TÜBİTAK

Turkish Journal of Zoology

http://journals.tubitak.gov.tr/zoology/

Research Article

Turk J Zool
(2014) 38: 273-284
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doi:10.3906/zoo-1304-4

Morphological differentiation among species of the genus *Mugil* Linnaeus, 1758 (Mugilidae) from Côte d'Ivoire

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Received: 01.04.2013 • **Accepted:** 17.11.2013 • **Published Online:** 21.03.2014 • **Printed:** 18.04.2014

Abstract: A study on the morphological diversity of the genus *Mugil* of the lagoons Ebrié and Grand-Lahou was carried out in order to differentiate species of Mugilidae in Côte d'Ivoire. Univariate and multivariate analyses of 40 metric and 11 meristic characters identified 3 homogeneous groups. This phenotypic plasticity within the genus *Mugil* allowed differentiating the species *Mugil curema*, *M. bananensis*, and *M. cephalus*. Contrary to the overlap presented by the metric parameters, meristic characters, in this case the number of branchiospines on the superior and inferior parts and the number of microbranchiospines on the first branchial arch, were very clearly discriminating for each species. The number of branchiospines on the superior part varies from 27 to 44, from 19 to 39, and from 43 to 58, respectively, for *Mugil curema*, *M. bananensis*, and *M. cephalus*. On the inferior part of that arch, *M. curema* (57 to 70) and *M. bananensis* (34 to 45) were separated without overlap. *M. bananensis* and *M. cephalus* (62 to 89) were also separated without overlap. Similarly, the number of microbranchiospines on the first arch differs in each of these species. It varies between 103 and 123 for *Mugil curema*, between 65 and 84 for *M. bananensis*, and between 123 and 165 for *M. cephalus*.

Key words: *Mugil*, meristic, morphological, branchiospine, microbranchiospine, species, characterization

1. Introduction

Fish of the family Mugilidae are permanent and often abundant in coastal ecosystems, estuaries, and lagoons (Albaret and Legendre, 1985). Their distribution is vast, and covers both tropical–equatorial and temperate regions (Harrison and Howes, 1991). In West Africa, Mugilidae are of great economic significance (Pandaré and Capdeville, 1986; FAO, 2005), and often the subject of specialized fisheries. In Côte d'Ivoire, they are highly exploited species, ranking close to Cichlidae, Clupeidae, and Carangidae in fisheries importance in the Aby, Ebrié, and Grand-Lahou lagoon systems (Albaret and Legendre, 1985). In spite of this, knowledge on the species of this family in Côte d'Ivoire remains fragmented, and most fisheries statistics from Côte d'Ivoire do not provide adequate information to allow assessment of the species richness of this family in artisanal and commercial fisheries. Records from the Fisheries Department group all fishes of this family under the term "mullet" because of the difficulty of distinguishing different species (Séret and Opic, 1986). Indeed, morphological and anatomical characters that distinguish the species of this family are few and often hard to discern, thus the confusion in the taxonomy of this group in genus and species levels (Albaret, 2003). Existing identification keys are either incomplete (Albaret, 1984, 1987; Albaret and Legendre, 1985; Séret and Opic, 1986), poorly adapted (Daget and Iltis, 1965; Blache et al., 1970), or specialized for dissections and descriptions of anatomical features of the fish (Fischer et al., 1981). Moreover, identification keys by Albaret (2003) and Harrison (2007) present large overlaps of features at species level.

In Côte d'Ivoire, systematic studies are lacking, even though they would be of great importance for better management of the stocks. Of all identification methods available (e.g., Ihssen et al., 1981; Templeman, 1983; Smith and Jamieson, 1986), the analysis of morphologic and morphometric characters is one of the most commonly used (e.g., Taylor and McPhail, 1985; Melvin et al., 1992; Hurlbut and Clay, 1998; Britz and Ferraris, 2003; Heok, 2003; Smith and Karmovskaya, 2003; Kamilari and Sfenthourakis, 2009; Yokoo et al., 2009). In the same way, meristic characters have been widely used in studies of fish populations and species (e.g., Kaya et al., 1998; Turan et al., 2011). Unlike body proportions or coloration, meristic characters are fixed usually at or before metamorphosis and remain constant throughout the life of an individual (Albaret and Legendre, 1985).

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To date, a limited number of studies on morphological characters among *Mugil* species in the Ivoirian lagoons have been done (Albaret and Legendre, 1985). These authors investigated 2 species (*Mugil cephalus* and *M. curema*) of the family Mugilidae with morphologic data in Ebrié Lagoon. Due to interspecific morphological similarities of the species, this article seeks to clarify morphological differences and to provide a means of quick and accurate identification of the genus *Mugil* of the Ebrié and Grand-Lahou lagoons in Côte d'Ivoire.

2. Materials and methods

2.1. Sampling and data collection

A total of 366 specimens were collected in the lagoons of Ebrié and Grand-Lahou (Figure 1): 274 specimens between February and August 2008 in Ebrié Lagoon, and 94 specimens in March 2010 in Grand-Lahou Lagoon. All samples were collected from commercial fishing.

All individuals were analyzed together because of the lack of sexual dimorphism. Each specimen was examined for qualitative morphological variation in fin aspect and body coloration in natural light. Afterwards, the specimens were classified according to morphological similarity. Linear measurements were always taken by the same person with digital Vernier calipers and recorded to the nearest 0.05 mm. Measurements follow those of Gourène and Teugels (1993), Thomson (1997), and Boussou et al. (2010). A total of 53 characters—40 metrics (Figure 2), 2 morphologics (based on the body color and appearance of the fins), and 11 meristics—were measured on each specimen. The meristic characters used were number of first dorsal rays (DR1), number of second dorsal rays (DR2), number of pelvic soft rays (PeR), number of pectoral soft rays (PcR), number of anal soft rays (AR), number of anal spines (AS), number of scale lines (ScL), number of scales on longitudinal line (ScLL), number of branchiospines on the inferior part of the first branchial (Inf Brsp), number of branchiospines on the superior part of the first branchial (Sup Brsp), and number of microbranchiospines of the first branchial arch (MicBrsp).

