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# Morphological variations, length-weight relationships and condition factors of *Hemichromis camerounensis* (Cichliformes, Cichlidae) in three lakes in northern Cameroon

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**Abstract**
The presence of numerous crater lakes in the Cameroon Volcanic Line offers an exceptional opportunity to study the influence of habitat on the evolution of cichlids. We examined the characteristics of three lake populations of *Hemichromis camerounensis*, all located on the Adamawa plateau in northern Cameroon. In total, 31 morphometric characters were examined of 277 fish specimens caught in two lakes with an outlet (Dang and Bini) and in a lake without an outlet (Tizong). Length-weight relationships and condition factors were estimated for each population. The physico-chemical parameters of the water were measured. Lake Tizong differed significantly from the other two lakes by its higher values of pH, conductivity and TDS. The length/depth and height/width ratios of different parts of the body and the total number of gill rakers on the first gill arch were significantly reduced in the population of Tizong, which was also characterized by small size individuals. The length-weight relationship was positively allometric for the populations of Bini and Dang but negatively allometric for the population of Lake Tizong. The condition factor of the fish was very low in Tizong. The morphological differences observed between the three populations should be taken into account in any systematic study that includes *H. camerounensis* populations from the studied zone.

**Keywords:** cichlids, crater lake, outlet, volcanic line, negative allometry

## 1. Introduction
Populations of species with a large distribution area are generally characterized by morphological variation that may complicate the delineation of the species and renders their identification ambiguous. Consequently, the same populations may be assigned to different species by different authors when the influence of their habitats on morphology and physiology has not been assessed sufficiently and taken into account [1]. (Many studies on fishes worldwide concern the morphological variability, length-weight relationships and condition factors of different fish species or populations of the same species [2-6]. In most cases, the inter-population variation is influenced by physico-chemical parameters of aquatic habitats [7-10], genetic mutations and natural selection [11, 12] or by the bio-geographical history and life history strategies of the populations [13].

The group of five-spotted *Hemichromis* Peters, 1858 [24] in West Africa and Lower Guinea includes three known species: *Hemichromis camerounensis* Bitja Nyom *et al.* 2021 [14] is the latest species described recently from the coastal basins in Western Cameroon and in the upper Logone River (Chad basin) in Cameroon. It differs from *H. fasciatus* Peters 1858 [24] and from *H. elongatus* (Guichenot, 1861) by many morphological et genetic traits [14]. Furthermore, *H. fasciatus* has a large distribution in West Africa (from the Senegal to the Chad basin) while *H. elongatus* is found in part of Lower Guinea including the coastal rivers of Gabon, Equatorial Guinea and the Republic of the Congo, and also in a small part of the Cameroonese Congo Basin (Dja) [14].

The Adamawa Plateau in northern Cameroon contains eight lakes [15]. Some of them, like Bini, Dang and Tizong, host populations of *H. camerounensis*. Tizong is a crater lake without outlet whiles each of other two crater lakes are connected to its tributary river by outlet. The aim of this work is to study the morphological variations of these three *H. camerounensis* populations and the relationships between the aquatic environment and the morphology, based on the analysis of water physico-chemical parameters, length-weight relationships and condition factors.

## 2. Materials and Methods

### 2.1 Study area

This work was carried out in three lakes (Bini, Dang and Tizong) all located near Ngaoundéré, Cameroon (Figure 1).

Lake Bini (N: 7°25'54.01''; E: 13°30'26.63''; Altitude: 1076 m) drains its waters into the Bini river, which belongs to the Lake Chad basin [16]. Its surface is approximately 20 ha while the depth is unknown. It is a eutrophic lake [17] characterized by the presence of significant savannah vegetation on its banks used for agricultural activities and livestock pastoralism [18]. There is an uncontrolled fishing activity in the lake.

