients of correlation "r" between 0.70 and 0.99 for most regressions. The positive slopes "b"<3 (2.97 for Lake Hlan; 2.67 for Sô River) from the Total Length - Body Weight relationships suggest that *Heterotis niloticus* exhibited an allometric growth in the Lake Hlan - Sô River system. Overall, the results showed insignificant ($0.0001 \leq F_{1,38} \leq 3.275$; $P \geq 0.05$) sexual variation for most morphometric features, ratios and meristic counts for both sub-populations, Lake Hlan and Sô River. Also, insignificant ($0.003 \leq F_{1,38} \leq 3.978$; $P \geq 0.05$) variation where found between Lake Hlan and Sô River (males and females indiscriminately) for most morphological and meristic traits. The significant (P<0.05) variations recorded in few morphological (ratios HL/ED and HHe/ED) and meristic (NSpH; NTLoJ) traits between males and females and between Lake Hlan and Sô River were probably due to habitats characteristics, environment degradation and geographical factors. As results, the population of *Heterotis* in the Lake Hlan-Sô River system of southern Benin is morphologically and taxonomically inseparable indicating that *Heterotis* may probably be a unique species in the Lake Hlan – Sô River system and, therefore, may not be genetically diversified. Further studies on morphological and meristic characterization of bonytongues in all Benin freshwater systems, coupled with molecular analysis are required to implement ecological sound management program including habitat protection, conservation scheme, aquacultural valorization and sustainable fisheries management.

Keywords: body ratios, Benin, conservation, fisheries, genetic diversification, *Heterotis*, taxonomy

Introduction

Heterotis niloticus (Pisces: Osteoglossiformes: Osteoglossidae), is one of the top largest non-predatory fish species occurring in rivers, floodplains, streams and natural lakes of the Nilo-Sudian region, the Congo region of Central Africa and West Africa [1-9]. Indeed, in Lake Gambie, Depierre &Vivien [10] reported a bonytongue specimen with an individual weight (W) of 5800 g for a standard length (SL) of 847 mm. Likewise, in the Sô River of the Southern Benin, Adite *et al*. [11] recorded a weight of 5838 g for a bonytongue specimen measuring 765 mm - SL. In an intensive aquaculture system, *Heterotis* could reach a total length of one (1) meter within 11 months of rearing, which corresponds roughly to a monthly growth rate of 91 mm [11-12].

In Lake Hlan (South-Benin), called "*Heterotis* Lake" for its high abundance in *Heterotis*, the bonytongue population was composed of 36.5% of juveniles, 17.8% of subadults, and 45.7 % of adults. Also, in the Sô River of the Southern Benin, 35.1% of bonytongues were juveniles, 60.2% were sub-adults and 4.7% were adults [13]. The combined data from Lake Hlan - Sô River aquatic system gave a sex-ratio of 1: 0.86, corresponding to 53.7% of bonytongue males and 46.3% of females. Lowest and highest fecundities (number of mature oocytes in the ovary) recorded for individual fish were 2,697 (500 mm-SL) and 27,508 oocytes (735 mm-SL), respectively [13]. *Heterotis* exhibited a nearly K reproductive strategy to maintain the population at an appropriated level [13-14]. *Heterotis* is an omnivore consuming a variety of food resources, ranging from detritus, aquatic invertebrates to small seeds [15-19]. In addition to its high growth rate, *Heterotis* show a high degree of food plasticity behavior that allow this species to colonize various freshwater habitats [19-21]. In Lake Hlan and Sô River, *Heterotis* matured at about 575 mm – total length for both genders, and spawning accured during the wet and high water seasons [13].

Known in Benin as fish species of high commercial and

economic values, *Heterotis* has colonized almost all the Benin freshwater systems ranging from rivers, streams, floodplains to natural and artificials lakes where this species is intensively exploited for sale and foods. Adite *et al.* [13] reported an estimated annual capture of 742 tons only for some rivers (Oueme, Mono, Couffo, Sô, Zou) and lakes (Nokoue, Hlan, Toho-Todougba, Toho) of Southern Benin. In paticular, the Sô River and Lake Hlan called "*Heterotis* lake" by the fishermen and grassroots, produce yearly together about 474 tons of bonytongues, yielding 63.75% of the total capture of bonytongues in the Southern Benin. In addition to the exploitation of the wild stocks, *Heterotis* has been widely introduced in controlled and semi-controlled aquaculture in the Sub-Sahelian region of Africa [21]. Especially in Bénin, the African bonytongues has been introduced in couple artificial lakes and in fish ponds.

Despite its fisheries and aquacultural importance, little is known about the morphological and meristic characterization, and genetic diversification of this unique African osteoglossid species in the degrading aquatic ecosystems of Benin [22-23]. Paugy [24] gave a description of *Heterotis* in the African Sub-Sahelian region using body proportions such as the ratio of body height to standard length ranging between 3.5-5, and that of head length to standard length varying from 3.5 to 5. Also, meristic counts were limited to the number of rays on the dorsal fin (33-37) and on the anal fin (34-38), and the number of gill rakers on the gill arch (21-98). In Benin, from preliminary examinations of microsatellite DNA loci, Hurtado *et al.* [25] reported high levels of genetic differentiation among populations of bonytongues from three river basins namely, Oueme-Sô and Mono of Southern Benin, and the Niger River basin of the Northern Benin.

Potential threats on *Heterotis* are primarily overfishing, loss of spawning and nursery grounds, pollution, habitat dégradation, alteration of water quality, modification of flooding regimes and climate. In evolutionary ecology, the combined effects of environmental degradations within *Heterotis* habitats and geographic isolation of populations could cause morphological variations and genetic diversification [19, 25-27]. Consequently, database on morphological and meristic trait variations are badly required for the search of genetic diversity, and to implement sound management scheme encompassing habitat protection, species conservation and aquaculture valorization warranting a sustainable exploitation of bonytongues.

The present study was undertaken (1) to search on morphological and meristic variations among bonytongue population of Lake Hlan - Sô River aquatic system with regard to genders and (2) to investigate on spatial variations in order to detect whether the two sub-populations sampled were morphologically and taxonomically separable. The outputs gathered will contribute to implement habitat protection and species conservation/valorization program, and will serve as data base for bonytongue follow-up pending any further changes in the ecosystem.

Study Area and Methods

Study Area

The study area includes two connected aquatic ecosystems, the Sô River and Lake Hlan, both located in South-Benin (Fig. 1). The climate in the southern region of Benin is sub-equatorial with two wet seasons (April to July, mid-September to October) and two dry seasons (December to March, August to mid-September) with an annual rainfall reaching 1053.4 mm. Highest monthly rainfall is usually recorded in June and reached 364.2 mm, and monthly ambient temperatures varied between 22.1°C and 33.4°C [28].

The Sô River (6º 34.97 N; 2º 23.75 E) and floodplains cover about 1000 km2 (Fig. 1). It receives water via a connection with the Oueme River (450 km) and flows southward about 70 km

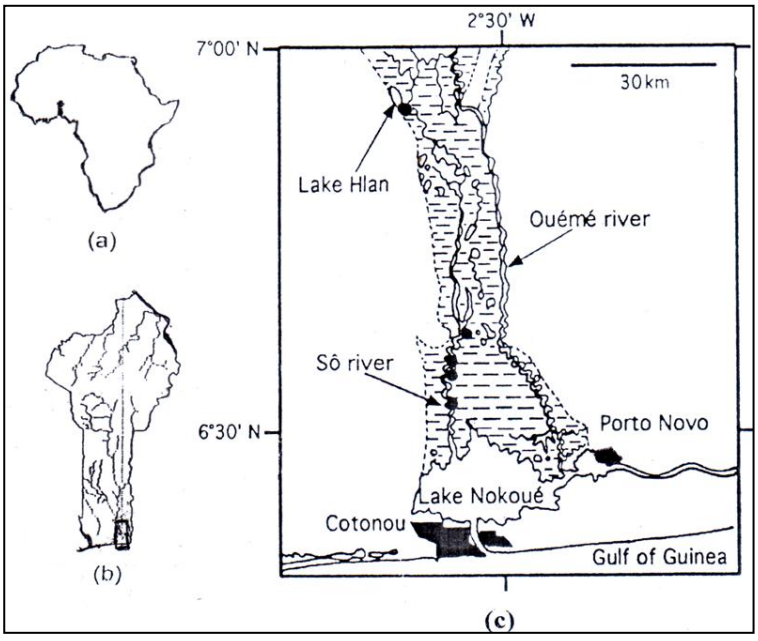

Fig 1: Map showing (a) Benin in Africa, (b) the study area in South- Benin, and the sampling sites (dots) in the Sô River (villages Ahome-Gblon, Ahome-Lokpo Zoungome, Kinto, from South to North, respectively) and Lake Hlan (Source: Adite *et al.*, 2013).

