**ESI Preprints** **Not Peer-reviewed**

# Intra-population Variability of Two *Chrysichthys* Species in six Aquatic Ecosystemes of Côte d'Ivoire

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Doi: 10.19044/esipreprint.7.2023.p137

Approved: 04 July2023
Posted: 08 July 2023

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*Cite As:*
Coulibaly-Ouattara T.A.S. & Adepo-Gourene A.B. (2023). *Intra-population Variability of Two Chrysichthys Species in six Aquatic Ecosystemes of Côte d'Ivoire*. ESI Preprints. https://doi.org/10.19044/esipreprint.7.2023.p137

## Abstract

In Côte d'Ivoire, fish of the genus *Chrysicthys* colonise most hydrosystems. Setting up a sustainable management programme for these fish requires in-depth knowledge of the different species. The aim of this study was to assess the morphological variability of populations of two species of the genus *Chrysichthys.* To do this, forty-one morphological measurements were taken on 167 specimens of the species *C. maurus* and 160 specimens of the species *C. nigrodigitatus*. Discriminant factor analysis and hierarchical classification analysis were used to determine intra-specific variability. The differences between the populations indicate the probable existence of phenotypic plasticity linked to their environment. The similarities can be explained by a potential capacity for exchange of individuals between populations.

**Keywords:** Côte d'Ivoire, *Chrysichthys*, Variability, population, morphometrics

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## 1. Introduction

The *Claroteidae* family includes African and Asian freshwater and brackish forms. Only two of the twelve genera belonging to this family are represented in Côte d'Ivoire. These are the genera *Auchenoglanis* and *Chrysichthys* (Daget et Iltis, 1965). The genus *Chrysichthys* (Bleecker, 1862) comprises several species, four of which have been identified in Ivorian rivers. These fish are euryhaline, but prefer oligo- and meso-haline waters (salinity varying from 0 to 20g.l-1) (Albaret, 1994). They live in waters where the temperature is between 28° and 32° C (Hem *et al*, 1994). Overexploitation of the sea and lagoon beds has led to the depletion of certain natural stocks (Albaret and Laë, 2003). The preservation of biodiversity and the sustainable management of aquatic ecosystems therefore require basic tools. They are necessary for an in-depth knowledge of the species that inhabit the environments that we want to manage or preserve. In this perspective, it is necessary to have knowledge on the morphological diversity of fish of the genus *Chrysichthys* which colonise most of the hydrographic basins of the Ivory Coast. Thus, this study aims to determine the intra-specific variability of *C. maurus* and *C. nigrodigitatus* populations in six Ivorian rivers.

## 2. Material and methods

### 2.1. Study Area

Fish of the genus Chrysichthys were sampled in six hydro-systems, from east to west: the Bia river, the Aby lagoon, the Ebrié lagoon, the Agneby river, the Bandama river and the Grand-Lahou lagoon (Figure 1). The sampling sites were selected on the basis of ease of access and availability of fish.