Lake Dang (N: 07°25'29.01''; E: 13°32'54.01''; Altitude: 1072 m) also drains into the Bini river [16]. The median crater rim height above the lake surface is 5m; the surface is 80 ha [15] and the mean depth is about 2.5 m [19]. Also eutrophic, it is characterized by similar vegetation than that of Bini, but less dense, probably because of it closeness to the national road N1. Uncontrolled fishing, agriculture, livestock pastoralism and washing of clothes and cars are the main human activities in and around Dang [19].

Lake Tizong (N: 07°15'11.00''; E: 13°34'40.6''; Altitude: 1065 m) is an endorheic crater lake located on Mount Mardja; without outlet, it belongs to the Sanaga basin [16]. The median crater rim height above the lake surface is about 70 m; the lake surface is 8 ha, the maximal depth is 48 m and the mean depth 26.2m [15]. Fishing is little practiced there and vegetation grows on its banks.

### 2.2 Data sampling

The physico-chemical parameters of the surface water (temperature, pH, conductivity and Total Dissolved Solids (TDS)) were measured monthly in each lake in the dry season between January and March 2017, using a PCSTestr multiparameter. Fish were caught using three sets of gillnets with different mesh sizes: 20, 25, 30, 35 and 40 mm. Each month each lake was fished during 24h. Gillnets were set in the evening at 6h p.m. and hauled at 6h p.m. the next day. The captured fish were photographed, weighed using an electronic balance, and their standard and total lengths measured using a caliper.

### 2.3 Estimation of the length-weight relationship

The relationship between total length and weight of *Hemichromis* specimens was estimated by the classical equation $W = aL^b$ [20]. $W$ is the weight and $L$ the total length of fish expressed respectively in grams (g) and centimeters (cm); $a$ is a constant and $b$ the coefficient of allometry. The logarithmic transformation of this formula corresponds to the linear equation: $Log\ W = Log\ a + b\ Log\ L$. The Pearson correlation "*r*" between $W$ and $L$ was calculated. The coefficient of allometry $b$ can differ between populations because of different environmental conditions; this was tested using a $t$ test that estimate difference from isometry with the following formula: $t = (b - 3)/SE$, with $b$ as slope and SE the standard error at the slope [21, 22].

### 2.4 Estimation of the condition factor

The condition factor of the fish was evaluated by the $K$ index according to Lévêque [23], $K = W \times 100 / L^b$. $b$ is the coefficient of allometry corresponding to the exponent of the weight-length relationship estimated above.

### 2.5 Morphometric analyses

Live and freshly-killed specimens were identified phenotypically based on their colour pattern [24-26]. Measurements and meristic counts were taken following Snoeks [27] and Bitja Nyom *et al.* [28]. Measurements were taken point-to-point to the nearest 0.1 mm on the left side of specimens using digital calipers. Principal Component Analyses (PCA) of log-transformed measurements and PCA of percent-transformed measurements [body metrics as a percentage of standard length (SL) and head metrics as a percentage of head length (HL)] were performed using Statistica software (version 12.0. of Stat Soft inc. 2012); only plot with the last option is presented. The raw data were used for meristics. Meristic and metric data were analysed separately. When log-transformed metrics were used in the PCA, the first axis was interpreted as a proxy for size [27-30]; therefore, only the second, third and fourth axes were used to explore data. The variance analysis (ANOVA) followed by the univariate comparisons were performed using the non-parametric Mann-Whitney $U$ test to compare inter-population parameters (morphometric characters, physico-chemicals parameters, length-weight parameters and factor condition of fish). P values < 0,05 were considered significant.

## 3. Results

### 3.1 Physico-chemical characteristics of the water

The temperature, pH, conductivity and TDS of the surface water in the lakes during the study period are recorded in Table 1. The ANOVA showed that certain values differ significantly between the three lakes compared and post-hoc Tukey test showed that the temperature was similar in lakes Tizong and Dang, while the pH and the TDS were similar in Lakes Bini and Dang. The conductivity differed significantly in the three habitats. Except for the temperature, the highest values of the parameters were recorded in Tizong.