into Lake Nokoue, the largest brackish water system in Benin, which also receives freshwaters from the Oueme River, and marine waters from the Atlantic Ocean [13, 29]. As reported by Adité *et al* [11], water level in the river averaged 421.2 (±210.1) cm and Secchi depth averaged 40.3 (±28.2) cm. Water temperature averaged 28.6 (±2.2) ºC and mean pH was nearly acid (5.4±0.6). Dissolved oxygen concentration was low and averaged 1.30 (±1.29) m/l with 19.4% of saturation. Mean electric conductivity was 99.4 (±3.1) µs/cm and mean total dissolved solid (TDS) was 46.7 (±5.38) mg/l. Nitrite concentrations were low and averaged 0.002 (±0.0015) mg/l and total iron was moderately high with a mean of 1.04 (±0.66) mg/l. The Sô River is partially covered by dominant floating vegetation, *Ecchornia crassipes* (Poaceae) that impeds boat navigation, alters water quality and affect fish community structure and abundance. Other common aquatic plants were *Pistia stratiotes* (Araceae), *Ipomea aquatica* (Convolvulaceae), and *Elaies guinensis* (palm tree). The Sô River was dominated by green-blue algae (Myxophyceae), green algae (Chlorophyceae) and diatoms. Zooplankton species were dominated rotifera, les cladocera, ostracods and copepods. Fish composition of the Sô River was mainly dominated by freshwater species such as *Sarotherodon melanotheron*, *Sarotherodon galilaeus*, *Tilapia guineensis*, *Tilapia zillii*, *Clarias guariepinus*, *Parachanna africana*, *Parachanna obscura*, Mormyrids, and *Heterotis niloticus*. Multi-species fisheries occured on the Sô River exploited by more than 8000 sedentary and migrant fishermen, and *Heterotis* is the target species captured during the flooding seasons [13, 29].

Lake Hlan (6º56.88 N; 2º19.48 E), is the Sô River's floodplain and located near Kpomey village (Toffo city, Sehoue County) about 80 km from the Atlantic coast (Fig. 1). The seasonal floodings of the Sô River strongly influences not only the water quality of Lake Hlan, but also the spawning, the recruitment, the growth and the migration of bonytongues. As reported by Adité *et al.* [11], mean water level of Lake Hlan approximated 250.3±128.47 cm, water transparency and water temperature averaged 88.1 (±25.2) cm and 27.6 (±1.8) ºC, respectively. Mean conductivity was 97.0 (±5.5) µs/cm and mean total dissolved solids (TDS) was 47.0 (±2.8) mg/l. Nitrites and total iron concentrations were low and averaged 0.002 (±0.001) mg/l and 0.67 (±0.26) mg/l, respectively. Mean pH in the lake was 5.3 (±0.2), dissolved oxygen concentrations averaged 1.69 (±1.13) m/l (25.5 percent of saturation). Plant communities included floating grasses, such as *Cyperus difformis* (Cyperaceae) covering a huge area of the lake. Other dominant floating plants in Lake Hlan were *Pistia stratiotes* (Araceae), *Azolla africana*, *Nymphaea lotus* (Nymphaeaceae), *Nymphaea maculatus* (Nymphaeacea), *Ecchornia crassipes*, *Echinochloa pyramides* (Poaceae) and some immerged plants such as *Ceratophyllum demersum* (Ceratophyllaceae) and *Utricularia inflexa* (Lantibulariaceae). Dominant phytoplankton species in Lake Hlan were green-blue algae (Myxophyceae) and green algae (Chlorophyceae). Like the Sô River, zooplanktons in Lake Hlan were dominated by rotifera, cladocera, ostracods and copepods. The ichtyofaunal community of Lake Hlan was dominated by freshwater species and included *H. niloticus*, *Tilapia guineensis*, *Tilapia zillii*, *Clarias guariepinus*, *Clarias agboyiensis*, *Sarotherodon galilaeus*, *Parachanna africana*, *Parachanna obscura*, Mormyrids, *Lates niloticus*, *Chrysichthys* sp, *Brycinus* sp. etc. [13, 29]. Lake Hlan is exploited by more than 200 sedentary and migrant fishermen. Well known as "*Heterotis* Lake" for its high abundance in bonytongues, the fish community of Lake Hlan was underexploitated because of the strong local traditions that regulate fishing methods and effort.

Fish Sampling

Bonytongues were collected twice a month from June to December 2013 with the assistance of professional fishermen. In the Sô River, samplings were made near the villages "Ahome-Gblon", "Ahome-Lokpo", "Zoungome", and "Kinto" from both vegetation and open water. In the open water, *Heterotis* were captured with castnets (50-80 mm mesh). Aquatic vegetation samplings were made by enclosing an area with a seine net (10 mm-mesh), then removing the vegetation and fish. Also, in Lake Hlan, samplings were made both in aquatic vegetated swamps surrounding the Lake, and in open water. At both sampling site, *Heterotis* were captured with traps nets (50 mm opening), gill nets (20 x 2 m with 60 mm mesh) and hooks. At the aquatic vegetation site, traps were set at the spawning grounds, close to exits of bonytongue nests.

In both Sô River and Lake Hlan, samplings encompassed wet, high-water and dry season. After collection, the specimens of *Heterotis* were immediately preserved in a cooler with water proof tags [30], and then transported to the laboratory of the "Département de Zoologie" of the "Faculté des Sciences et Techniques, Université d'Abomey-Calavi" for morphometric measurements, meristic counts and appreciation of sexual maturation. Once conveyed to the laboratory, ten (10) morphological descriptors (morphometric measurements) and (14) meristic descriptors were considered for the characterization of bonytongues [8, 19, 31-33]. Morphometric measurements (Fig 2) were made on each specimen and were body weight (BW), total length (TL), standard length (SL), body height (BHe), head length (HL), head height (HHe), snout length (StL), eye diameter (ED), caudal peduncle length (CPL), and caudal peduncle height (CPHe). Body weight of each *Heterotis* specimen was measured to the nearest 0.1 g with an electronic scale Camry (Model EHA1) and the 9 remaining morphometric measurements were done to the nearest 1.0 mm with a Vernier calipers and an ichtyometer.

Meristic counts made on each bonytongue specimen were:

- The number of scales on the lateral line (NSLL);
- The number of scales on the transversal line (NSTL);
- The number of scales between the lateral line and the dorsal fin (NS/LL-DF);
- The number of scales between the lateral line and the ventral fin (NS/LL-VF);
- The number of scales surrounding the caudal peduncle (NSsCP);
- The number of gill rakers on the first gill arch (upper side) of the left side of the fish (NGRa/FtGA-USi/LeSiF);
- The number of gill rakers on the first gill arch (lower side) of the left side of the fish (NGRa/FtGA-LoSi/LeSiF);
- The number of rays at the anal fin (NRAFi);
- The number of rays at the dorsal fin (NRDFi);
- The number of spots on the head (NSpH);

- The number of teeth on the higher jaw (NTHiJ);
- The number of teeth on the lower jaw (NTLoJ)
- The number of spots on the left side of the fish (NSp-LeSiF);
- The number of spots on the right side of the fish (NSp-RiSiF);

After the morphometric measurements and meristic counts, each specimen was dissected to examine sex and gonad maturation. Data on morphometric measurements and meristic counts of *H. niloticus* from both Sô River and Lake Hlan served to characterize the species and to compare the two sub-populations of bonytongues with regard to genders and habitats.

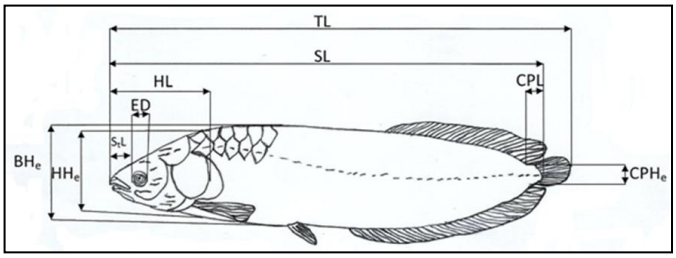

Fig 2: Morphometric measurements used in characterizing *Heterotis niloticus* from Lake Hlan – River Sô aquatic system, Southern Benin: TL = total length, SL = standard length, BHe = body height, HL = head length, HHe = head height, StL = snout length, ED = eye diameter, CPL = caudal peduncle length, CPHe = caudal peduncle height

Data Analysis

The data on morphometric measurements and meristic counts were recorded in Excel software spreadsheet and mean values, ranges and standard errors (±SE) of each feature were computed for both sub-populations. Computed values were from males, females and combined sexes. Length - weight relationships of *Heterotis* from the two habitats were evaluated using linear regressions to search for growth trends. The total length – body weight relationships of bonytongues were obtained from the relationship [34]:

$$W = aTL^b$$

Where,
W = body weight (g);
TL = total length (mm);
a = constant;
b = slope.