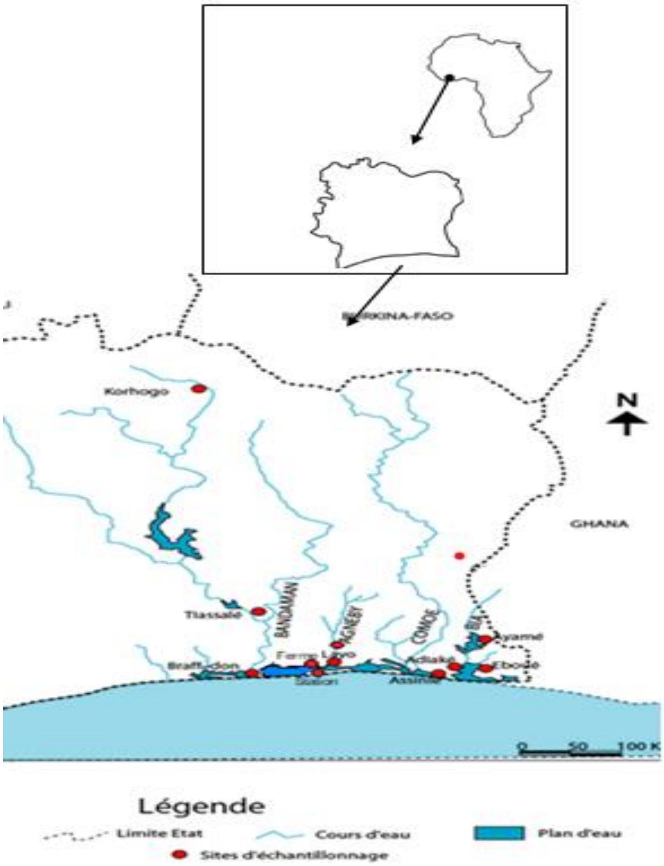


**Figure 1**. Sampling sites for *Chrysichthys* fish

## 2.2. Fish sampling

The interspecific morphological analysis included 167 specimens of the species *C. maurus* and 160 specimens of the species *C. nigrodigitatus*. The fish were obtained from the sampling campaign that took place from 2012 to 2014. On each fish, 41 measurements were taken (Figure 2) and standardised in order to avoid size variations due to age differences between individuals. To do this, all measurements expressed in millimetres were converted into a percentage of the standard length, except for those concerning the head, which are reported as a percentage of the length of the head tête (Mayr, 1970; Thys van den Audenaerde, 1970 ; Teugels, 1986) .

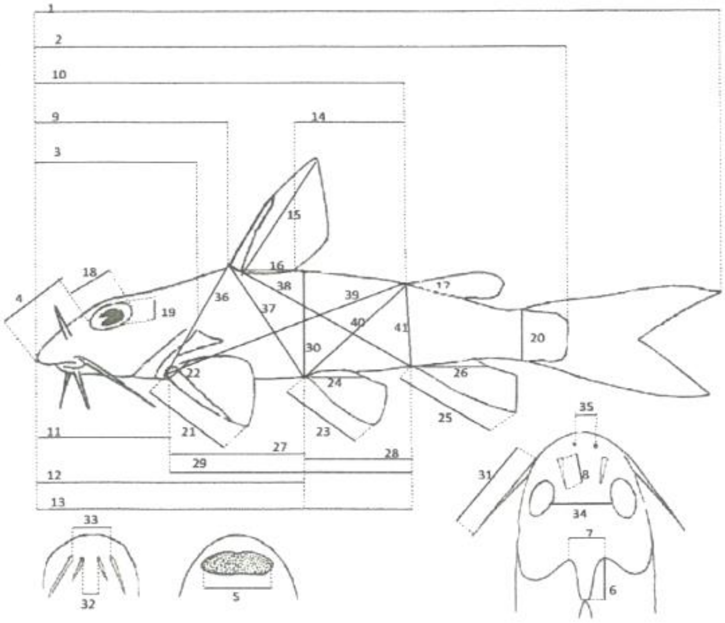


**Figure 2**. Metrics measurements taken from the individuals of the four species of *Chrysichthys*

NB: 1. total length (TL); 2. standard length (SL); 3. head length (HL); 4. snout length (SnL); 5width of premaxillary toothplate (WPm T); 6. occipital process length (OPL); 7. occipital process width (OPW); 8. nasal barbel length (NBL); 9.predorsal length (DsL); 10. preadipose length (AdL); 11.prepectoral length (PtL);

12. prepelvic length (PlL); 13. preanal length (AnL); 14. distance between dorsal and adipose fins (DDsAd);