### 3.2 Comparative morphology of three populations of *H. camerounensis*

#### 3.2.1 Colour patterns of live and fresh specimens

The three populations had several common phenotypic characteristics (two red opercular spots surrounding a large black spot, absence of small black dots between the first three black major spots on the flanks), which should be referred to *H. camerounensis* [14] (Figure 2).

#### 3.2.2 Comparative morphometry

The principal component analyses showed that the population of Tizong diverged slightly respectively towards the positive part of the axis 1 for measurements and the negative part of the axis 2 (Figure 3a and 3b). The overlap is considerable, which indicates that the three populations most probably belong to the same species.

The univariate analysis showed that individuals from Tizong had a narrower head and smaller interorbital width, a shallower body and caudal peduncle and a shorter dorsal fin base (Table 2). This evolution is also characterized by the reduction of the number of gill rakers on the first gill arch and the number of cheek scales (Table 3).

### 3.3 Length-weight relationships
The values of parameters of the length-weight relationships are given in Table 4.
The values of *b* estimated for the three *H. camerounensis* populations differed significantly with 3.0. The growth was positively allometric in Bini and Dang (large weight compared to fish size) and negatively allometric in Tizong (small weight compared to size).

### 3.4 Condition factor
The mean weight and length of individuals from Bini and Dang were generally higher than those from Tizong caught with the same fishing effort (Table 5). The differences in means of weight and size of the three fish populations were highly significant for the ANOVA (respectively F = 47.728, $P$ <0.001 and F = 41.644, $P < 0.001$) and for the pairwise comparisons.
The condition factor of fish was significantly different between the three populations; that of Dang were the highest; that of Tizong was lowest.

## 4. Discussion
### 4.1 Comparative limnology
The present study showed that Lakes Bini and Dang differed significantly from Lake Tizong in pH, conductivity and TDS. About three decades ago, the limnological study by Kling [15] had also shown that Tizong differed from the other two lakes by its enclosure in a volcanic crater with highest crater rim height, its greater depth, its smaller surface and the absence of an outlet. Compared to Bini and Dang, the particular limnological characteristics of Tizong range it among isolated aquatic environments. The origin of this population remained a matter of concern.

### 4.2 Fish morphological variability
Several measurements (head length, pectoral fin length, lower jaw length, dorsal fin base length, snout length, body depth and the caudal peduncle length and depth) differed significantly between the *H. camerounensis* populations from Bini and Dang, and that from Tizong. The total number of gill rakers on the first gill arch was also lower in the specimens from Tizong. Among these characters, the head and dorsal fin base lengths as well as the number of gill rakers of the first gill arch are often considered as good descriptors of populations in West Africa and Lower Guinea cichlid fishes; it was the case of divergent populations of *Sarotherodon melanotheron* in Côte d'Ivoire [31] and *Coptodon kottae* from Barombi Kotto and Mboandong lakes in Cameroon [28].

### 4.3 Environmental pressures and tendency to size reduction of fish in Lake Tizong
The insulation of Lake Tizong may have exerted an evolutionary pressure on its *H. camerounensis* population, which responds by a tendency to size reduction of fish, illustrated by the dominance of small-sized individuals in the catches. The presence of dwarfed populations of an "elongatus-like" fish in crater lakes Barombi Kotto and Mboandong in southern Cameroon was also documented [24, 32]. These dwarfed populations were identified recently as *H. camerounensis* [14].
At the species scale, the existence of dwarf species has been documented in other cichlids from the crater lakes of the Cameroon Volcanic Line. This is the case in Lake Bermin for *Coptodon snyderae* Stiassny *et al.*, 1992 [33], the smallest *Coptodon* known, with a maximum size which rarely exceeds 60 mm SL [26, 33].