The linear regressions were obtained by a logarithmic transformation according to the following formula [34-36]:

$$Log_{10}\ W = Log\ a + bLog_{10}\ TL$$

In this equation, the slope b determines the plumpness (well-being) and growth trends of bonytongues in both habitats [34]. Furthermore, ten (10) other linear regressions (TL – SL; TL – BH_e; TL – HL; TL – S_tL; TL – ED; TL – CPL; TL – CPH_e; HL – S_tL; HL – ED; CPL - CPH_e) were performed using the remaining morphometric measurements to evaluate the general trends.

Also, using morphometric data, nine (9) ratios, TL/SL, SL/BHe, SL/HL, HL/HHe, HL/StL, HL/ED, HHe/ED, BHe/HHe and CPHe/CPL were computed. Ratios are efficient tool to characterize and to identify fish species [30]. Indeed, morphometric measurements, when expressed as body proportions, are very useful tool to describe, characterize and to identify fish because body structures expressed as percentage of total length or other body sizes, generate similar ratio in same species [37-38]. Using genders (males; females) and habitats (Lake Hlan; Sô River) as factors, one-way analysis of variances was run with the Statistical Package for Social Sciences (SPSS version 9.0) [39] to determine if there were any morphological and meristic variations with regard to sex and habitats.

Results

Aspects of Population Structure

A total of eighty (80) specimens of bonytongues has been collected, fourty (40) from Lake Hlan and fourty (40) from Sô River. In both habitats, males dominated the population of *Heterotis* with sex-ratios of 1:0.90 (males: 52.5 %; females: 47.5%) and 1:0.74 (males: 57.5 %; females: 42.5%), in Lake Hlan and Sô River, respectively. In Lake Hlan, 85% of bonytongues had mature gonads whereas 15% had just initiated maturation. In the Sô River, only 60% had mature gonads. In Lake Hlan sample, total length (TL) ranged from 515 mm to 796 mm (mean: 712.60±10.43 mm) and individual weight from 1010.00 g to 3750.00 g (mean: 2860.80±109.20 g). In the Sô River sample, TL varied from 581 mm to 835 mm (mean: 691.00±9.91mm) and individual weights ranged between 1750.00 g and 4550.00 g (mean: 2782.50±112.30 g).

Morphological Relationships and Growth Trends

To explore relationships between morphological factors, eleven (11) regression equations were performed on morphometric measurements of bonytongue samples of each habitat. In Lake Hlan, all the slopes recorded were positive and ranged between 0.39 and 2.97 (Table 1) with coefficient of correlations "*r*" between 0.41 and 0.99. Except for TL – S_tL and HL – S_tL regressions, all the correlation coefficients were significant ($P<0.05$) indicating that the increase in the first morphological factor (mostly TL) led to the increase in the second factor (Table 1). Likewise, in the Sô River, all the slopes recorded were positive and varied between 0.47 and 2.67 (Table 2) with coefficients of correlation "*r*" ranging between 0.54 and 0.99. Except for TL – ED regression ($r = 0.54$), all the correlation coefficients were significant ($P<0.05$) for the 10 remaining regressions (Table 2). In particular, the growth trends and the plumpness of *Heterotis* from both habitats were evaluated through total length (TL) - body weight (BW) relationships, and regression equations were as follows [34-35]:

Lake Hlan: $Log_{10}\ W = -1.6576 + 2.97\ Log_{10}\ TL$ (N = 40, $r = 0.96$)
Sô River : $Log_{10}\ W = -1.3279 + 2.67\ Log_{10}\ TL$ (N = 40, $r = 0.96$)

Both regression equations for Lake Hlan and Sô River showed positive slopes, 2.97 and 2.67, respectively, with significant ($P < 0.01$) correlation coefficients (Fig. 3 and 4).

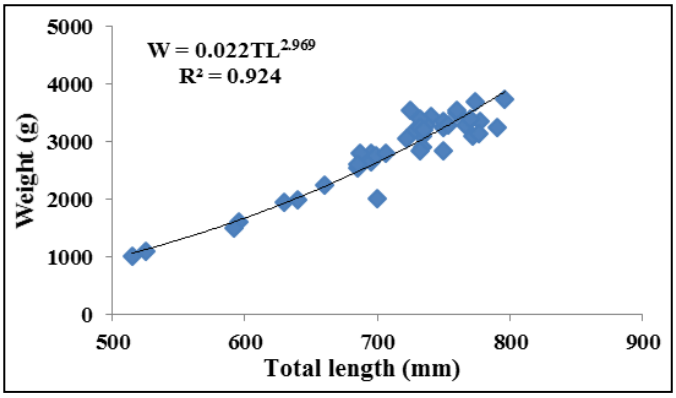

Fig 3: Length – Weight relationships of *Heterotis niloticus* (*N* = 40) captured in Lake Hlan (South-Benin). The slope *b*= 2.969 < 3, with the significant (*P* < 0.01) correlation coefficient "*r*" = 0.96 indicated an allometric growth.

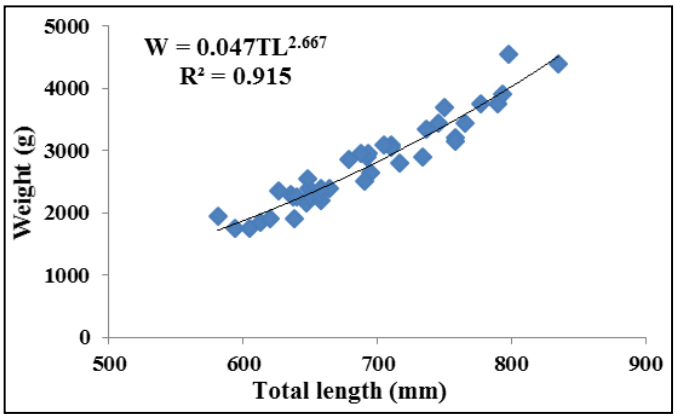

Fig 4: Length – Weight relationships of *Heterotis niloticus* (*N* = 40) captured in River Sô (South-Benin). The slope *b*= 2.667 < 3, with the significant (*P* < 0.01) correlation coefficient "*r*" = 0.96 indicated an allometric growth.

Table 1: Relationships between morphological traits of *Heterotis niloticus* (N = 40) captured in Lake Hlan (South-Benin) from June to December 2013. Morphological measurements were Log_{10} transformed data.

Regression factors	Regression slope (b)	Intercept (Log_{10} a)	Determination coefficient (r^2)	Correlatin coefficient (r)
TL – BW	2.970	-1.6576	0.92	0.96
TL – SL	0.988	-0.006	0.98	0.99
TL – BH_e	0.768	-0.085	0.77	0.88
TL – HL	0.623	0.320	0.77	0.88
TL – S_tL	0.432*	0.246	0.17	0.41
TL – ED	0.450	-0.099	0.44	0.66
TL – CPL	1.616	-4.000	0.61	0.78
TL – CPH_e	0.845	-0.878	0.65	0.81
HL – S_tL	0.827*	-0.257	0.31	0.56
HL – ED	0.502	-0.080	0.40	0.63
CPL - CPH_e	0.386	0.963	0.58	0.76

* Values of males and females indiscriminately. *P*<0.05 for all regression slopes, except for the TL – S_tL and HL – S_tL regressions. BW = body weight, TL = total length, SL = standard length, BH_e = body height, HL = head length, HH_e = head height, S_tL = snout length, ED = eye diameter, CPL = caudal peduncle length, CPHe = caudal peduncle height.

Table 2: Relationships between morphological traits of *Heterotis niloticus* (N = 40) captured in the Sô River (South-Benin) from June to December 2013. Morphological measurements were Log_{10} transformed data.

Regression factors	Regression slope (b)	Intercept (Log_{10} a)	Determination coefficient (r^2)	Correlation coefficient (r)
TL – BW	2.668	-1.3279	0.91	0.96
TL – SL	0.988	-0.004	0.99	0.99
TL – BH_e	0.735	0.013	0.67	0.82
TL – HL	0.563	0.483	0.75	0.87
TL – S_tL	0.735	-0.627	0.45	0.68
TL – ED	0.472*	-0.197	0.29	0.54
TL – CPL	1.039	-1.484	0.53	0.73
TL – CPH_e	0.765	-0.667	0.58	0.76
HL – S_tL	1.442	-1.542	0.75	0.86
HL – ED	0.843	-0.612	0.40	0.63
CPL -CPH_e	0.491	0.787	0.49	0.70

* Values of males and females indiscriminately. *P*<0.05 for all regression slopes, except for the TL – ED regression. BW = body weight, TL = total length, SL = standard length, BH_e = body height, HL = head length, HH_e = head height, S_tL = snout length, ED = eye diameter, CPL = caudal peduncle length, CPHe = caudal peduncle height.

