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Phenotypic characterization of clams of the genus *Egeria* Roissy, 1805 (Bivalvia: Donacidae) in the lower Sanaga River, Cameroon

Tekou Guegang[1], Judith Georgette Makombu[2], Claudine Tekounegning Tiogue[3], Alexia Kevine Noubissi Chiassa[1], Pamela Cynthia Mepa Tchiegang[1], Boddis Tsiguia Zebaze[1] and Augustave Kenfack[4]

[1]*Laboratory of Applied Ichthyology and Hydrobiology, Department of Animal Productions, Faculty of Agronomy and Agricultural Sciences, The University of Dschang, P.O. Box 222, Dschang, Cameroon*
[2]*Department of Fisheries and Aquatic Resources Management, Faculty of Agriculture and Vetenary Medicine, University of Buea, P.O. Box 63, Buea, Cameroon*
[3]*Laboratory of Applied Ichthyology and Hydrobiology, School of Wood, Water and Natural Resources, Faculty of Agronomy and Agricultural Sciences, The University of Dschang, P.O. Box 786, Ebolowa Campus, Cameroon*
[4]*Laboratory of Reproduction and Animal Health, Department of Animal Productions, Faculty of Agronomy and Agricultural Sciences, The University of Dschang, P.O. Box 188, Dschang, Cameroon*
[*]*Corresponding author: tekouguegang@yahoo.com*

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Abstract

In order to evaluate wild clams for possible domestication with a view to aquaculture, the present study focused on the phenotypic characteristics of wild clams of the genus *Egeria* Roissy, 1805 in the Lower Sanaga River of Cameroon, with the main objective of contributing to a better understanding of their biology. A total of 2340 clams of different sizes were collected between March 2018 to March 2019 at three sites in the lower part of the Sanaga River, namely Bolounga-Moulongo, Mpombo-Boloy and Maldjedou-Bonapembe. Phenotypic characteristics (including internal and exterior coloration of the shell, type and number of shell stripes, color of the mantle, shape of the pallial sinus, and indices of elongation, compactness and convexity) were collected on each individual and evaluated according to the site and the season. The results showed four predominant colors on the exterior face of the shell (66.0% yellow, 29.1% brown, 4.7% dark and 0.2% pink), three colors on the internal face of the shell (89.4% white, 10.5% white-purple and 0.1% white-pink), three types and number of shell stripes (57.8% visible stripes, 23.4% barely visible stripes and 18.8% absent stripes), two colors of the mantle (17.5% white and 82.5% orange), two types of the pallial sinus (60.5% dorsally angular, and 39.5% regularly rounded), 99.8% oval shapes (elongation index), 99.7% convex shapes (convexity index) and 52.7% compact shapes (compactness index). The results for clam characteristics were not influenced by the site nor the season, apart from the compactness index which varied according to the site. Phenotypically, the clams of the Lower Sanaga River showed several similarities with the species *Egeria radiata* and the specimens that showed a pink color of the shell similar to the species *Egeria rubicunda*. Molecular characterization is therefore necessary to explain the origin of the diversity of phenotypic characteristics in the clam's species population in this area.

Key words: Clams, *Egeria*, phenotypic, sites, seasons, Sanaga River, Cameroon

Introduction

The African freshwater bivalve molluscs are found in 9 families, 27 genera and comprise 172 species (Purchon, 1963a, b; Daget, 1998; FAO, 2016). These species have for centuries been the basis of a thriving artisanal fishery and a means of employment and livelihood for riparian people and constitute an important and affordable protein source for them (Adjei-Boateng et al., 2012; Abarike et al., 2015).

The shells of the bivalves have an important use as a source of calcium in animal (poultry) feed, as pavement material and in the manufacture of local paints and concrete (Adjei-Boateng et al., 2012; Olutoge et al., 2016). The main threats for these bivalves are overexploitation, dam construction, drought and climate change (IUCN, 2010; Obirikorang et al., 2013b). According to IUCN (2010), conservation and fisheries management strategies for bivalve molluscs are based on prerequisite research on taxonomy, geographic distribution, ecology, population dynamics and the threats these bivalves face. Among these bivalve molluscs are clams of the genus *Egeria* Roissy, 1805, endemic to the eastern Atlantic coast of the African continent. They have already been the subject of research in Ghana (Adjei-Boateng and Wilson, 2012; Adjei-Boateng and Wilson, 2013; Olayemi et al., 2012; Obirikorang et al., 2013a, b) and in Nigeria (Etim and Brey, 1994; Etim et al., 1997).