### 4.4 Length-weight relationship and condition factor of fish
The length-weight relationship was positively allometric for the populations of Bini and Dang but negatively allometric for the population of Lake Tizong. This is probably related to the restrictive environmental conditions (lack of food, life area reduced, high values of physico-chemical parameters as conductivity and TDS) that exist in Tizong compared to the other two lakes.
According to Froese [3], across fish species in the world the expected range of b is $2.5 < b < 3.5$. Studies which investigated the length-weight relationship of the five-spotted *Hemichromis* taxa, mostly reported positive allometric growth in relatively open ecosystems such as rivers and lagoons, e.g. in *H. elongatus* from the Dzoumouna river (b = 3.305) in the Republic of Congo [34], in *H. fasciatus* from West African estuaries and lagoons with b = 3.330 [35], b = 3.164 [36] and b = 3.17 [37] and from the Taï National Park Basin in Côte d'Ivoire with b = 3.12 [38]. Conversely, negative allometric growth has been reported for *H. fasciatus* in other lagoons in West Africa, with b = 2.20 and b = 2.37 respectively in the lagoons of Ono and Kodjoboué in Côte d'Ivoire [37] and b = 2.39 in New Calabar River in Nigeria [39].
The condition factor in the population of Lake Tizong was very low (K = 0.45 ± 0.05). This value is lower than those reported in the literature for the five-spotted *Hemichromis* taxa: K = 1.929 ± 0.270 for *H. elongatus* from the Dzoumouna river [34]; K = 1.95 ± 0.14, K = 2.78 ± 0.14 and K = 2.07 ± 0.57 for *H. fasciatus* respectively from the Ono, Kodjoboué and Hebe lagoons in Côte d'Ivoire [37]; K = 1.96 ± 0.03 for *H. fasciatus* in New Calabar River in Nigeria [39].
According to Le Cren [20] a condition factor greater than 1.0 indicates a good physiological condition of the fish. Therefore, it appears that the populations of Lakes Bini and Dang live in better environmental conditions than the population of Lake Tizong, which might face greater environmental pressures that significantly reduce their condition factor. The larger K values (> 1.0) in Bini and Dang can be explained by a greater availability of nutrients correlated with the high primary productivity observed in these lakes, a constant renewal of water flow evacuated through the outlets probably determines the renewal of the dissolved oxygen and nutrient exchanges with the surrounding environment. These conditions are different in Lake Tizong where the *H. camerounensis* population is surviving in an island environment.

**Table 1:** Physico-chemical parameters of the surface water in lakes Bini, Dang and Tizong. For each parameter, values with different symbols (α, β or γ) are significantly different

| Population | Temperature (°C) | pH | Total dissolved solids (ppm) | Conductivity (µS/cm) |
|---|---|---|---|---|
| Bini | 23.09 ± 0.22 α | 5.15 ± 0.08 β | 10.22 ± 3.43 β | 16.87 ± 3.28 γ |
| Dang | 21.90 ± 0.22 β | 5.14 ± 0.08 β | 16.55 ± 3.43 β | 27.27 ± 1.28 β |
| Tizong | 21.99 ± 0.25 β | 7.52 ± 0.09 α | 169.20 ± 3.80 α | 260.47 ± 3.63 α |

**Table 2:** Measurements of *H. camerounensis* expressed as mean ± standard deviation (minimum-maximum). † indicates traits that differ significantly (Mann-Whitney U test) between individuals from Lake Tizong and those from Lakes Bini and Dang; ‡ the only one that differs between fish from Lake Bini and those from Lake Dang