Morphometric Measurements

i) Lake Hlan versus Sô River

Means and ranges of ten (10) morphometric measurements of *Heterotis* (gender regardless) captured from Lake Hlan and Sô River are shown in Tables 3 and 4. Overall, morphometric measurements varied between habitats. Indeed, body weight (BW) varied between 1010.00 g – 4550.00g and mean values were 2860.80±109.20g and 2782.50±112.30g for Lake Hlan and Sô River, respectively. Total length (TL) ranged between 515.00 mm - 835.00 mm and had means of 712.60±10.43 mm and 691.00±9.91mm for Lake Hlan and Sô River, respectively. Standard length (SL) varied from 472.00 mm - 758.00 mm and averaged 652.30±9.58 mm for Lake Hlan and 632.30±8.98 mm for Sô River. Body height (BHe) ranged between 98.00 mm - 150.00 mm and had means of 127.50±1.68 mm and 125.70±1.59 mm, respectively, for Lake Hlan and Sô River. Head length (HL) varied from 101.00 mm - 136.00 mm and gave means of 125.30±1.35 mm for Lake Hlan and 120.80±1.11 mm for Sô River and head height (HHe) gave means of 105.80±1.49 mm and 103.90±1.12 mm, respectively, for Lake Hlan and Sô River. Average snout lengths (StL) were 30.27±0.50 mm and 28.92±0.45 mm, respectively, for Lake Hlan and Sô River, and eye diameter (ED) averaged 15.25±0.15 mm for Lake Hlan and 13.95±0.17 mm for Sô River. Caudal peduncle lengths (CPL) ranged between 14.00 mm – 40.00 mm and had means of 30.45±0.86 mm and 29.35±0.62 mm for Lake Hlan and Sô River, respectively, whereas caudal peduncle heights (CPHe) varied from 25.00 mm to 40.00 mm and had means of 34.22±0.53 mm for Lake Hlan and 32.10±0.46 mm for Sô River.

One-way analysis of variances on the morphometric traits of *Heterotis* from Lake Hlan and Sô River indicated that the variations of most morphometric measurements (BW, TL, SL, BHe, HHe, StL, CPL) across these two habitats were not significantly different ($P \geq 0.05$). Indeed, the computed *F*-values, along with degrees of freedom and *p*-values were $F_{1,78}$ = 0.250, *p* = 0.619 for body weight; $F_{1,78}$ = 2.262, *p* = 0.137 for total length; $F_{1,78}$ = 2.063, *p* = 0.155 for standard

length; $F_{1,78}$ = 0.624, p = 0.432 for body height; $F_{1,78}$ = 0.003, p = 0.320 for head height; $F_{1,78}$ = 3.978, p = 0.051 for snout length; $F_{1,78}$ = 1.077, p = 0.303 for caudal peduncle length. Nevertheless, bonytongue samples from Lake Hlan and Sô River exhibited significant difference (P<0.05) for head length ($F_{1,78}$ = 6.463, p = 0.013), eye diameter ($F_{1,78}$ = 30.871, p = 0.0001) and caudal peduncle height ($F_{1,78}$ = 9.025, p = 0.004).

ii) Sexual Variations in Morphometric Measurements

Tables 3 and 4 show means and ranges of morphometric measurements of both genders of *Heterotis* captured in Lake Hlan and Sô River, respectively. In Lake Hlan, one-way analysis of variances on morphometric traits of bonytongues across the two sexes failed to show any significant differences (P≥0.05) between males and females. Indeed, the computed F-values, along with degrees of freedom and p-values were: $F_{1,38}$ = 0.195, p = 0.661 for body weight; $F_{1,38}$ = 0.711, p = 0.404 for total length; $F_{1,38}$ = 0.934, p = 0.340 for standard length; $F_{1,38}$ = 0.159, p = 0.692 for body height; $F_{1,38}$ = 0.426, p = 0.518 for head length; $F_{1,38}$ = 0.114, p = 0.738 for head height; $F_{1,38}$ = 0.509, p = 0.480 for snout length; $F_{1,38}$ = 0.298, p = 0.589 for eye diameter; $F_{1,38}$ = 0.711, p = 0.404 for caudal peduncle length and $F_{1,38}$ = 0.092, p = 0.764 for caudal peduncle height.

Also, in the Sô River, one-way ANOVA on morphometric traits of bonytongues across the two sexes failed to show any significant differences (P≥0.05) in morphometric measurements between males and females. Indeed, the computed F-values, along with degrees of freedom and p-values were $F_{1,38}$ = 0.809, p = 0.374 for body weight; $F_{1,38}$ = 1.188, p = 0.283 for total length; $F_{1,38}$ = 1.265, p = 0.268 for standard length; $F_{1,38}$ = 0.006, p = 0.937 for body height; $F_{1,38}$ = 2.736, p = 0.106 for head length; $F_{1,38}$ = 0.956, p = 0.334 for head height; $F_{1,38}$ = 3.275, p = 0.078 for snout length; $F_{1,38}$ = 0.061, p = 0.806 for eye diameter; $F_{1,38}$ = 0.656, p = 0.423 for caudal peduncle length and $F_{1,38}$ = 0.382, p = 0.540 for caudal peduncle height.

Body Ratios

Body proportions of *bonytongues* were computed using morphometric data from Lake Hlan and Sô River samples. The results included both spatial (Lake Hlan versus Sô River) and sexual (males versus females) variations.

iii) Lake Hlan versus Sô River

Means and ranges of body ratios of *Heterotis* (males and females indiscriminately) from Lake Hlan and Sô River are shown in Tables 3 and 4. The ratio of standard length to total length (TL/SL) ranged from 1.07-1.10 and mean values of 1.08±0.001 and 1.09±0.001 were recorded for Lake Hlan and Sô River, respectively. The ratio of body height to standard length (SL/BHe) ranged from 4.59-5.78 and mean values of 5.11±0.04 and 5.03±0.04 were recorded for Lake Hlan and Sô River, respectively. Head length: standard length ratio (SL/HL) showed mean values of 5.20±0.04 and 5.23±0.04, respectively for Lake Hlan and Sô River. The ratio of head height to head length (HL/HHe) showed mean values of 1.18±0.01 for Lake Hlan sample and 1.16±0.01 for Sô River sample, and the ratios of the snout length to the head length (HL/StL) averaged 4.16±0.05 and 4.19±0.04 in Lake Hlan and in Sô River, respectively. Eye diameter: head length ratio (HL/ED) varied between 7.25-9.84 and mean values were 8.23±0.07 for Lake Hlan and 8.69±0.08 for Sô River.

The ratio of eye diameter to head height (HHe/ED) varied from 5.61-8.46 and gave mean values of 6.94±0.07 for Lake Hlan and 7.47±0.08 for Sô River. The head height to body height ratio (BHe/HHe) ranged from 1.13-1.46 and mean values of 1.21±0.01 and 1.20±0.01 were recorded in Lake Hlan and Sô River, respectively. Caudal peduncle length: caudal peduncle height ratio (CPHe/CPL) varied from 0.87-1.93 and averaged 1.15±0.03 in Lake Hlan and 1.10±0.02 in the Sô River.

One-way ANOVA on bonytongue body ratios across the two habitats show insignificant differences (P≥0.05) between Lake Hlan and Sô River for most body proportions. Indeed, the computed F-values and p-values were: $F_{1,78}$ = 0.434, p = 0.512 for TL/SL ratio; $F_{1,78}$ = 1.594, p = 0.211 for SL/BHe ratio; $F_{1,78}$ = 0.384, p = 0.537 for SL/HL ratio; $F_{1,78}$ = 3.361, p = 0.071 for HL/HHe ratio; $F_{1,78}$ = 0.204, p = 0.653 for HL/StL ratio; $F_{1,78}$ = 0.016, p = 0.900 for BHe/HHe ratio and $F_{1,78}$ = 2.053, p = 0.156 for CPHe/CPL ratio. Nevertheless, the ratios of eye diameter to head length (HL/ED) with $F_{1,78}$ = 16.185, p = 0.0001 and those of eye diameter to head height (HHe/ED) with $F_{1,78}$ = 24.931, p = 0.0001 showed significant differences (P <0.0001) between Lake Hlan and Sô River.

Table 3: Means, standard errors, minima and maxima of morphomtric measurements, and body ratios recorded on *Heterotis niloticus* (regardless of genders) captured in Lake Hlan and the Sô River (South-Benin) from June to December 2013.