2.2. Data analysis

Due to variations in size of fish from different areas, only morphometric data were statistically adjusted to permit comparative analysis of shape independently of size (Thorpe, 1976). Thus, to remove the effect of size, all morphometric characters were standardized. Measurements on the head are presented as proportions of head length (HL). Except for the pectoral fin, head length and other body measurements are expressed as proportions of standard length (SL). Analyses were carried out separately for morphometric and morphomeristic

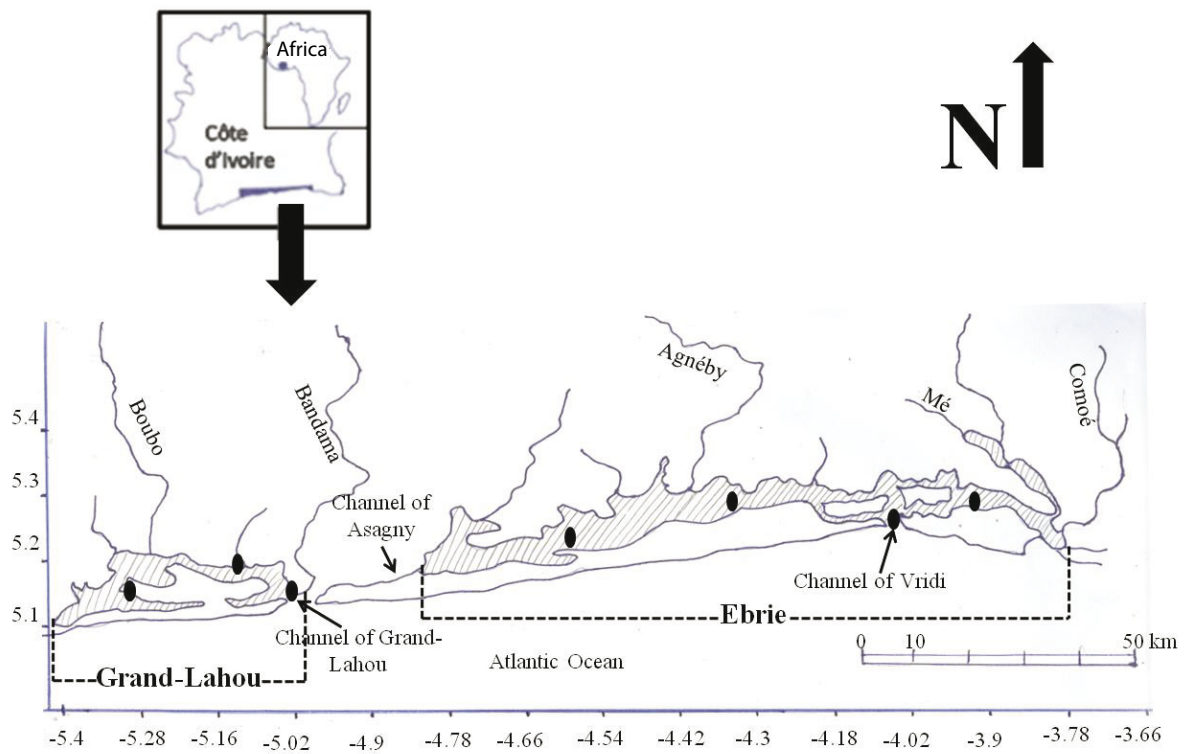

Figure 1: Map showing the sample sites. Lagoon of Ebrié and lagoon of Grand-Lahou. • : Sample sites