15. dorsal fin heigth (DsH); 16. dorsal base (DsB), 17. adipose base (AdB), 18. eye diameter horizontal (ED1); 19. eye diameter vertical (ED2); 20. caudal peduncle length (CPcL); 21. pectoral height (PtH); 22. pectoral base (PtB); 23. pelvic height (PlH); 24. pelvic base (PlB); 25. anal height (AnH); 26. anal base (AnB); 27. distance pectoral/pelvic (DPtPl); 28. distance pelvic/anal (DPlAn); 29. distance pectoral/anal (DPtAn); 30. body height (BdH); 31. mandible barbell length 1 (MBlL1); 32. mandible barbell length 2 (MBlL2); 33. mandible barbell length 3 (MBlL3); 34. distance inter-orbital (DIO); 35. distance inter-nostril (DIN); 36. distance pectoral/dorsal (DPtDs); 37. distance pelvic/dorsal (DPlDs); 38. distance anal/dorsal (DAnDs); 39. distance pectoral/adipose (DPtAd); 40. distance pelvic/adipose (DPlAd); 41. distance anal/adipose (DAnAd).

## 2.3. Statistical Analysis

Discriminant Factor Analysis (DFA) was run to test the effectiveness of the characters in predicting different species location. For this analysis, a stepwise inclusion procedure was carried out to reduce the number of characters according and to identify the combinations of characters that best separated specie (Jain *et al*, 2000; Poulet *et al*, 2004). The percentage of correct classification of individuals is determined to assess the effectiveness of the discriminant analysis (Silva, 2003; Tomovíc and Džukíc, 2003;

Marques *et al.*, 2006). Hierarchical Cluster Analysis (HCA) based on Mahalanobis distance matrices determined with DFA, was used to evaluate population relationships. The hierarchical clustering process was represented as a dendrogram, where a join of the tree illustrated each step in the clustering process. The minimum variance clustering method or Ward’s method was used with the Euclidean distances. All treatments were performed using the program STATISTICA (StatSoft, version 7.1).

## 3. Results

### 3.1. Morphological diversity of *Chrysichthys maurus* populations

The analysis focused on 167 specimens of the species *Chrysichthys maurus*: 25 samples taken from the Bia river, 34 from the Aby Lagoon, 35 from the Ebrié Lagoon and 73 from the Bandama River.

### 3.1.1. Discriminant factor analysis of populations

The metric variables were subjected to an analysis of variance. Of these descriptors, 31 vary significantly between the *C. maurus* populations. They are subjected to Wilk's Lambda test of bottom-up stepwise discriminant factor analysis. Of the 18 traits identified by the test, the following nine descriptors: DsH, AdB, OPW, AnL, PtB, DAnAd, NBL, OPL and DDsAd have a highly significant level of discrimination ($p < 0.001$) (Table I).

**Table I.** Multivariate Wilk's Lambda (λ) significance tests of metric variables in the populations of the species *Chrysichthys maurus*.

| Variables | λ | F | p |
|---|---|---|---|
| DsH | 0,70 | 20,75 | *** |
| AdB | 0,78 | 14,16 | *** |
| OPW | 0,82 | 10,80 | *** |
| AnL | 0,82 | 10,50 | *** |
| PtB | 0,86 | 8,15 | *** |
| DAnAd | 0,87 | 7,00 | *** |
| NBL | 0,88 | 6,7 | *** |
| OPL | 0,88 | 6,37 | *** |
| DDsAd | 0,89 | 6,00 | *** |
| OPcL | 0,90 | 5,53 | ** |
| PtH | 0,91 | 4,93 | ** |
| DIO | 0,92 | 4,49 | ** |
| AdL | 0,92 | 4,48 | ** |
| WPmT | 0,92 | 4,34 | ** |
| ED1 | 0,93 | 3,91 | * |
| DPtDs | 0,93 | 3,6 | * |
| AnH | 0,93 | 3,42 | * |
| DIN | 0,94 | 3,2 | * |