| Miaulements | Bini | Dang | Tizong |
|---|---|---|---|
| **Head measurements: (% Head length)** | | | |
| Lachrymal depth | 26.6 ± 1.0<br>(24.9 - 28.7) | 26.3 ± 1.3<br>(23.8 - 294) | 25.3 ± 0.8<br>(234. - 26.2) |
| Snout length | 33.3 ± 1.4<br>(31.2 - 35.8) | 33.8 ± 1.9<br>(28.2 - 38.2 | 32.1 ± 1.0<br>(30.4 - 33.7) |
| Lower jaw length | 46.6 ± 1.8<br>(43.2 - 51.2) | 46.9 ± 1.9<br>(44.0 - 53.0) | 45.1 ± 1.4<br>(43.5 - 48.3) |
| Premaxillary pedicel length | 46.0 ± 1.1<br>(44.2 - 48.7) | 45.8 ± 1.6<br>(43.5 - 51.4) | 44.9 ± 1.2<br>(43.1 - 46.6) |
| Cheek depth | 23.6 ± 1.4<br>(21.1 -25.9) | 24.1 ± 1.8<br>(20.2 - 28.7) | 22.3 ± 1.5<br>(20.1 - 25.1) |
| Eye diameter | 22.2 ± 2.1<br>(17.6 - 26.9) | 29.8 ± 36.8<br>(20.2 - 220.8) | 24.7 ± 2.1<br>(20.9 - 27.6) |
| Interorbital width† | 28.3 ± 1.5<br>(23.5 -31.4) | 28.2 ± 1.5<br>(25.2 - 31.9) | 26.3 ± 1.7<br>(23.1 - 29.1) |
| Head width† | 37.0 ± 1.4<br>(33.4 - 39.0) | 36.6 ± 1.5<br>(34.3 - 40.8) | 34.8 ± 1.2<br>(32.5 - 36.7) |
| **Body measurements (% Standard length)** | | | |
| Head length† | 38.0 ± 0.9<br>(36.6 - 39.8) | 37.4 ± 2.2<br>(29.3 - 40.6) | 39.1 ± 1.2<br>(37.5 - 40.9) |
| Body depth† | 37.7 ± 1.8<br>(33.7 - 40.0) | 37.6 ± 2.5<br>(29.0 - 42.6) | 35.6 ± 2.0<br>(33.0 - 39.2) |
| Dorsal fin base length† * | 53.5 ± 1.2<br>(50.4 - 56.1) | 53.8 ± 2.4<br>(43.7 - 56.6) | 51.9 ± 1.1<br>(50.4 - 54.3) |
| Anal Fin Base length | 16.9 ± 1.2<br>(14.4 - 19.1) | 16.9 ± 1.2<br>(13.5 - 19.5) | 16.7 ± 0.7<br>(15.9 - 18.3) |
| Predorsal distance | 38.2 ± 1.2<br>(35.9 - 40.7) | 38.0 ± 2.4<br>(30.0 - 42.6) | 38.7 ± 0.9<br>(36.8 - 40.3) |
| Prepectoral distance | 36.8 ± 1.1<br>(33.1 - 39.0) | 36.9 ± 1.9<br>(29.1 - 39.4) | 38.0 ± 0.8<br>(36.9 - 39.2) |
| Prepelvic distance | 41.6 ± 1.6<br>(38.2 - 43.9) | 41.7 ± 2.3<br>(32.7 - 45.1) | 41.8 ± 1.8<br>(39.2 - 44.7) |
| Preanal distance | 73.9 ± 1.9<br>(67.5 - 76.8) | 74.1 ± 1.8<br>(71.0 - 79.5) | 73.4 ± 2.2<br>(69.3 - 75.6) |
| Caudal peduncle length | 13.4 ± 0.9<br>(11.3 - 15.2) | 12.9 ± 0.9<br>(10.3 - 14.5) | 13.7 ± 1.1<br>(12.4 - 16.1) |
| Caudal peduncle depth | 16.6 ± 0.9<br>(14.2 - 18.1) | 16.6 ± 0.6<br>(15.3 - 17.6) | 15.9 ± 1.1<br>(13.1 - 16.6) |
| Caudal peduncle (length/ depth)†‡ | 125.0 ± 10.2<br>(103.8 - 147.5) | 128.1 ± 8.3<br>(112.5 - 145.9) | 116.7 ± 12.9<br>(95.1 - 134.6) |