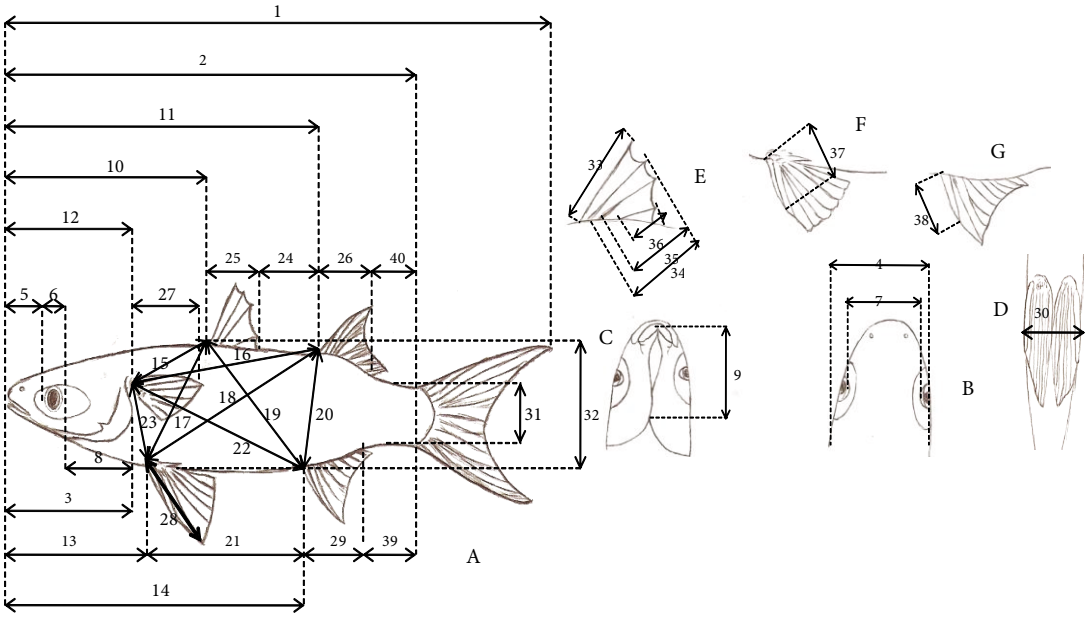

Figure 2: 1. Total length (TL); 2. Standard length (SL); 3. Head length (HL); 4(**B**). Head width (HW); 5. Muzzle length (ML); 6. Eye diameter (ED); 7(**B**). Interorbital distance (ID); 8. Eye–operculum distance (EOD); 9(**C**). Jugular space (JS); 10. First predorsal distance (PrDD 1); 11. Second predorsal distance (PrDD 2); 12. Prepectoral distance (PrPcD); 13. Prepelvic distance (PrPeD); 14. Preanal distance (PrAD); 15. Pectoral–first dorsal fin origin distance (PcDD 1); 16. Pectoral–second dorsal fin origin distance (PcDD 2); 17. Pelvic–first dorsal fin origin distance (PeDD 1); 18. Pelvic–second dorsal fin origin distance (PeDD 2); 19. Anal–first dorsal fin origin distance (ADD 1); 20. Anal–second dorsal fin origin distance (ADD 2); 21. Pelvic–anal fin origin distance (PeAD); 22. Pectoral–anal fin origin distance (PcAD); 23. Pectoral–pelvic fin origin distance (PcPeD); 24. First–second dorsal fins distance (D1D2D); 25. First dorsal fin base length (DL 1); 26. Second dorsal fin base length (DL2); 27. Pectoral fin length (PcL); 28. Pelvic fin length (PeL); 29. Anal fin base length (AL); 30(**D**). Pelvic–pelvic spines distance (PePeD); 31. Caudal peduncle depth (CPDe); 32. Body depth (BDe); 33(**E**). Dorsal first spine length (DSL 1); 34(**E**). Dorsal second spine length (DSL 2); 35(**E**). Dorsal third spine length (DSL 3); 36(**E**). Dorsal fourth spine length (DSL 4); 37(**F**). Pelvic spine length (PeSL); 38(**G**). Anal first spine length (ASL 1); 39. Anal–caudal fin origin distance (ACD); 40. Second dorsal–caudal fin origin distance (D2CD).

characters, since these variables are different both statistically and biologically (Allendorf et al., 1987).

Since the data matrix was too large for simultaneous specimen-level analyses, morphologically similar taxa were pooled into different operational taxonomic units (OTUs) as implemented by Sneath and Sokal (1973), Chimimba et al. (1998), and Chimimba (2001). Three OTUs (X1, X2, and X3) were defined in this study.

Morphological character variation was assessed using univariate analysis (ANOVA) and multivariate analysis (principal components analysis (PCA) and stepwise discriminant factorial analysis [DFA]). For each variable, average values were compared between different species by Kruskal–Wallis tests for the meristic parameters and ANOVA for the metric parameters. These analyses were used to identify characters that express variability between species. Those parameters were used for the multivariate analyses. Principal component analysis (PCA) was used to evaluate morphometric variation among specimens and to identify variables contributing substantially to that variation (Johnson and Wichern, 1998). Discriminant factorial analysis (DFA) was performed to clarify the relative importance of such traits as discriminators between a priori groups (Tomović and Džukić, 2003; Loy et al., 2008) and the relative positions of the centroids of those groups (Tomovíc and Džukic, 2003). A classification procedure based on a matrix of Mahalanobis distances was used to evaluate group membership, without prior analysis of variance. For DFA, significant traits for group assignment were accessed through a stepwise inclusion procedure to reduce the number of variables (Jain et al., 2000; Poulet et al., 2004, 2005) and identify the combinations of variables that best separate the groups (Hair et al., 1996). The Mahalanobis distances matrix was used to evaluate population relationships, as implemented by Slabova and Frynta (2007) and Ferrito et al. (2007).

Descriptive statistics (standard error, standard deviation, maximum, and minimum) of all measurements were recorded for each species. The coefficient of variation (CV) was computed for each character according to the equation: $CV = 100 \times SD/X$, where SD is Standard Deviation and X is the mean of the transformed measurements of morphometric characters in each group.

All statistical analyses except for the coefficient of variation were performed using STATISTICA software (release 7.1, StatSoft, 2005).

3. Results

3.1. Morphological analyses

Three major groups emerged from the morphological assessments. Group X1 comprised 79 specimens characterized by a general silvery gray coloration and a yellow-orange diffuse mark on the upper edge of the operculum at the pectoral fin level. The anal fin of these fishes is greyish edged with yellow blade coloration. The second group (X2) is constituted of 223 specimens that are generally brown, with the second dorsal, pectoral, and anal fins covered with small scales, giving them a speckled dark gray appearance. The operculum of these individuals is generally yellow fluorine. The third group (X3) was composed of 64 specimens having a general yellowish-gray body color and yellow ventral, anal, and caudal fins. These fish were determined by the presence of very dark longitudinal lines visible in the higher part of the body midheight. The 3 groups were retained for further analyses.

3.2. Morphometric analyses

Low coefficients of variation (CV) of each group identified morphologically are recorded in Table 1. These values are 1.08%–17.53%, 1.09%–29.74%, and 2.44%–12.67% for groups X1, X2, and X3, respectively. Groups X1 and X3 are homogeneous for all characters (CV < 25%), while group X2 is heterogeneous for the first anal spine length (CV = 29.74%) only. ANOVA revealed highly significant differences ($P < 0.001$) for all morphometric parameters among the different groups identified morphologically, except for first predorsal distance and preanal distance (Table 1).

Tukey's honest significant difference test shows that the specimens of group X1 are morphologically very different from the individuals of the 2 other groups for the majority of the parameters. In fact, individuals in group X1 are characterized by a shorter head (24.88 ± 0.09), a moderately larger mouth (27.77 ± 0.15), larger eyes (23.99 ± 0.23), and a larger jugular area (79.01 ± 0.34) than the other 2 groups.

Individuals in group X3 have a larger head (67.26 ± 0.33) and consequently a large interorbital space (49.37 ± 0.42), a wide mouth (29.18 ± 0.18), and eyes (20.64 ± 0.24) and jugular area (70.56 ± 0.41) that are smaller compared to the other 2 groups. As for individuals in group X2, parameters related to the head are intermediate of the populations of X1 and X3. For characters of the body, individuals in group X3 displayed higher values than individuals from groups X1 and X2. These are variables such as ADD2 (24.34 ± 0.13), PcL (19.93 ± 0.11), PeL (18.08 ± 0.09), CPDe (12.09 ± 0.06), DSL1 (15.71 ± 0.13), DSL2 (14.75 ± 0.12), PeSL (12.17 ± 0.10), and D2CD (14.13 ± 0.11). Individuals of the X1 population show high values for parameters such as PeD1D (27.10 ± 0.14), PcD2D (50.48 ± 0.15), PeAD (34.44 ± 0.18), PcAD (49.7 ± 0.16), PcPeD (49.7 ± 0.16), and AL (14.32 ± 0.07). As for specimens of group X2, they have higher values for PrPeD (39.66 ± 0.07) and AxPc (38.02 ± 0.52). For the last parameter quoted, the X3 population has the smallest value (AxPc: 34.97 ± 0.44), and population X2 displays 37.32 ± 0.62.

All characters that have proved to be significant among the 3 different groups were subjected to principal component analysis (PCA). The PCA showed that the first 3 principal components (Table 2) account for 68.43% of the total variance (40.65% for PC1, 18.05% for PC2, and 9.73% for PC3).