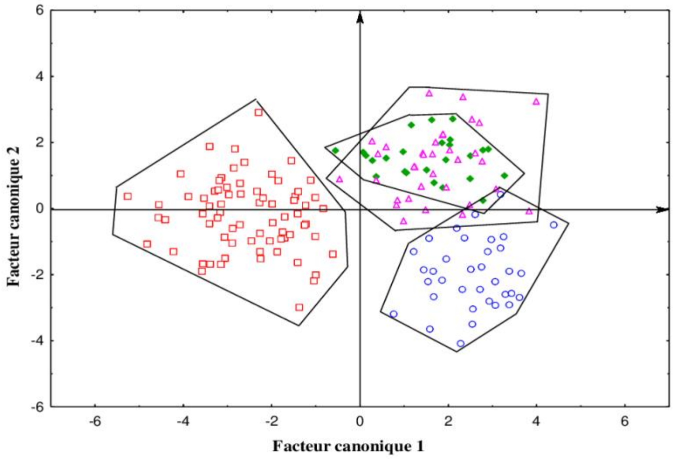
Discriminant Factor Analysis indicates a total correct classification rate of 95.21% (Table II). Individuals from the Ebrié Lagoon were correctly classified at 97.14%; only one individual was assigned to the Bia population. The majority of the Bia specimens, 80%, were correctly assigned to their group of origin, only five specimens from this population were assigned to the Aby lagoon. The percentages of correct classification of specimens from Aby Lagoon and Grand-Lahou Lagoon are 79.41% and 85.71% respectively. As for the specimens from the Bandama population, their membership to their group of origin was confirmed by the Factorial Discriminant Analysis at 100%.

**Table II**. Matrix for classification of specimens of the species *Chrysichthys maurus* by DFA

| | % correct | Ebr | Bad | Bia | Aby |
|---|---|---|---|---|---|
| Ebr | 97.14 | 34 | 0 | 0 | 1 |
| Bad | 100 | 0 | 73 | 0 | 0 |
| Bia | 84 | 0 | 0 | 21 | 4 |
| Aby | 91.18 | 0 | 0 | 3 | 31 |
| Total | 95.21 | 34 | 73 | 24 | 36 |

Ebr: Ebrié, Bad: Bandama.

Figure 3 shows the distribution of populations in the canonical 1 and 2 planes of the Discriminant Factor Analysis. On the graph, the Bandama and Ebrié Lagoon populations are clearly differentiated from the others, while the scatterplots representing the Bia River and Aby Lagoon populations overlap entirely.



□Bandama Ebrié ○ Aby △ Bia ◆

**Figure 3**. Projection of *C. maurus* populations in the canonical 1 x 2 plane of the Discriminant Factor Analysis of metric data.

## 3.1.2. Hierarchical cluster analysis of the populations

The results of the Hierarchical Classification Analysis, grouping the different populations, are presented in Figure 4. At the Euclidean distance of

20, three distinct batches emerge; batch I formed by the population of the Ebrié lagoon, batch II by the populations of the Bia river and the Aby lagoon and batch III represented by the population of the Bandama river.

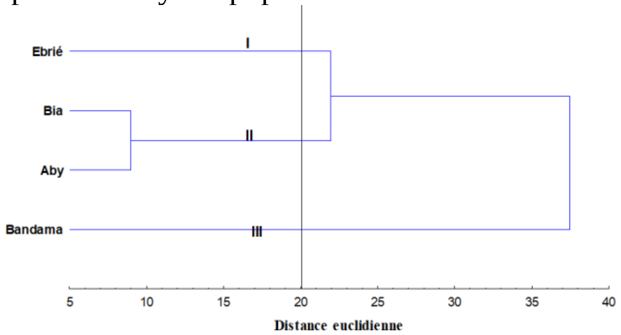


**Figure 4**. Dendrogram showing morphometric similarities between populations of the species *Chrysichthys maurus*

## 3.2. Morphological diversity of *C. nigrodigitatus* populations

The sample of the species *C. nigrodigitatus* is composed of 160 specimens of which 15 were collected in the Bia river, 47 in the Ebrié lagoon, 11 in the Agneby river, 50 in the Aby lagoon, 20 in the Bandama and 17 in the Grand-Lahou lagoon