**Table 3:** Measurements of *H. camerounensis* examined by lake, expressed as median (minimum-maximum). † indicates traits that differ significantly (Mann-Whitney U test) between individuals from Lake Tizong and those from Lakes Bini and Dang

| Meristics | Bini | Dang | Tizong |
|---|---|---|---|
| Total gill rakers† | 11 (10 - 12) | 11 (10 -12) | 10 (9 - 12) |
| Dorsal fin spines | 14 (14) | 14 (14) | 14 (14) |
| Dorsal fin soft rays | 12 (11 - 13) | 12 (11 - 13) | 12 (11 -13) |
| Anal fin soft rays | 10 (9 -11) | 10 (9 - 11) | 10 (9 -11) |
| Pectoral fin soft rays | 14 (13 - 15) | 14 (14) | 14 (12 -14) |
| Longitudinal line scales | 29 (28 - 30) | 29 (28 - 29) | 29 (28 -30) |
| Upper lateral line scales | 17 (16 - 18) | 17 (15 - 19) | 16 (14 -18) |
| Lower lateral line scales | 12 (11 - 13) | 11 (11 - 13) | 12 (10 -13) |
| Upper transverse line scales | 4 (4 - 4,5) | 4 (4 - 4,5) | 4 (4 -4,5) |
| Lower transverse line scales | 9 (9 - 10) | 10 (9 -10) | 9 (9 - 11) |
| Pectoral-pelvic fins range scales | 4 (4 - 5) | 5 (4 -6) | 5 (4 - 5) |
| Caudal peduncle rows scales | 16 (14 - 17) | 16 (16) | 16 (16) |
| Cheek scales† | 5 (4 -5) | 5 (5) | 4 (4 - 5) |

**Table 4:** Length-weight relationship parameters in the three *H. camerounensis* populations. a: proportionality constant; b: coefficient of allometry; r: correlation coefficient; *: b-value significantly different from 3

| Population | Number (n) | a | b | r | Allometry |
|---|---|---|---|---|---|
| Bini | 93 | -1.97 | 3.75 * | 0.95 | Positive |
| Dang | 109 | -2.34 | 3.48 * | 0.96 | Positive |
| Tizong | 75 | -1.49 | 2.71 * | 0.95 | Negative |

**Table 5:** Weight, length and condition factor for the three *H. camerounensis* populations studied. For each parameter, the values assigned by different symbols (α, β or γ) in the same column are significantly different at the 5% threshold

| Population | Weigth (g) | | Length (cm) | | Condition factor (K) | |
|---|---|---|---|---|---|---|
| | Min-max | Mean ± SD | Min-max | Mean ± SD | Min-max | Mean ± SD |
| Bini | 13.5 - 88.5 | 43.19 ± 16.81 α | 9.3 - 17.8 | 13.68 ± 1.76 α | 0.80 - 1.38 | 1.09 ± 0.14 α |
| Dang | 13 - 82.5 | 33.54 ± 15.44 β | 9.6 - 17.7 | 12.64 ± 1.92 β | 1.84 - 5.41 | 3.30 ± 0.46 β |
| Tizong | 6.5 - 54.5 | 23.48 ± 10.75 γ | 8.3 - 14.7 | 11.44 ± 1.50 γ | 0.28 - 0.55 | 0.45 ± 0.05 γ |