The factor scores from the PCA were plotted on the first and second principal components for morphometrics (Figure 3). The PCA did not show a clear separation of the populations identified. However, individuals in population X1 are mostly located on both sides of the negative part of axis 2. Those of population X2 are around the origin of the axis, but in the majority formed by the positive parts of the 2 axes. As for specimens X3 of the population, they are located in the negative part of the 2 axes.

The negative parts of the first principal components are strongly correlated with head length, head width, snout length, eye–operculum distance, pelvic–first dorsal fin origin distance, pelvic–second dorsal fin origin distance, anal–first dorsal fin origin distance, anal–second dorsal fin origin distance, pelvic–anal fin origin distance, pectoral–anal fin origin distance, pectoral–pelvic fin origin distance, second dorsal fin base length, pectoral fin length, pelvic fin length, anal fin base length, caudal peduncle depth, dorsal first spine length, and dorsal second spine length ($P < 0.001$). Axis 2 is in turn correlated in its negative section by PrDD2, PrPcD, PrPeD, PcDD1, and PcDD2.

Stepwise discriminant analysis retained 20 out of 40 variables as the most discriminant of the different groups (Table 3) and of primary importance in distinguishing between groups: head length ($\lambda = 0.72$), interorbital distance ($\lambda = 0.82$), head width ($\lambda = 0.83$), anal fin base length ($\lambda = 0.83$), pelvic–pelvic spines distance ($\lambda = 0.86$), snout length ($\lambda = 0.87$), dorsal first spine length ($\lambda = 0.87$), jugular space ($\lambda = 0.89$), eye–operculum distance ($\lambda = 0.89$), anal–second dorsal fin origin distance ($\lambda = 0.89$), pectoral–pelvic fin origin distance ($\lambda = 0.92$), pectoral fin

Table 1. Descriptive statistics of morphometric variables of *Mugil* specimens in the 3 species (see Figure 2 for abbreviations). S.E.: standard error; S.D.: standard deviation; CV: coefficient of variation.