Morphometric measurements & Ratios	Lake Hlan (N=40)				Sô River (N=40)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
BW	2860.80	109.20	1010.00	3750.00	2782.50	112.30	1750.00	4550.00
TL	712.60	10.43	515.00	796.00	691.00	9.91	581.00	835.00
SL	652.30	9.58	472.00	730.00	632.30	8.98	534.00	758.00
BHe	127.50	1.68	98.00	145.00	125.70	1.59	105.00	150.00
HL	125.30	1.35	101.00	136.00	120.80	1.11	107.00	135.00
StL	30.27	0.50	25.00	37.00	28.92	0.45	25.00	35.00
ED	15.25	0.15	13.00	17.00	13.95	0.17	12.00	16.00
CPL	30.45	0.86	14.00	39.00	29.35	0.62	23.00	40.00
CPHe	34.22	0.53	25.00	40.00	32.10	0.46	25.00	40.00
HHe	105.80	1.49	73.00	116.00	103.90	1.12	90.00	120.00
Ratios								
TL/SL	1.08	0.00	1.07	1.10	1.09	0.00	1.07	1.10
SL/BHe	5.11	0.04	4.72	5.64	5.03	0.04	4.59	5.78

SL/HL	5.20	0.04	4.52	5.58	5.23	0.04	4.75	5.69
HL/HHe	1.18	0.01	1.09	1.46	1.16	0.01	1.09	1.26
HL/StL	4.16	0.05	3.25	4.78	4.19	0.04	3.65	4.64
HL/ED	8.23	0.07	7.25	9.28	8.69	0.08	7.25	9.84
HHe/ED	6.94	0.07	5.61	8.00	7.47	0.08	6.37	8.46
BHe/HHe	1.21	0.01	1.13	1.46	1.20	0.01	1.15	1.35
CPHe/CPL	1.15	0.03	0.97	1.93	1.10	0.02	0.87	1.30

Table 4: Means, standard errors, minima and maxima of morphomtric measurements and body ratios recorded on *Heterotis niloticus* males and females captured in Lake Hlan (South-Benin) from June to December 2013.

Morphometric measurements & Ratios	Male (N=21)				Female (N=19)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
BW	2907.10	167.00	1100.00	3750.00	2809.50	141.00	1010.00	3450.00
TL	721.00	16.40	525.00	796.00	703.30	12.53	515.00	770.00
SL	659.90	15.24	475.00	730.00	643.80	11.23	472.00	696.00
BHe	126.90	2.65	98.00	145.00	128.20	2.03	100.00	142.00
HL	126.10	1.97	105.00	136.00	124.30	1.85	101.00	135.00
StL	30.61	0.77	25.00	35.00	29.89	0.63	25.00	37.00
ED	15.33	0.23	13.00	17.00	15.16	0.22	13.00	16.00
CPL	31.14	1.14	20.00	39.00	29.68	1.30	14.00	37.00
CPHe	34.38	0.91	25.00	40.00	34.05	0.53		
HHe	106.30	1.90	85.00	116.00	105.30	2.40	73.00	115.00
Ratios								
TL/SL	1.09	0.00	1.07	1.10	1.09	0.00	1.08	1.10
SL/BHe	5.20	0.06	4.81	5.64	5.02	0.03	4.72	5.33
SL/HL	5.22	0.06	4.52	5.58	5.17	0.05	4.67	5.57
HL/HHe	1.18	0.01	1.11	1.26	1.18	0.02	1.09	1.46
HL/StL	4.14	0.07	3.65	4.78	4.18	0.08	3.25	4.64
HL/ED	8.23	0.10	7.33	9.21	8.22	0.12	7.25	9.28
HHe/ED	6.94	0.09	6.00	7.36	6.94	0.13	5.61	8.00
BHe/HHe	1.19	0.01	1.13	1.28	1.22	0.02	1.15	1.46
CPHe/CPL	1.12	0.02	1.00	1.27	1.19	0.06	0.97	1.93

Table 5: Means, standard errors, minima and maxima of morphomtric measurements and body ratios recorded on *Heterotis niloticus* males and females captured in the Sô River (South-Benin) from June to December 2013.

Morphometric measurements & Ratios	Male (N=23)				Female (N=17)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
BW	2869.60	173.20	1750.00	4550.00	2664.70	122.50	1750.00	3700.00
TL	700.20	15.15	581.00	835.00	678.40	10.92	594.00	758.00
SL	641.00	13.59	534.00	758.00	620.60	10.21	543.00	695.00
BHe	125.60	2.43	105.00	150.00	125.80	1.88	110.00	135.00
HL	122.30	1.59	107.00	135.00	118.70	1.37	107.00	131.00
StL	29.61	0.61	25.00	35.00	28.00	0.60	25.00	33.00
ED	104.90	1.67	90.00	120.00	102.60	1.36	95.00	113.00
CPL	13.91	0.24	12.00	16.00	14.00	0.24	13.00	16.00
CPHe	32.35	0.74	25.00	40.00	31.76	0.45	30.00	36.00
HHe	29.78	0.95	23.00	40.00	28.76	0.67	23.00	35.00
Ratios								
TL/SL	1.08	0.00	1.06	1.10	1.09	0.00	1.08	1.10
SL/BHe	5.10	0.05	4.64	5.78	4.93	0.05	4.59	5.41
SL/HL	5.23	0.05	4.75	5.65	5.23	0.03	4.76	5.69
HL/HHe	1.16	0.00	1.09	1.25	1.16	0.01	1.09	1.25
HL/StL	4.15	0.04	3.65	4.62	4.25	0.05	3.72	4.64
HL/ED	8.82	0.11	7.81	9.84	8.50	0.11	7.25	9.15
HHe/ED	7.56	0.11	6.67	8.46	7.35	0.09	6.37	8.08
BHe/HHe	1.19	0.00	1.15	1.28	1.22	0.01	1.16	1.35
CPHe/CPL	1.09	0.02	0.87	1.30	1.11	0.02	0.94	1.30

iv) Sexual variations of body ratios

Tables 4 and 5 show means and ranges values of body ratios of bonytongues males and females from Lake Hlan and Sô River. In Lake Hlan (Table 4), one-way analysis of variances on bonytongue body ratios across the two sexes failed to show any significant differences ($P \geq 0.05$) between males and females for most body proportions. Indeed, the computed F-values and p-values were: $F_{1,38} = 0.433$, $p = 0.514$ for TL/SL ratio; $F_{1,38} = 0.611$, $p = 0.439$ for SL/HL ratio; $F_{1,38} = 0.0001$, $p = 0.993$ for HL/HHe ratio; $F_{1,38} = 0.093$, $p = 0.763$ for

HL/StL ratio; $F_{1,38}$ = 0.016, p = 0.901 for HL/ED ratio; $F_{1,38}$ = 0.002, p = 0.964 for HHe/ED ratio; $F_{1,38}$ = 2.558, p = 0.118 for BHe/HHe ratio, and $F_{1,38}$ = 1.525, p = 0.224 for CPHe/CPL ratio. Nevertheless, the ratio of body height to standard length (SL/BHe) exhibited significant differences ($F_{1,38}$ = 6.944, p = 0.012) between males and females from Lake Hlan.

Also, in the Sô River (Table 5), one-way ANOVA on the body ratios of bonytongues across the two sexes, indicated that the variations of body proportions between males and females were not significantly different ($P \geq 0.05$) for most body ratios. Indeed, the computed F-values and p-values were: $F_{1,38}$ = 0.224, p = 0.638 for TL/SL ratio; $F_{1,38}$ = 0.001, p = 0.970 for SL/HL ratio; $F_{1,38}$ = 0.567, p = 0.456 for HL/HHe ratio; $F_{1,38}$ = 2.156, p = 0.150 for HL/StL ratio; $F_{1,38}$ = 3.832, p = 0.058 for HL/ED ratio; $F_{1,38}$ = 1.939, p = 0.172 for HHe/ED ratio; $F_{1,38}$ = 0.192, p = 0.664 for CPHe/CPL ratio. Nevertheless, the ratio of body height to standard length (SL/BHe), and that of head height to body height (BHe/HHe) exhibited significant differences ($F_{1,38}$ = 4.491, p = 0.041 and $F_{1,38}$ = 5.161, p = 0.029, respectively) between males and females from Sô River.