### 3.2.1. Discriminant factor analysis of populations

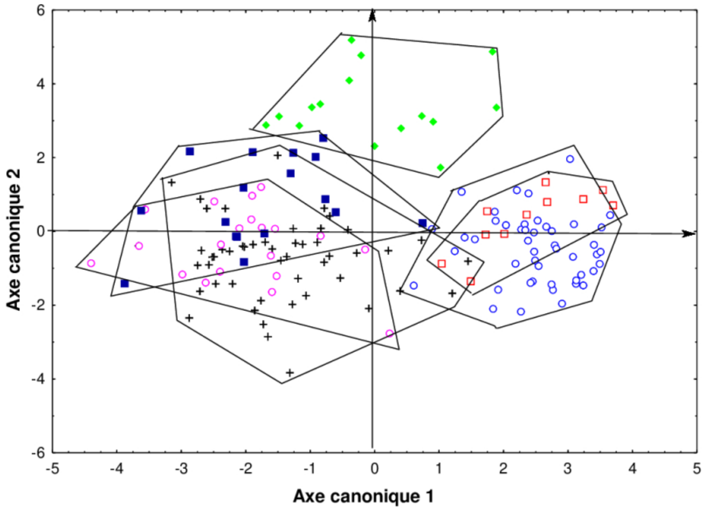
The results of the bottom-up stepwise factor analysis are shown in Table III. The nine descriptors DPlDs; DAnAd; HL; LBlM1; WPmT; DDsAd; DIO; NBlL and BdH contribute strongly to the discrimination of the different populations ($p < 0.001$).

**Table III**. Multivariate Wilk's Lambda (λ) significance tests of metric variables in the populations of the species *Chrysichthys nigrodigitatus*.

| Variables | λ | F | p |
|---|---|---|---|
| DPlDs | 0,73 | 10,27 | *** |
| DAnAd | 0,76 | 8,79 | *** |
| HL | 0,77 | 8,24 | *** |
| LBlM1 | 0,77 | 8,04 | *** |
| WPmT | 0,81 | 6,57 | *** |
| DDsAd | 0,82 | 6,14 | *** |
| DIO | 0,82 | 6,14 | *** |
| NBlL | 0,83 | 5,41 | *** |
| BdH | 0,86 | 4,54 | *** |
| PtB | 0,88 | 3,81 | ** |
| LBlM2 | 0,88 | 3,72 | ** |
| AdB | 0,89 | 3,46 | ** |
| DPtAn | 0,90 | 3,07 | * |
| DIN | 0,90 | 3,02 | * |
| DPtPl | 0,90 | 2,96 | * |
| DsL | 0,91 | 2,85 | * |

| | | | |
|---|---|---|---|
| AnH | 0,91 | 2,54 | * |
| PlH | 0,92 | 2,50 | * |
| PtH | 0,92 | 2,46 | * |

Figure 5 shows the distribution of populations along the canonical axes 1 and 2 of the DFA. The scatterplot representing the Bia River population is clearly distinct from the others. The populations of the Aby, Grand-Lahou and Bandama lagoons overlap and are located in the negative sector of canonical axis 1, while the scatterplots representing the taxa of the Agneby River and the Ebrié lagoon overlap in the positive sector of canonical axis 1.



□**Agneby** ○**Ebrié** + **Aby** ◆**Bia** **Bandama** ○ **Grand-Lahou** ■

**Figure 5**. Projection of the populations of *C. nigrodigitatus* in the plane formed by the canonical axis 1 and 2.

The classification matrix confirms 91.25% of the specimens belong to their group of origin (Table IV). The correct classification rate is 100% for the Bia River, 93.62% for the Ebrié Lagoon, 92% for the Aby Lagoon, 90% for the Bandama River, 88.24% for the Grand-Lahou Lagoon and 72.73% for the Agneby River.