Metric variables		X 1		X 2		X 3		Metric variables		X 1		X 2		X 3	
	Mean ± SE	24.88 ±	0.09 a	26.32 ±	0.05 b	26.01 ±	0.12 b		Mean ± SE	33.37 ±	0.14 a	32.37 ±	0.06 b	33.32 ±	0.13 ca
HL	SD	0.84		0.81		0.98		ADD1	SD	1.25		0.96		1	
	CV	3.36		3.07		3.77			CV	3.74		2.95		3	
	Min–Max	21.36–26.64		22.08–28.38		23.62–29.06			Min–Max	27.3–35.99		26.94–35.44		28.46–35.54	
	Mean ± SE	63.33 ±	0.26 a	63.69 ±	0.16 a	67.26 ±	0.33 b		Mean ± SE	23.53 ±	0.1 a	22.36 ±	0.06 b	24.34 ±	0.13 c
HW	SD	2.32		2.38		2.63		ADD2	SD	0.9		0.92		1.01	
	CV	3.67		3.74		3.9			CV	3.83		4.1		4.16	
	Min–Max	59.74–73.09		58.78–75.87		61.07–76.48			Min–Max	21.38–26.07		20.2–24.51		21.02–27.15	
	Mean ± SE	27.77 ±	0.15 a	25.88 ±	0.1 b	29.18 ±	0.18 c		Mean ± SE	34.44 ±	0.18 a	33.54 ±	0.11 b	33.71 ±	0.24 b
ML	SD	1.37		1.53		1.46		PeAD	SD	1.56		1.62		1.91	
	CV	4.93		5.92		5.02			CV	4.52		4.84		5.68	
	Min–Max	24.59–31.74		21.78–30.62		26.13–32.57			Min–Max	31.59–38.13		30.03–38.61		26.46–37.74	
	Mean ± SE	23.99 ±	0.23 a	22.31 ±	0.2 b	20.64 ±	0.24 c		Mean ± SE	49.7 ±	0.16 a	47.82 ±	0.09 b	47.96 ±	0.34 b
ED	SD	2.04		2.93		1.87		PcAD	SD	1.4		1.31		2.67	
	CV	8.5		13.12		9.08			CV	2.82		2.74		5.57	
	Min–Max	19.89–30.38		16.42–31.33		16.6–25.26			Min–Max	46.17–52.92		44.41–52.09		32.13–52.46	
	Mean ± SE	42.81 ±	0.38 a	41.63 ±	0.24 a	49.37 ±	0.42 b		Mean ± SE	20.48 ±	0.09 a	19.34 ±	0.05 b	19.49 ±	0.13 b
ID	SD	3.41		3.52		3.32		PcPeD	SD	0.76		0.77		1	
	CV	7.98		8.46		6.72			CV	3.69		3.98		5.14	
	Min–Max	35.36–54.74		34.57–59.12		42.81–60.3			Min–Max	18.91–22.63		16.95–21.98		15.71–21.88	
	Mean ± SE	50.76 ±	0.23 a	53.35 ±	0.14 b	55.92 ±	0.21 c		Mean ± SE	14.01 ±	0.14 a	14.4 ±	0.11 a	13.03 ±	0.19 b
EOD	SD	2.05		2.04		1.63		D1D2D	SD	1.26		1.66		1.47	
	CV	4.05		3.83		2.92			CV	8.96		11.49		11.31	
	Min–Max	43.18–59.19		48.54–65.43		52.04–59.83			Min–Max	11.91–17.15		10.6–18.3		10.38–18.26	
	Mean ± SE	79.01 ±	0.34 a	73.95 ±	0.23 b	70.56 ±	0.41 c		Mean ± SE	12.03 ±	0.12 ab	11.57 ±	0.09 b	12.28 ±	0.18 ca
JS	SD	2.99		3.49		3.22		DL1	SD	1.11		1.31		1.43	
	CV	3.78		4.73		4.56			CV	9.19		11.35		11.66	
	Min–Max	71.3–87.09		58.43–95.06		61.42–80.76			Min–Max	8.53–14.41		7.4–14.57		8.46–15.02	
	Mean ± SE	50.08 ±	0.14 a	49.94 ±	0.08 a	49.57 ±	0.17 a		Mean ± SE	11.37 ±	0.06 ab	11.52 ±	0.04 b	11.18 ±	0.08 ca
PrDD1	SD	1.22		1.15		1.40		DL2	SD	0.54		0.53		0.6	
	CV	2.44		2.30		2.83			CV	4.74		4.61		5.37	
	Min–Max	47.25–57.33		44.96–53.39		43.9–54.33			Min–Max	9.92–12.79		10.39–13.17		9.34–12.94	
	Mean ± SE	74.43 ±	0.11 a	74.43 ±	0.1 a	73.16 ±	0.32 b		Mean ± SE	37.32 ±	0.62 ab	38.02 ±	0.52 b	34.97 ±	0.44 ca
PrDD2	SD	1.02		1.49		2.63		AxPc	SD	5.53		7.84		3.52	
	CV	1.37		2.01		3.59			CV	14.83		20.62		10.08	
	Min–Max	71.19–76.57		64.92–77.96		57.37–76.49			Min–Max	22.36–54.79		22.21–62.62		27.27–43.41	
	Mean ± SE	25.8 ±	0.1 a	27.05 ±	0.06 b	27.18 ±	0.17 b		Mean ± SE	19.17 ±	0.08 a	18.73 ±	0.06 b	19.93 ±	0.11 c
PrPcD	SD	0.87		0.95		1.39		PcL	SD	0.71		0.94		0.85	
	CV	3.37		3.53		5.11			CV	3.68		5.04		4.25	
	Min–Max	22.67–27.69		19.79–29.7		24.41–34.71			Min–Max	17.63–20.93		16.15–22.25		17.94–21.67	
	Mean ± SE	38.84 ±	0.1 a	39.66 ±	0.07 b	38.94 ±	0.15 a		Mean ± SE	16.21 ±	0.07 a	16.97 ±	0.08 b	18.08 ±	0.09 c
PrPeD	SD	0.85		1.01		1.21		PeL	SD	0.66		1.12		0.75	
	CV	2.19		2.54		3.12			CV	4.08		6.61		4.12	
	Min–Max	37.18–41.2		36.74–44.55		34.47–43.75			Min–Max	14.31–17.61		14.35–20.33		15.63–19.65	
	Mean ± SE	71.93 ±	0.15 a	71.63 ±	0.12 a	71.45 ±	0.33 a		Mean ± SE	14.32 ±	0.07 a	13.32 ±	0.04 b	12.99 ±	0.08 c
PrAD	SD	1.3		1.78		2.70		AL	SD	0.63		0.6		0.6	
	CV	1.81		2.48		3.78			CV	4.41		4.5		4.65	
	Min–Max	67.27–74.8		64.04–84.17		54.26–74.62			Min–Max	12.75–15.97		12.05–17.05		10.45–14.27	
	Mean ± SE	26.8 ±	0.1 a	26 ±	0.06 b	25.75 ±	0.15 b		Mean ± SE	6.51 ±	0.03 a	6.92 ±	0.02 b	6.38 ±	0.03 c
PcDD1	SD	0.91		0.92		1.20		PePeD	SD	0.25		0.35		0.24	
	CV	3.40		3.53		4.68			CV	3.80		5.03		3.79	
	Min–Max	24.61–29.51		23.51–28.45		21.99–29.34			Min–Max	5.98–7.13		5.96–8.24		5.65–6.85	
	Mean ± SE	50.48 ±	0.15 a	49.54 ±	0.1 b	48.69 ±	0.22 c		Mean ± SE	11.02 ±	0.07 a	10.86 ±	0.05 a	12.09 ±	0.06 b
PcDD2	SD	1.35		1.54		1.83		CPDe	SD	0.6		0.71		0.46	
	CV	2.68		3.11		3.75			CV	5.44		6.57		3.79	
	Min–Max	46.38–53.39		44.75–54.14		41.93–53.83			Min–Max	10.13–15.18		9.31–12.75		10.47–13.24	
	Mean ± SE	27.10 ±	0.14 a	26.52 ±	0.08 b	26.36 ±	0.19 b		Mean ± SE	25.83 ±	0.16 a	25.01 ±	0.08 b	25.46 ±	0.17 ba
PeDD1	SD	1.29		1.15		1.50		BDe	SD	1.46		1.2		1.39	
	CV	4.75		4.35		5.68			CV	5.64		4.8		5.46	
	Min–Max	24.79–31.49		23.89–31.78		21.42–30.35			Min–Max	22.91–30.47		21.97–29.8		21.82–29.62	
	Mean ± SE	43.99 ±	0.15 a	43.35 ±	0.09 b	43.18 ±	0.24 b		Mean ± SE	14.69 ±	0.1 a	14.19 ±	0.06 b	15.71 ±	0.13 c
PeDD2	SD	1.35		1.38		1.89		DSL1	SD	0.86		0.91		1	
	CV	3.07		3.18		4.37			CV	5.85		6.39		6.34	
	Min–Max	41.01–48.75		39.39–49.88		36.3–47.96			Min–Max	12.98–16.98		11.28–18.27		13.47–17.58	
	Mean ± SE	13.13 ±	0.09 a	12.6 ±	0.06 b	14.13 ±	0.11 c		Mean ± SE	13.48 ±	0.1 a	13.57 ±	0.06 a	14.75 ±	0.12 b
D2CD	SD	0.8		0.94		0.88		DSL2	SD	0.88		0.89		0.94	
	CV	6.13		7.47		6.25			CV	6.52		6.59		6.37	
	Min–Max	11.03–15.87		9.81–15.54		10.73–16.44			Min–Max	11.86–16.96		9.91–15.88		12.59–17.62	
	Mean ± SE	11.78 ±	0.09 a	12.3 ±	0.06 b	12.92 ±	0.11 c		Mean ± SE	2.5 ±	0.05 a	2.62 ±	0.05 ab	2.87 ±	0.05 b
DSL3	SD	0.82		0.83		0.89		ASL1	SD	0.44		0.78		0.36	
	CV	6.93		6.73		6.9			CV	17.53		29.74		12.67	
	Min–Max	10.08–14.79		9.98–14.66		10.93–15.13			Min–Max	1.48–4.15		1.18–4.89		2.1–3.78	
	Mean ± SE	6.13 ±	0.08 a	6.71 ±	0.06 b	7 ±	0.10 b		Mean ± SE	14.39 ±	0.12 a	15.18 ±	0.07 b	15.17 ±	0.20 b
DSL4	SD	0.72		0.84		0.78		ACD	SD	1.08		0.97		1.61	
	CV	11.82		12.57		11.1			CV	7.54		6.41		10.59	
	Min–Max	4.52–9.86		4.51–9.88		5.02–9.18			Min–Max	11.99–18.33		12.82–17.68		11.9–18.78	
	Mean ± SE	11.3 ±	0.08 a	11.73 ±	0.05 b	12.17 ±	0.10 c								
PeSL	SD	0.74		0.76		0.77									
	CV	6.54		6.47		6.33									
	Min–Max	10.11–14.33		9.35–13.85		10.21–14.11									

Table 2. Loading scores on the first 3 principal components. Variables in bold are highly correlated with each of the axes.* Significant loadings (> 0.70).