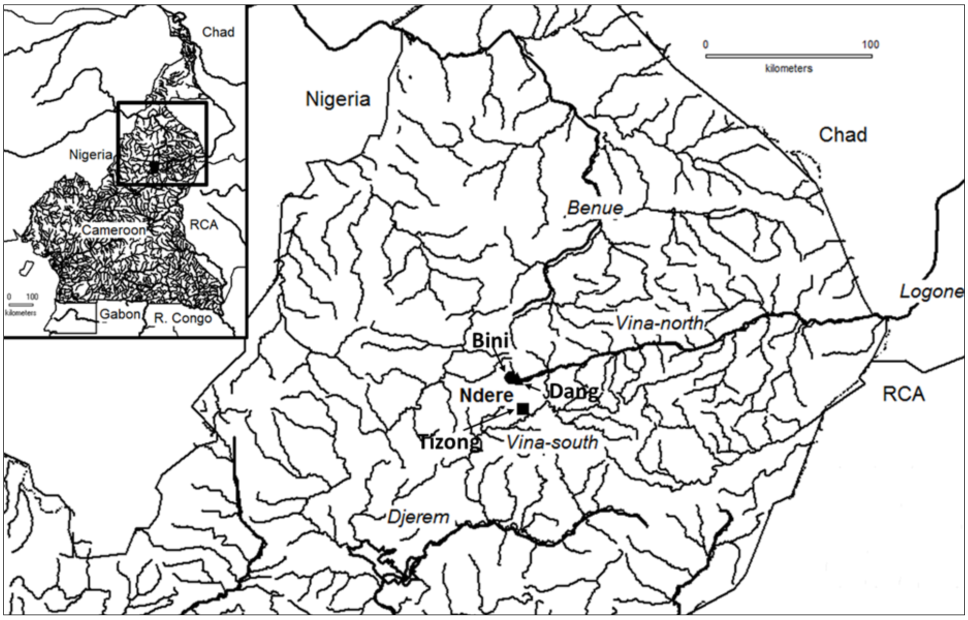


**Fig 1:** Map of geographical location of the three lakes studied. Ndere = Ngaoundere. Lake Bini (circle) is very closed to Lake Dang (triangle); both symbols overlap


**Fig 2:** Photographs of three specimens from lakes Bini (a), Dang (b) and Tizong (c)

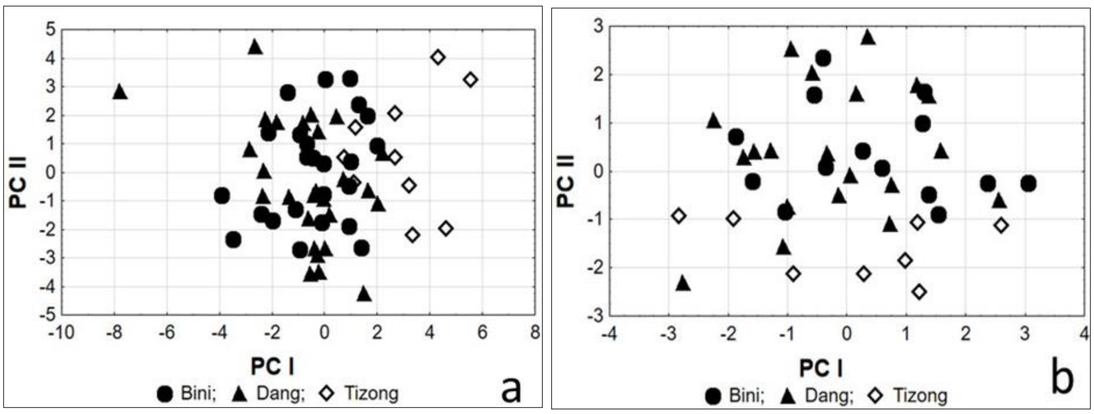


**Fig 3:** Plot of the scores on PCI and PCII of a principal component analysis (n = 86) of measurements (a) and counts (b)

## 5. Conclusion

The *H. camerounensis* population from Lake Tizong diverges in the insular environment with the two other populations which live in open and little restrictive environments. It is recommended to take into account this divergence for any systematic study of *H. camerounensis* carried out on the study zone. Finally, some crater lakes from the Cameroon volcanic line behave like islands in which Cichlid fishes evolve rapidly. The present study is a contribution to the improvement of knowledge on *H. camerounensis* (a new species described from Cameroon recently) and the influence of the volcanic crater lakes on the rapid evolution of Cichlid fishes.

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