**Table IV**. Matrix for classification of specimens of the species *Chrysichthys nigrodigitatus* by DFA

| | correct percentage | Ebr | Agb | Bia | Aby | Bad | GL |
|---|---|---|---|---|---|---|---|
| Ebr | 93.62 | 44 | 2 | 0 | 1 | 0 | 0 |
| Agb | 72.73 | 3 | 8 | 0 | 0 | 0 | 0 |
| Bia | 100 | 0 | 0 | 15 | 0 | 0 | 0 |
| Aby | 92 | 1 | 0 | 0 | 46 | 1 | 2 |
| Bad | 90 | 0 | 0 | 0 | 2 | 18 | 0 |
| GL | 88.24 | 0 | 0 | 0 | 0 | 2 | 15 |
| Total | 91.25 | 48 | 10 | 15 | 49 | 21 | 17 |

Ebr: Ebrié, Agb: Agneby, Bad: Bandama, GL: Grand-Lahou.

### 3.2.2. Hierarchical cluster analysis of the populations

The Hierarchical Cluster Analysis allowed the populations to be divided into three distinct groups at aggregation distance 20 (Figure 6). Group I consists of the populations of the Agneby River and the Ebrié Lagoon, which are morphometrically close. Group II is made up of the Bia River population which is in an intermediate position. The populations of the Aby lagoon, the Grand-Lahou lagoon and the Bandama form group III and are close to each other.

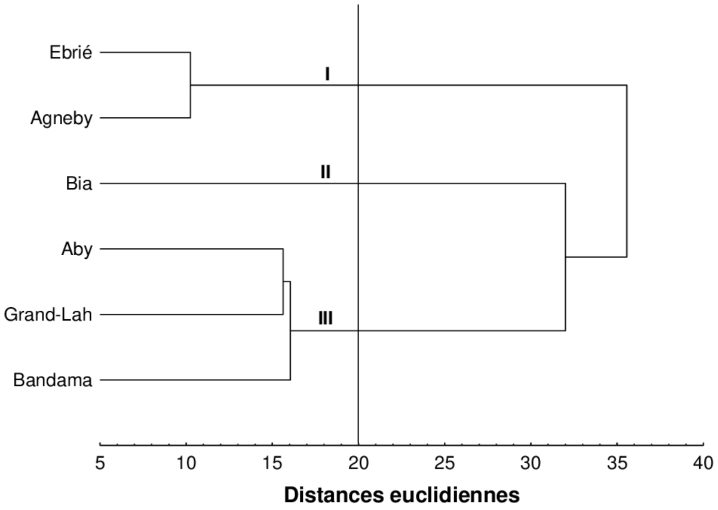


**Figure 6**. Dendrogram illustrating the morphological variability of *C. nigrodigitatus* populations based on metric descriptors.