Variables	PC 1	PC 2	PC 3
HL	**–0.83**	0.02	–0.07
HW	**–0.86**	0.00	0.13
ML	**–0.73**	–0.04	0.02
ED	–0.37	0.07	0.61
ID	–0.61	–0.11	0.04
EOD	**–0.82**	0.02	–0.06
JS	–0.69	0.11	0.45
PrDD2	–0.02	**–0.98**	0.17
PrPcD	0.14	**–0.98**	0.03
PrPeD	0.06	**–0.99**	0.12
PcDD1	0.14	**–0.97**	0.11
PcDD2	0.03	**–0.98**	0.18
PeDD1	**–0.85**	0.02	0.21
PeDD2	**–0.89**	0.07	0.25
ADD1	**–0.93**	0.06	0.11
ADD2	**–0.89**	–0.04	–0.13
PeAD	**–0.80**	0.05	0.17
PcAD	**–0.87**	0.07	0.26
PcPeD	**–0.84**	0.04	0.27
D1D2D	–0.29	–0.04	0.43
DL1	–0.36	–0.11	–0.05
DL2	**–0.71**	0.03	0.28
AxPc/LNPc	–0.24	0.04	0.46
PcL	**–0.86**	–0.03	–0.22
PeL	**–0.77**	–0.07	–0.45
AL	**–0.73**	0.08	0.22
PePeD	–0.63	0.09	0.24
CPDe	**–0.78**	–0.10	–0.46
BDe	–0.69	–0.03	0.21
DSL1	**–0.75**	–0.12	–0.40
DSL2	**–0.73**	–0.17	–0.46
DSL3	–0.69	–0.15	–0.50
DSL4	–0.22	–0.25	–0.62
PeSL	–0.68	–0.10	–0.22
ASL1	0.18	–0.22	–0.66
ACD	–0.51	–0.12	–0.22
D2CD	–0.65	–0.13	–0.37
Eigenvalues	**15.85**	**7.04**	**3.79**
Variance (%)	**40.65**	**18.05**	**9.73**
Cumulative variance (%)	**40.65**	**58.70**	**68.43**

Table 3. Discriminatory power of morphometric characters of X1, X2, and X3 groups retained by stepwise discriminant analysis. **: P < 0.01; ***: P < 0.001.

Variables	Wilk's lambda (λ)	F to enter/remove	Probability
HL/LS	0.72	67.62	***
ID/HL	0.82	37.85	***
HW/HL	0.83	35.76	***
AL/LS	0.83	35.74	***
PePeD/LS	0.86	27.33	***
ML/HL	0.87	26.25	***
DSL1/LS	0.87	24.97	***
JS/HL	0.89	21.40	***
EOD/HL	0.89	21.15	***
ADD2/LS	0.89	20.43	***
PcPeD/LS	0.92	15.63	***
PcL/LS	0.93	13.65	***
DSL4/LS	0.93	12.87	***
PeDD1/LS	0.94	10.28	***
AxPc/PcL	0.95	9.68	***
D2CD/LS	0.95	8.81	***
PrDD1/LS	0.96	7.06	**
ED/HL	0.97	6.20	**
PrPeD/LS	0.97	5.86	**
PeL/LS	0.97	5.17	**

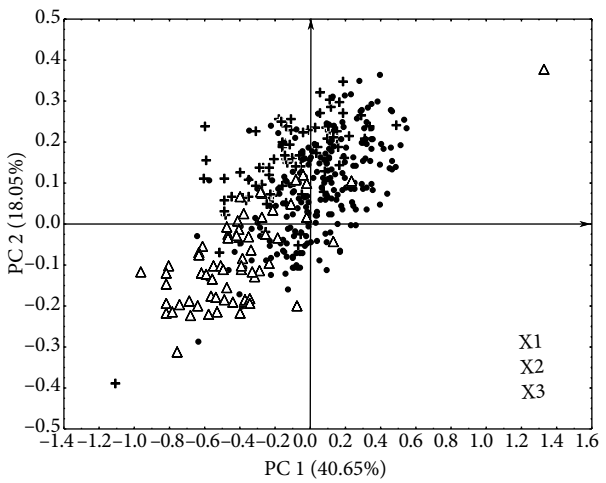

Figure 3. Scatterplot of first 2 principal components from the principal components analysis of the metric variables.

length (λ = 0.93), dorsal fourth spine length (λ = 0.93), pelvic–first dorsal fin origin distance (λ = 0.94), pectoral axillary process (λ = 0.95), second dorsal–caudal fin origin distance (λ = 0.95), first predorsal distance (λ = 0.96), eye diameter (λ = 0.97), prepelvic distance (λ = 0.97), and pelvic fin length (λ = 0.97).

On the basis of these morphometric characters, the 3 populations were well defined, with a classified individual percentage of 99.72% (Table 4). All specimens of groups X1 and X3 were correctly classified, with a percentage of 100%. These groups were most differentiated (distance = 8.58; F = 59.82; P < 0.001) according to the Mahalanobis distance (Table 5). Only one specimen of group X2 was assigned to group X3. Thus, the percentage of classification of group X3 was 98.43%. The lowest distance was noted between X2 and X1 (distance = 6.38; F = 54.49; P < 0.001).

The discriminant factorial analysis presents an almost perfect segregation of the 3 groups from the 20 most discriminating characters emerging from Wilk's lambda test (Figure 4). Individuals in group X1 are located in the plane formed by the positive parts of both axes (1 and 2). They were opposed to the group X2 specimens, which are predominantly located in the plane formed by the negative parts of both axes. Individuals of population X3 are mainly located in the plane formed by the negative side of axis 1 and the positive side of axis 2.