Meristic Counts

i) Lake Hlan Versus Sô River

Tables 6 shows means and ranges values of the fourteen (14) meristic characters recorded on bonytongues (regardless of genders) from Lake Hlan and Sô River. In general, meristic counts varied within and between habitats. Indeed, the number of scales on the lateral line (NSLL) ranged from 36-41 and mean values were 38.05±0.18 and 38.37±0.19, respectively for Lake Hlan and Sô River samples. Also, the number of scales on the transversal line (NSTL) varied from 10 to 13 and mean values were 11.90.05±0.06 and 12.10±0.08, respectively for Lake Hlan and Sô River. The number of scales between the lateral line and the dorsal fin (NS/LL-DF) ranged from 4.50-6.50 and the mean values of 5.40±0.04 and 5.55±0.06 were recorded for Lake Hlan and Sô River, respectively. The number of scales between the lateral line and the ventral fin (NS/LL-VF) showed mean values of 6.5±0.04 and 6.55±0.05, respectively for Lake Hlan and Sô River. The number of scales surrounding the caudal peduncle (NSsCP) showed mean values of 13.47±0.12 for Lake Hlan and 13.32±0.14 for Sô River. The number of gill rakers on the first gill arch (upper side) of the left side of the fish (NGRa/FtGA-USi/LeSiF) averaged 73.65±0.62 and 72.25±0.89 in Lake Hlan and in Sô River, respectively, and the number of gill rakers on the first gill arch (lower side) of the left side of the fish (NGRa/FtGA-LoSi/LeSiF) averaged 95.32±0.81 and 95.25±0.0.69 in Lake Hlan and in Sô River, respectively. The number of rays at the anal fin (NRAFi) varied from 34-38 and the mean values were 35.75±0.15 and 35.90±0.13, respectively, for Lake Hlan and Sô River. The number of rays at the dorsal fin (NRDFi) ranged from 31-36 and gave mean values of 34.15±0.16 for Lake Hlan and 34.30±0.17 for Sô River. The number of spots on the head (NSpH) ranged from 37-45 and mean values of 42.37±0.33 and 43.75±0.11 were recorded in Lake Hlan and Sô River, respectively. The number of spots on the right side of the fish (NSp-RiSiF) varied from 0-24 and averaged 17.90±0.59 in Lake Hlan and 17.12±0.87 in the Sô River. The number of spots on the left side of the fish (NSp-LeSiF) ranged from 2-26 and gave mean values of 18.92±0.66 for Lake Hlan and 18.25±0.84 for Sô River. The number of teeth on the higher jaw (NTHiJ) varied from 41-65 and averaged 58.32±0.78 in Lake Hlan and 55.95±0.90 in the Sô River. The number of teeth on the lower jaw (NTLoJ) ranged from 30-58 and mean values of 49.60±1.05 and 43.42±0.77 were recorded in Lake Hlan and Sô River, respectively.

In general, one-way ANOVA on bonytongue meristic counts across the two habitats failed to show any significant differences ($P \geq 0.05$) between Lake Hlan and Sô River for most meristic characters. Indeed, the computed F-values along with degree of freedom and p-values were: $F_{1,78}$ =3.245, p = 0.076 for the number of scales on the lateral line (NSLL); $F_{1,78}$ = 3.628, p = 0.061 for the number of scales on the transversal line (NSTL); $F_{1,78}$ = 3.695, p = 0.058 for the number of scales between the lateral line and the dorsal fin (NS/LL-DF); $F_{1,78}$ = 0.661, p = 0.419 for the number of scales between the lateral line and the ventral fin (NS/LL-VF); $F_{1,78}$ = 0.619, p = 0.434 for the number of scales surrounding the caudal peduncle (NSsCP); $F_{1,78}$ = 1.638, p = 0.204 for the number of gill rakers on the first gill arch (upper side) of the left side of the fish (NGRa/FtGA-USi/LeSiF); $F_{1,78}$ =0.005, p = 0.944 for the number of gill rakers on the first gill arch (lower side) of the left side of the fish (NGRa/FtGA-LoSi/LeSiF); $F_{1,78}$ = 0.53, p = 0.465 for the number of rays at the anal fin (NRAFi); $F_{1,78}$ = 0.411, p = 0.524 for the number of rays at the dorsal fin (NRDFi); $F_{1,78}$ = 3.952, p = 0.051 for the number of teeth on the higher jaw (NTHiJ); $F_{1,78}$ = 0.540, p = 0.464 for the number of spots on the right side of the fish (NSp-RiSiF); $F_{1,78}$ = 0.397, p = 0.530 for the number of spots on the left side of the fish (NSp-LeSiF). Nevertheless, the number of spots on the head (NSpH) with $F_{1,78}$ = 15.135, p = 0.0001, and the number of teeth on the lower jaw (NTLoJ) with $F_{1,78}$ = 22.284, p = 0.0001 showed significant differences (P<0.0001) between bonytongue samples from Lake Hlan and those from the Sô River.

Table 6: Means, standard errors, minima and maxima of meristic counts recorded on *Heterotis niloticus* (regardless of genders) captured in Lake Hlan and in the Sô River (South-Benin) from June to December 2013.

Meristic characters	Lake Hlan (N=40)				Sô River (N=40)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
NSLL	38.85	0.18	36.00	41.00	38.37	0.19	36.00	41.00
NSTL	11.90	0.06	11.00	13.00	12.10	0.08	10.00	13.00
NS/LL-DF	5.40	0.04	4.50	5.50	5.55	0.06	4.50	6.50
NS/LL-VF	6.50	0.04	5.50	7.50	6.55	0.05	5.50	7.50
NSsCP	13.47	0.12	11.00	15.00	13.32	0.14	11.00	14.00
NGRa/FtGA-USi/LeSiF	73.65	0.62	63.00	80.00	72.25	0.89	45.00	80.00

NGRa/FtGA-LoSi/LeSiF	95.32	0.81	73	101	95.25	0.69	87	105
NRAFi	35.75	0.15	34	37	35.90	0.13	34	38
NRDFi	34.15	0.16	31	36	34.30	0.17	32	36
NSpH	42.37	0.33	37	45	43.75	0.11	41	45
NTHiJ	58.32	0.78	41	65	55.95	0.90	42	65
NTLoJ	49.60	1.05	30	58	43.42	0.77	33	54
NSp-LeSiF	18.92	0.66	5	25	18.25	0.84	2	26
NSp-RiSiF	17.90	0.59	9	24	17.12	0.87	0	24

Table 7: Means, standard errors, minima and maxima of meristic counts recorded on *Heterotis niloticus* males and females captured in Lake Hlan (South-Benin) from June to December 2013.

Meristic characters	Male (N=21)				Female (N=19)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
NSLL	39.09	0.23	37.00	41.00	38.58	0.26	36.00	41.00
NSTL	11.90	0.09	11.00	13.00	11.89	0.07	11.00	12.00
NS/LL-DF	5.35	0.07	4.50	5.50	5.44	0.05	4.50	5.50
NS/LL-VF	6.55	0.05	6.50	7.50	6.44	0.05	5.50	6.50
NSsCP	13.38	0.20	11.00	14.00	13.58	0.16	12.00	15.00
NGRa/FtGA-USi/LeSiF	74.23	0.91	65.00	80.00	73.00	0.84	63.00	78.00
NGRa/FtGA-LoSi/LeSiF	96.19	0.89	86.00	101.00	94.36	1.37	73.00	100.00
NRAFi	35.76	0.19	34.00	37.00	35.74	0.25	34.00	37.00
NRDFi	34.23	0.18	32.00	36.00	34.05	0.28	31.00	36.00
NSpH	42.43	0.47	37.00	45.00	42.32	0.49	38.00	44.00
NTHiJ	57.71	1.25	41.00	65.00	59.00	0.90	46.00	63.00
NTLoJ	48.71	1.68	30.00	58.00	50.58	1.23	31.00	54.00
NSp-LeSiF	19.43	0.74	9.00	24.00	18.36	1.13	5.00	25.00
NSp-RiSiF	17.57	0.80	9.00	24.00	18.26	0.88	9.00	24.00

Table 8: Means, standard errors, minima and maxima of meristic counts recorded on *Heterotis niloticus* males and females captured in the Sô River (South-Benin) from June to December 2013.