## 4. Discussion

For the species *C. maurus*, the results of the study of the populations of the rivers sampled made it possible to detect more or less significant morphological differences between the populations. Specimens from the Bandama River are characterised by small eyes and wide nostrils, a large adipose fin, a long dorsal fin which, when folded, reaches or exceeds the adipose fin, large pelvic and pectoral fins. Specimens from other rivers sampled are characterised by a small dorsal fin, a small adipose fin and small pectoral and pelvic fins. In addition, specimens from the Ebrié Lagoon are distinguished by small eyes and wide nostrils, those from the Bia River are distinguished by small eyes and close nostrils, while those from the Aby Lagoon have large eyes and close nostrils. All these morphological differences indicate the probable existence of phenotypic plasticity. Indeed, Ferrito *et al*, (2007) reported that habitat differences influence morphology differently in several populations. Discriminant Factor Analysis reveals that the Aby and Bia populations show strong morphological similarity, whereas the Ebrié Lagoon and Bandama River populations are distinct. In addition, the hierarchical classification indicates that the first two populations are closer to the Ebrié lagoon population than to the Bandama River population. The phenotypic similarity between specimens from the Bia River and the Aby Lagoon and their morphological affinities with specimens from the Ebrié Lagoon, could be due to the fact that these three rivers are connected to each other. Indeed, the Aby lagoon is fed directly with fresh water by the Bia river and to facilitate navigation, the Aby lagoon and the Ebrié lagoon were connected by the Assinie canal, built between 1955 and 1957 (Kouassi, 2010). Therefore, specimens can probably migrate over long distances implying an exchange of individuals between the rivers. Thus, the potential capacity of populations to evolve as independent biological entities is limited by the exchange of individuals between populations (Cheng *et al*., 2005). The morphological similarity between the populations could also be due to the fact that the Aby lagoon, the Ebrié lagoon and the Bia river are subject to the same physico-chemical parameters. The results of the analyses showed that the Bandama River population is morphologically isolated from the other populations. This isolation is noticed in this taxon by a great morphological particularity: a long filament on the dorsal fin which when folded reaches or exceeds the adipose fin. This particularity was observed by Risch (1992) during his work on fish from the same river. This morphological difference would be attributable to the adaptation of the specimens to different environmental conditions; the Bandama River being subject to several climatic regimes (tropical and equatorial). According to Paugy and Lévêque (1999), populations belonging to the same species, living in different geographical areas, can be morphologically different. In addition, the Grand-Lahou lagoon provides connectivity between the Bandama River and the Ebrié Lagoon. Fish from this river have a filament on the dorsal fin that is smaller than that of the Bandama specimens and longer than that of the Ebrié lagoon specimens. According to Turan (2004), a sufficient degree of isolation can result in significant phenotypic differentiation among fish populations of a species.

For the species *C. nigrodigitatus*, the results of the intra-population study revealed low values of the coefficient of variation for the populations of the Ebrié Lagoon and the Agneby River. This low morphological variation could be explained by a phenotypic homogeneity linked to the low variations in environmental conditions. The analysis of variance made it possible to highlight the differences between the populations of the rivers sampled. Specimens from the Bia River are characterised by a long head, large eyes and long pectoral fins. Those from the Bandama River have a moderately elongated head, large eyes and long pectoral fins. The population of the Grand-Lahou lagoon is distinguished by an elongated head, large eyes and short pectoral fins. Specimens from the Aby lagoon are distinguished by a short head, large eyes and long pectoral fins. Specimens from the Agneby River have a short head, small eyes and small pectoral fins. Specimens from the Ebrié Lagoon are characterised by a short head, small eyes and small pectoral fins. In contrast to the *C. maurus* species, the populations of the *C. nigrodigitatus* species differ in few variables. On the one hand, the population in the Agneby River is similar to that in the Ebrié Lagoon. On the other hand, the populations of the Bandama River, the Aby Lagoon and the Grand-Lahou Lagoon show a great similarity due to the overlap of morphometric descriptors. The Bia River population occupies the intermediate position. The phenotypic similarities between the Agneby and Ebrié lagoon populations would result from the fact that these two habitats are subject to similar environmental variations. Indeed, the swampy area in which the Layo station is located (on the Ebrié lagoon) has a hydroclimate strongly influenced by the flooding of the Agneby forest river (Durand et Guiral, 1994). In addition, the absence of a geographical barrier between these two rivers probably leads to an exchange of individuals between the populations. The few morphological differences observed at the level of the relatively "homogeneous" populations would be related to certain environmental parameters. This variability could result from phenotypic plasticity in relation to the environmental factors of each river: these populations would therefore be ecological variants or ecotypes (Dkhil-Abbes and Kraïem, 2011).

## Conclusion

The results of the study of the populations of the sampled rivers made it possible to detect more or less significant morphological differences between the populations. These differences indicate the probable existence of phenotypic plasticity in the populations. The similarities are explained by the fact that the potential capacity of populations to evolve as independent biological entities is limited by the exchange of individuals between populations. Molecular analyses associated with these morphological analyses will clarify the relationships between the different populations.

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