3.3. Meristic analysis

On the 11 meristic characters analyzed, 4 did not express any variability among the 3 groups according to the Kruskal–Wallis tests. These variables are the number of

Table 4. Result of discriminant analysis of the metric characters.

	X 1	X 2	X 3	Percent correct
X 1	79	0	0	100
X 2	0	223	0	100
X 3	0	1	63	98.43
Total	79	224	63	99.72

Table 5. The Mahalanobis distance between the 3 samples.

	X 1	X 2	X 3
X 1	-		
X 2	6.38 (F = 54.49; P < 0.001)	-	-
X 3	8.58 (F = 59.82; P < 0.001)	6.47 (F = 47.87; P < 0.001)	-

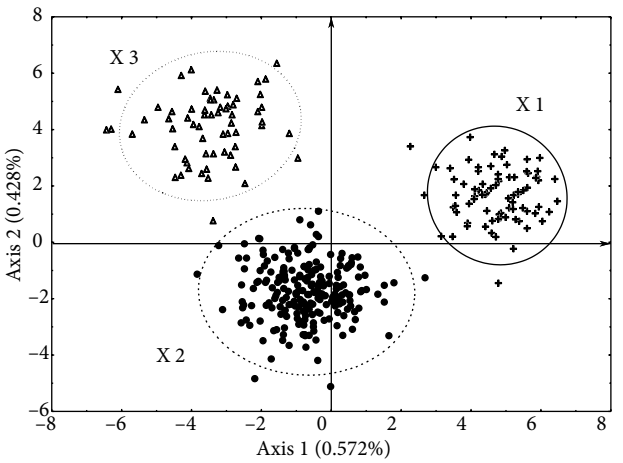

Figure 4. Scatterplot of first 2 significant canonical variables from the discriminant analysis of the metric variables. Plots of the centroids of the sample groups in the circle defined by the discriminant variables.

first (4) and second (9) dorsal rays, the number of pelvic soft rays (5), and the number of anal spines (3). Seven vary significantly (P < 0.05) but 3 among them present a remarkable variation between the different populations (Table 6).

These 3 characters are the number of branchiospines on the inferior and superior parts and the number of microbranchiospines on the branchial arch. The coefficients of variation recorded in all populations are low, and vary between 0% and 14.97%. Each population was shown to be homogeneous for these meristic characters, except for population X1 and X2, differentiated due to the number of branchiospines on the superior part of the first branchial arch. Individuals in populations X1 and X2 are distinguished by the number of branchiospines and microbranchiospines on the inferior part of the first branchial arch. Population X1 presents a mean of 64.46 ± 0.42 with a range of 57 to 70 and a mean of 110.38 ± 0.6 with a range of 103 to 123 for both parameters, respectively; population X2 presents means of 37.91 ± 0.17 and 74 ± 0.3 with a range of 34 to 45 and 65 to 84 respectively; population X3 has a mean of 76.05 ± 0.77 with a range of 62 to 89 for the branchiospines number on the inferior part of the first branchial arch, and a mean 146.38 ± 1.46 with an interval of 123 to 165 microbranchiospines on the first branchial arch. The number of branchiospines on the superior part of the first branchial arch separates the population of X2 from that of X3 without overlap. These populations recorded ranges of 19 to 39 and 43 to 58, respectively. However, a slight overlap is observed for the number of anal soft rays level which is 9, rarely 8 or 10, in individuals of X1, while those of groups X2 and X3 record 8.

The PCA showed that the first 2 principal components (Table 7) account for 85.93% of the total variance (62% for PC1, 23.93% for PC2). The scores from the PCA (Figure 5) were plotted on the first and second principal components for meristic variables. The PCA shows a clear separation of the populations identified. Indeed, X1 individuals are in the plane formed by the positive coordinates of the axes, while the X3 population is in the plane formed by the negative coordinates of axis 2 and positive of axis 1. The specimens of the X2 population are in the plane formed by the negative parts of axes 1 and 2. The discrimination of populations X2 and X3 appears to be influenced by ScL, BrspSup, BrspInf, MicBrsp, and ScLL, while PcR and AR are responsible for the segregation of population X1 (Table 7).

Table 6. Descriptive statistics of meristic variables of *Mugil* specimens in the 3 populations. S.E.: standard error; S.D.: standard deviation; CV: coefficient of variation.

Meristic variables	Statistics	X1		X2		X3		Meristic variables	Statistics	X1		X2		X3	
PcR	Mean ± SE	16.49 ±	0.07 a	15.80 ±	0.03 b	16.05 ±	0.03 c	Brsp Inf	Mean ± SE	64.46 ±	0.42 a	37.91 ±	0.16 b	76.05 ±	0.77 c
	SD	0.62		0.4		0.21			SD	3.76		2.39		6.14	
	CV	3.74		2.55		1.33			CV	5.83		6.3		8.07	
	Min–Max	15–17		15–16		16–17			Min–Max	57–70		34–45		62–89	
AR	Mean ± SE	9.03 ±	0.03 a	8 ± 0	b	8 ± 0	B	Mic Brsp	Mean ± SE	110.38 ±	0.6 a	74 ±	0.3 b	146.38 ±	1.46 c
	SD	0.23		-		-			SD	5.35		4.46		11.68	
	CV	2.49		0		0			CV	4.84		6.02		7.98	
	Min–Max	8–10		8		8			Min–Max	103–123		65–84		123–165	
ScL	Mean ± SE	12.09 ±	0.03 a	12 ±	0.01 a	14.05 ±	0.05 b	ScLL	Mean ± SE	37.71 ±	0.10 a	37.39 ±	0.06 a	42.34 ±	0.14 b
	SD	0.29		0.18		0.38			SD	0.92		0.97		1.13	
	CV	2.37		1.48		2.67			CV	2.44		2.58		2.67	
	Min–Max	12–13		11–13		13–15			Min–Max	36–39		36–40		40–44	
Brsp Sup	Mean ± SE	34.95 ±	0.41 a	26.92 ±	0.27 b	51.53 ±	0.58 c								
	SD	3.64		4.03		4.64									
	CV	10.41		14.97		9									
	Min–Max	27–44		19–39		43–58									

Table 7. Loading scores on the first 2 principal components. Variables in bold are highly correlated with each of the axes. * Significant loadings (>0.70).