Meristic characters	Male (N=23)				Female (N=17)			
	Mean	±SE	Minima	Maxima	Mean	±SE	Minima	Maxima
NSLL	38.39	0.24	37.00	41.00	38.35	0.31	36.00	41.00
NSTL	12.08	0.12	10.00	13.00	12.12	0.12	11.00	13.00
NS/LL-DF	5.54	0.07	4.50	6.50	5.56	0.10	4.50	6.50
NS/LL-VF	6.54	0.07	5.50	7.50	6.56	0.06	6.50	7.50
NSsCP	13.56	0.16	12.00	14.00	13.00	0.23	11.00	14.00
NGRa/FtGA-USi/LeSiF	72.21	1.49	45.00	80.00	72.29	0.71	67.00	79.00
NGRa/FtGA-LoSi/LeSiF	96.17	0.97	87.00	105.00	94.00	0.89	88.00	102.00
NRAFi	36.00	0.16	35.00	37.00	35.76	0.21	34.00	38.00
NRDFi	34.21	0.22	32.00	36.00	34.41	0.25	32.00	36.00
NSpH	43.61	0.17	41.00	44.00	43.94	0.10	43.00	45.00
NTHiJ	55.61	1.05	45.00	65.00	56.41	1.61	42.00	65.00
NTLoJ	43.47	1.04	33.00	54.00	43.35	1.20	36.00	53.00
NSp-LeSiF	18.30	0.99	7.00	26.00	18.18	1.49	2.00	25.00
NSp-RiSiF	16.13	1.39	0.00	24.00	18.47	0.73	14.00	24.00

ii) Sexual variations of meristic counts

Tables 7 and 8 show means and ranges values of meristic counts on bonytongues males and females from Lake Hlan and Sô River.

In Lake Hlan, one-way analysis on meristic traits of bonytongue across the two sexes failed to show any significant differences ($P \geq 0.05$) between males and females. Indeed, the computed *F*-values and *p*-values were $F_{1,38} = 2.086$, $p = 0.157$ for the number of scales on the lateral line (NSLL); $F_{1,38} = 0.007$, $p = 0.935$ for the number of scales on the transversal line (NSTL); $F_{1,38} = 0.877$, $p = 0.355$ for the number of scales between the lateral line and the dorsal fin (NS/LL-DF); $F_{1,38} = 2.005$, $p = 0.165$ for the number of scales between the lateral line and the ventral fin (NS/LL-VF); $F_{1,38} = 0.581$, $p = 0.451$ for the number of scales surrounding the caudal peduncle (NSsCP); $F_{1,38} = 0.978$, $p = 0.329$ for the number of gill rakers on the first gill arch (upper side) of the left side of the fish (NGRa/FtGA-USi/LeSiF); $F_{1,38} = 1.285$, $p = 0.264$ for the number of gill rakers on the first gill arch (lower side) of the left side of the fish (NGRa/FtGA-LoSi/LeSiF); $F_{1,38} = 0.006$, $p = 0.937$ for the number of rays at the anal fin (NRAFi); $F_{1,38} = 0.320$, $p = 0.575$ for the number of rays at the dorsal fin (NRDFi); $F_{1,38} = 0.028$, $p = 0.869$ for the number of spots on the head (NSpH); $F_{1,38} = 0.334$, $p = 0.567$ for the number of spots on the right side of the fish (NSp-RiSiF); $F_{1,38} = 0.631$, $p = 0.432$ for the number of spots on the left side of the fish (NSp-LeSiF); $F_{1,38} = 0.666$, $p = 0.419$ for the number of teeth on the higher jaw (NTHiJ); $F_{1,38} = 0.777$, $p = 0.384$ for the number of teeth on the lower jaw (NTLoJ).

Also, in the Sô River, one-way analysis of variances on meristic traits of *Heterotis* across the two sexes showed

insignificant differences ($P \geq 0.05$) between males and females from the Sô River for most meristic characters. The computed *F*-values and *p*-values were $F_{1,38} = 0.010$, $p = 0.923$ for the number of scales on the lateral line (NSLL); $F_{1,38} = 0.030$, $p = 0.863$ for the number of scales on the transversal line (NSTL); $F_{1,38} = 0.015$, $p = 0.904$ for the number of scales between the lateral line and the dorsal fin (NS/LL-DF); $F_{1,38} = 0.022$, $p = 0.882$ for the number of scales between the lateral line and the ventral fin (NS/LL-VF); $F_{1,38} = 0.002$, $p = 0.967$ for the number of gill rakers on the first gill arch (upper side) of the left side of the fish (NGRa/FtGA-USi/LeSiF); $F_{1,38} = 2.503$, $p = 0.122$ for the number of gill rakers on the first gill arch (lower side) of the left side of the fish (NGRa/FtGA-LoSi/LeSiF); $F_{1,38} = 0.760$, $p = 0.389$ for the number of rays at the anal fin (NRAFi); $F_{1,38} = 0.319$, $p = 0.576$ for the number of rays at the dorsal fin (NRDFi); $F_{1,38} = 2.229$, $p = 0.144$ for the number of spots on the head (NSpH); $F_{1,38} = 1.796$, $p = 0.188$ for the number of spots on the right side of the fish (NSp-RiSiF); $F_{1,38} = 0.006$, $p = 0.941$ for the number of spots on the left side of the fish (NSp-LeSiF); $F_{1,38} = 0.190$, $p = 0.666$ for the number of teeth on the higher jaw (NTHiJ); $F_{1,38} = 0.006$, $p = 0.938$ for the number of teeth on the lower jaw (NTLoJ). Nevertheless, the number of scales surrounding the caudal peduncle (NSsCP) showed significant differences ($F_{1,38} = 4.291$, $p = 0.045$) between males and females from the Sô River.

Ecological Threats

In many African freshwater systems, and particularly in Lake Hlan and Sô River of Benin, the populations of bonytongues are on decline and *Heterotis* fall under threatened or endangered species [17, 26]. Indeed, this species undergoes several ecological threats which negatively affect survival, recruitment, its fisheries yields and population structure. Major recorded threats were, (1) the overexploitation of bonytongues caused by grassroots poverty, the increasing fishermen population, the massive use of controversial, sophisticated and prohibited fishing gears and fishing methods, and the non-respect of national fishing regulation, (2) the loss of habitats caused by the multiple utilizations (agriculture, aquaculture, dumping of domestic wastes, sand dragging etc.) of Lake Hlan and Sô River causing organic and chemical pollutions, loss of marginal and wetland vegetations, and overall habitat alterations, (3) the destruction of spawning and nursery grounds coupled with a high fishing pressure on genitor (spawners) and juveniles causing a probable low rate of breeding, and thus affecting recruitment, (4) the invasion of floating plants, mainly water hyacinths (*Eichhornia crassipes*), affecting water quality, (5) the frequent oil spills occurring in the Sô River which serve for navigation and transportation of gasoline from Nigeria to Benin, and (6) the introduction of exotic and non-native species (example: *Oreochromis niloticus*) in both habitats, which may lead to food competitions and replacement/extermination of native species [26].

Discussions

In most African Sub-Sahelian region, and particularly in Benin, *Heterotis niloticus* (Pisces: Osteoglossiformes: Osteoglossidae) is one of the largest and highly commercial fish that occurs abundantly in the freshwater systems (rivers, streams, floodplains, swamps etc.) such as Lake Hlan and Sô River where bonytongues contributed yearly to 20-70% (mean of ten years: 51.07±15.60%) of the total fish catches [6, 13, 15-18]. The present investigation on the morphological and meristic characterization of *Heterotis* is of great interest in (1) fisheries management, (2) species conservation and habitat protection, and (3) aquaculture [19, 40]. The results of this study give insight on length-weight relationships, growth trends, sexual and spatial variations of morphometric measurements, body ratios and counts of meristic characters, useful to depict whether the population of bonytongues in the Lake Hlan – Sô River system is taxonomically separable [32].

Growth Trends

Log_{10} transformed Total length - Body Weight relationships (Log_{10} TL - Log_{10}W) gave some positive slopes, 2.97 and 2.67, with significant ($P < 0.01$) correlation coefficients ($r = 0.96$; $r = 0.96$) for Lake Hlan and Sô River, respectively, suggesting that bonytongues exhibited an allometric growth (slopes $b < 3$) in both habitats [35-36, 41-42]. Similar trends of positive slopes and allometric growth were reported in previous study by Adite *et al.* [13] for *Heterotis* with "*b*" values of 2.81 and 2.94 for Lake Hlan and Sô River, respectively. In addition, ten (10) other regressions (Tables 1 and 2) established from morphometric measurements as factors showed positive slopes ranging between 2.97 - 0.39 for Lake Hlan and between 2.67 - 0.47 for Sô River with some significant ($P < 0.05$) positive correlation coefficients (*r*) varying between 0.70 – 0.99 for most regressions. Nevertheless, in Lake Hlan, the regressions TL – S_tL with $r = 0.41$ and that of HL – S_tL with $r = 0.56$ were not significant ($P \geq 0.05$). Also, in the Sô River, the regression TL – ED with $r = 0.54$ was not significant ($P \geq 0.05$).

Morphological and Meristic Variations

In fish communities, many authors [8, 19, 31-33] have used morphometric measurements such as total length, standard length, body height, head length, head height, snout length, eye diameter, caudal peduncle length, caudal peduncle height and appropriated derived body proportions to characterize or describe fish species. Likewise, meristic characters such as the counts of scales, fin rays, gill rakers, teeth are commonly utilized to characterize and differentiate fish species [43-46].

In this study, the results indicated that in both habitats, Lake Hlan and Sô River, there was no significant ($P \geq 0.05$) sexual variation in the morphometric measurements discussed, suggesting that males and females of *Heterotis* within Lake Hlan and within Sô River exhibited similar morphometric traits. Also, for most derived computed body ratios, the results showed insignificant ($P \geq 0.05$) sexual variation in bonytongue from both Lake Hlan and Sô River, except for the ratio of body height to standard length (SL/BHe) showing significant differences ($P < 0.05$) between males and females from Lake Hlan ($F_{1, 38} = 6.944$, $p = 0.012$) and from Sô River ($F_{1, 38} = 4.491$, $p = 0.041$), and the ratio of head height to body height (BHe/HHe) exhibiting significant ($F_{1, 38} = 5.161$, $p = 0.029$) sexual variation in the Sô River.

Likewise, for most computed body ratios, the results indicated insignificant ($P \geq 0.05$) spatial variations in the body

proportions, suggesting that bonytongues (regardless of genders) from Lake Hlan and from Sô River exhibited similar body proportions, except the ratios of eye diameter to head length and those of eye diameter to head height showing significant differences ($P < 0.0001$) between Lake Hlan and Sô River.

In fishes, the morphometric measurements, when expressed as the ratio of the total body length, standard length, body height, head length etc., are very useful tool to describe and to identify fish species [30, 32]. As reported by Anetekhai [38], equal ratios of such body measurements from two sub-populations are, in general, recorded in the same species [38]. In the present study, computed body ratios for bonytongues from the Lake Hlan – Sô River aquatic system indicated that total lengths were 1.07-1.10 times the standard length. Proportionally standard lengths were 4.59-5.78 times the body height and 4.52-5.69 times the head length. Also, head lengths were 1.09-1.46 times the head height, 3.25-4.78 times the snout length, and 7.25-9.84 times the eye diameter. Proportionally head heights were 5.61-8.46 times the eye diameter, and body heights were 1.13-1.46 times the head height. Caudal peduncle heights were 0.87-1.93 times the caudal peduncle length. In the Sub-Sahelian region of Africa, Paugy [24] gave a description of young *Heterotis* using body proportions such as the ratio of body height to standard length, ranging between 3.5-5, and that of head length to standard length varying from 3.5 to 5. These results, though comparable with our finding (ratio SL: BHe = 4.59-5.78; ratio HL: SL = 4.52-5.69) still lower, probably, because less developed young immature bonytongues were considered by Paugy [24] to estimate both body ratios. In the present study, fully developed mature bonytongues were considered to evaluate the body proportions.

Also, among anatomic traits, meristic counts are distinctive and useful taxonomic characters to diagnose, characterize and to separate fish species [24, 30, 32]. Fourteen (14) meristic counts related to scales, fin rays, gill rakers, teeth were used in this study to characterize and to differentiate fish taxa. Paugy [24] reported for young *Heterotis*, 33-37 rays on the dorsal fin, 34-38 rays on the anal fin, and 21-98 gill rakers on the gill arch for the West Region of Africa. Overall, these results are similar to our finding except for the number of gill rakers on the gill arch, higher in the present study and ranging between 63 and 101, probably, because young immature bonytongues were considered by Paugy [24] for the count of meristic characters. The present investigation revealed that in Lake Hlan, there was no significant ($p \geq 0.05$) sexual variation in the 14 meristic counts considered (Table 6), suggesting that males and females of *Heterotis* of Lake Hlan exhibited similar meristic characters. The same trends were observed in the Sô River (Table 7), except for the number of scales surrounding the caudal peduncle (NSsCP) showing significant differences ($F_{1,38} = 4.291$, $p = 0.045$) between males and females. Also, the results indicated insignificant ($P \geq 0.05$) spatial variation (Table 8), for most meristic counts, suggesting that bonytongues from Lake Hlan and those from the Sô River, exhibited similar meristic characters, except for the number of spots on the head (NSpH) with $F_{1, 78} = 15.135$ and $p = 0.0001$, and the number of teeth on the lower jaw (NTLoJ) with $F_{1, 78} = 22.284$ and $p = 0.0001$ showing significant differences between bonytongues from Lake Hlan and from Sô River.

In this study, as mentioned above, two body ratios, the ratio of eye diameter to head length (HL/ED) and that of eye diameter to head height (HHe/ED) showed significant differences between Lake Hlan and Sô River. Also, among the meristic characters, the number of spots on the head (NSpH) and the number of teeth on the lower jaw (NTLoJ) showed significant differences between bonytongues from Lake Hlan and Sô River. These spatial variations may be attributed to differential habitat characteristics, environment degradation, geographic variation and human activities which may affect the growth and functions of diverse organs of *Heterotis* [32, 40]. Indeed, Lake Hlan is a lentic, motionless environment with reduced water flow while the Sô River is a lotic and turbid habitat showing higher water flow and creating floodplains during the high-water seasons.

As results, the morphometric measurements, body ratios and meristic counts recorded on *Heterotis*, failed to show variations between the sub-population of Lake Hlan and the sub-population of the Sô River. Consequently, the bonytongue population of the Lake Hlan - Sô River aquatic system is morphologically and taxonomically inseparable, indicating that the population may not be genetically diversified. Indeed, Lake Hlan receives water from both Ouéme River and Sô River, this later is a secondary channel of the lower Ouemé River [19], suggesting that bonytongues from Lake Hlan and Sô River originated from the same source, the Ouemé River. The phenotypic variations recorded in few morphological and meristic descriptors were probably the results of habitat, environment degradation, geographic variation and human activities [31-32, 40], suggesting that *Heterotis* may probably be the only (unique) species in Lake Hlan - Sô River water system of Benin.

Nevertheless, between Lake Hlan and Sô River, considering the significant variations of ratio HL/ED, ratio HHe/ED, the number of spots on the head (NSpH) and the number of teeth on the lower jaw (NTLoJ), and considering the high occurrence of *Heterotis* in the Benin freshwater system, further studies on morphological and meristic characterization of bonytongues should be implemented in all Benin freshwater systems such as the Mono River, the Oueme River, the Niger River and associated floodplains and lakes to confirm the uniqueness of the bonytongue species in Benin. In addition, molecular analysis should be considered because it will provide more precise results on genetic diversification among the population of *Heterotis* in the Benin freshwater system [25, 32].

Management Implications

The study gives valuable database on morphological and meristic traits of bonytongues, and insight on its major ecological threats. To efficiently prevent the extinction of this one-species fish [47], an appropriate and holistic management scheme and conservation measures are required and should be urgently implemented for the recovery of *Heterotis* and its sustainable exploitation. The management scheme should include (1) an extensive morphological, meristic, ecological and biological studies on bonytongue populations from diverse water bodies of Benin, (2) the promotion of economic valorization of bonytongues through aesthetical creations, an

ecological sound ecotourism (aquarium, sport fisheries), aquaculture and fisheries (in Benin, *Heterotis* is among the most valuable fish species and a single adult bonytongue cost nearly $20); (3) strengthening and re-enforcing fishery regulation, laws and policies to prevent the use of detrimental fishing gears, overfishing and to protect spawning and nursery grounds; (4) developing an integrated environmental education program in participatory approach with grassroots; (5) Controlling exotic and non-native species such as the Nile tilapia, *Oreochromis niloticus*, occurring in most Benin aquatic habitats; (6) protecting and restoring bonytongue habitats: spawning and nursery grounds should be protected by having closed fishing seasons for bonytongues, and all water bodies or habitats with high potential of *Heterotis* in the country should be highly protected with special regulation and (7) developing an environment monitoring program as follow-up, to periodically assess the status of bonytongue populations [19].

Conclusion

The African bonytongue, *Heterotis niloticus*, is a highly valuable species both in fisheries and in aquaculture. This preliminary investigation on the characterization of *Heterotis* from Lake Hlan and Sô River give a better understanding and database on the morphological and meristic traits of this one-species fish of the Osteglossidae. In both habitats, *Heterotis* exhibited an allometric growth. Overall, the results indicated that in both habitats, Lake Hlan and Sô River, there were no sexual variation in the morphometric measurements and in meristic characters. Also, the two sub-populations of Lake Hlan and Sô River fail to show variation in the morphometric measurements and meristic characters. The result indicated that the two sub-populations are morphologically and taxonomically inseparable indicating that *H. niloticus* may probably be a unique species in the Lake Hlan – Sô River system. The implementation of a management strategy and conservation measures required further studies on morphological and meristic characterization of bonytongues coupled with ecological, biological and molecular studies in all Benin freshwater systems to gather better knowledge on the species in these degraded habitats [25, 32].

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