Meristic variables	PC 1	PC 2
PcR	–0.34	**–0.73**
AR	–0.20	**–0.90**
ScL	**–0.88**	0.39
Sup Brsp	**–0.93**	0.08
Inf Brsp	**–0.94**	–0.24
MicBrsp	**–0.97**	–0.07
ScLL	**–0.85**	0.34
Eigenvalues	4.34	1.67
Variance (%)	62	23.93
Cumulative variance (%)	62	85.93

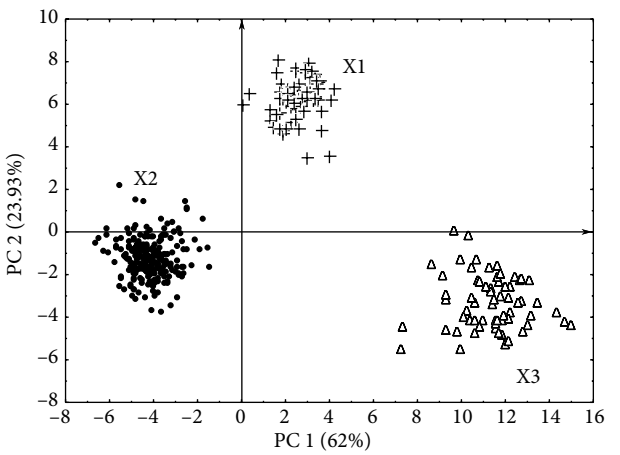

Figure 5. Scatterplot of first 2 principal components from the principal components analysis of the meristic variables.

4. Discussion

The present taxonomic study on the genus *Mugil* has revealed 3 distinct groupings. This large difference is attributable to significant variation in morphological, metric, and meristic characters. Morphological observations based on the color and appearance of the fins have permitted the identification of group X1, composed of specimens of silver-gray color with gray fins edged with pale yellow. In addition, these individuals have a diffuse orange-yellow spot on the edge of the operculum. On the other hand, specimens of group X2 are characterized by brown body coloration with the second dorsal fin and pectoral and anal fins covered with small scales, giving them a gray appearance with black spots. The third group (X3) contains individuals with a generally yellowish-gray body with a pronounced yellow on the pelvic fin and to a lesser degree the caudal fin. In addition, these individuals have visible longitudinal black bands on the upper part

of the body. These characteristics in all 3 populations are retained in the specimens regardless of the period of preservation in ethanol or formalin. However, when specimens were frozen, populations X1 and X2 were difficult to discriminate. The morphological characters discussed in this present study have also been very successful in identifying the species of *Mugil* (Harrison, 2007) in Lower Guinea.

The discrimination of these groups by coloration has been confirmed by univariate and multivariate analysis of metric characters. A high percentage of correct classification (99.72%) of individuals of different groups was obtained.

The specimens of group X3 have a wide head, a large interorbital space, and a wide mouth. Individuals of group X2 present the smallest measurements in these characteristics on the head, while X1 individuals are intermediate. Characters of the head showed only slight overlap, whereas those related to the body of the fish presented more overlap of the different groups. However, they expressed highly significant variation among the 3 groups according to ANOVA. Individuals of group X3 have higher values of the body parameters than the others and are thus the most robust. Group X1 comprises individuals with intermediate values of these parameters between those of the first 2 populations mentioned.

In meristic parameters, population X3 is discriminated by the presence of 8 soft rays in the anal fin, 13 to 15 scale lines between the pelvic and second dorsal fin, and 40 to 44 scales on the lateral line. This number of scales on the lateral line has already been quoted by different authors to be among the most discriminating characters between *Mugil platanus* and *M. cephalus* (Castro et al., 2008), as well as between *Mugil platanus* and *M. liza*, as Cousseau et al. (2005) and Menezes (1983) pointed out. In groups X1 and X2, the number of lateral line scales overlap significantly. However, the number of soft rays in the anal fin discriminates these 2 populations, with X1 recording 9 (rarely 8 or 10) while those in group X2 display 8 soft rays. This study has demonstrated morphological differences between the 3 related groups (X1, X2, and X3). Similarly, Heras et al. (2006) demonstrated morphometric differences between *M. cephalus* and *M. curema*, and Castro et al. (2008) between *M. cephalus* and *M. platanus*. On this basis, and supported by descriptions by Diouf (1991), Albaret (2003), Harrison (2007), and Castro et al. (2008), individuals of group X3 could therefore be assigned to the species *Mugil cephalus*, those of group X1 to the species *M. curema*, and individuals in group X2 to the species *M. bananensis*.

Previous studies mentioned here neglected the use of the branchiospines on the inferior and superior parts and microbranchiospines of the first branchial arch in the identification of species of the genus *Mugil*. These parameters proved to be the most discriminating in this study. The number of branchiospines on the superior parts of the first branchial arch separated the population of *M. bananensis* from *M. cephalus* without overlap. These populations recorded intervals of 19 to 39 and of 43 to 58, respectively. *M. curema*, with a range of 27 to 44, presented some overlap with both species.

The number of branchiospines on the inferior part of the first branchial arch also greatly contributed to the differentiation of these 3 species, varying from 57 to 70 for *M. curema*, from 34 to 45 for *M. bananensis*, and from 62 to 89 for *M. cephalus*. *M. curema* records for the number of microbranchiospines on the first branchial arch an interval from 103 to 123, *M. bananensis* shows from 65 to 84, and *M. cephalus* shows from 123 to 165.

In similar studies, the strong discriminating power of morphometric variables has been recognized (Waldman et al., 1997; Murta, 2000; Garcia-Davila et al., 2005; Ferrito et al., 2007; Anastasiadou and Leonardos, 2008; Anastasiadou et al., 2009). This has shown that the morphometric characters used in this study have an application in taxonomy and may be used as indices to measure morphometric variation among *Mugil* groups. Indeed, according to Warheit (1992), morphometrics are essential ingredients in systematic studies.

Morphologic and meristic characters have been successfully used for the problematic identification of these 3 species and showed a clear distinction between 3 populations. However, the meristic parameters were the most determinative in the differentiation of these species. For a better understanding of these species, this study should be complemented with genetic and osteological analyses to verify the morphometric differences.

Acknowledgments

I would like to express appreciation to the staff of the Laboratory of Environment and Aquatic Biology of Nangui Abrogoua University for assistance in collecting samples.

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