In Cameroon, the main exploitation area for populations of the genus of *Egeria* is in the lower Sanaga River (Ajonina et al., 2005) where some short-term studies have been done less than three months for most of them. These previous studies have focused on socio-economic surveys (Ajonina et al., 2005), bioecology (Dikoume et al., 2016; 2017; Tekou et al., 2020) and morpho-biometrics (Tekou et al., 2015).

In this locality in the lower Sanaga River, the exploitation of bivalves plays a significant role in the socio-economic and cultural well-being of local residents (Ajonina et al., 2005). The trend in catches is decreasing, falling from 240 t in 2005 to 127 t in 2008; a decrease of 47.1% (CWCS, 2009). This decrease could be due to the depletion of the available natural stock, itself linked to anthropogenic pressure. To ensure the sustainability of this natural resource, domestication for aquaculture seems the best alternative. However, domestication of any natural resource should be based firstly on knowledge of ecological and genetic diversity.

All previous studies on the diversity of clams in Cameroon reported two species namely *Egeria radiata* (Lamarck, 1805) and *Egeria schwabi* Clench, 1929 (Purchon, 1963a; Odiete, 1981; Daget, 1998). Therefore, there is no updated information on the biodiversity of *Egeria* clams in Cameroon. However, phenotypic morphological traits, which are characters that can be seen with the naked eye, and will contribute to establish clam breeding programs, are not yet studied.

The present study sought to assess the variability of phenotypic characteristics in *Egeria* clams in three main fishery sites on the lower part of the Sanaga River for one year. This will allow an assessment of the possible influence of sites and seasons on phenotypic characteristics. It will not only contribute to establishing a breeding plan but also in updating information on the biodiversity of clams in Cameroon.

Material and Methods

Study area and sites

The study was carried out from March 2018 to March 2019 at three main sites including Bolounga-Moulongo, Mpombo-Boloy and Maldjedou-Bonapembe of the lower Sanaga River, located in the District of Mouanko, Department of Sanaga Maritime, Littoral Region of Cameroon (Fig. 1). In this area (3°35'–3°39'N; 9°43'–9°47'E) the equatorial type of climate is influenced by the Atlantic Ocean with 4 distinct seasons: 1) a light dry season (LDS) from mid-November to mid-March, 2) a short rainy season (SRS) from mid-March to April, 3) a short dry season (SDS) from May to June and 4) a heavy rainy season (HRS) from July to mid-November (CWCS, 2006; PNDP, 2018). The annual rainfall ranges from 2000 to 3000 mm with temperatures from 25 to 30 °C and the altitude varies from 0 to 50 m (CWCS, 2006; PNDP, 2018).

The lower Sanaga River is a short 67 km stretch that joins the Atlantic Ocean and is under the influence of the tidal cycle (PANGIRE, 2009). The substrate has a higher percentage of sand than silt or clay across the three collection sites; however, the percentage of silt and clay varies with the seasons. The Maldjedou-Bonapembe site has the highest proportions of clay and silt during the long rainy season, while in the short rainy season, the Bolounga-Moulongo site has the highest percentage (Tekou et al., 2020). Water depths vary throughout the year, with Maldjedou-Bonapembe and Mpombo-Boloy being the deepest (10–700 cm) and Bolounga-Moulongo the shallowest (10–350 cm) (Tekou et al., 2020).

Clams collection

A total of 2340 clam specimens were collected from the three sites, over the consecutive 13-month period, on a section of the Sanaga River adjacent to the village of Malimba. Three sampling points were chosen randomly (average radius of 1 km) at each site per month and 20 individual clams were collected from each point, for a total of 180 clams per month. The sampling technique used at each site was

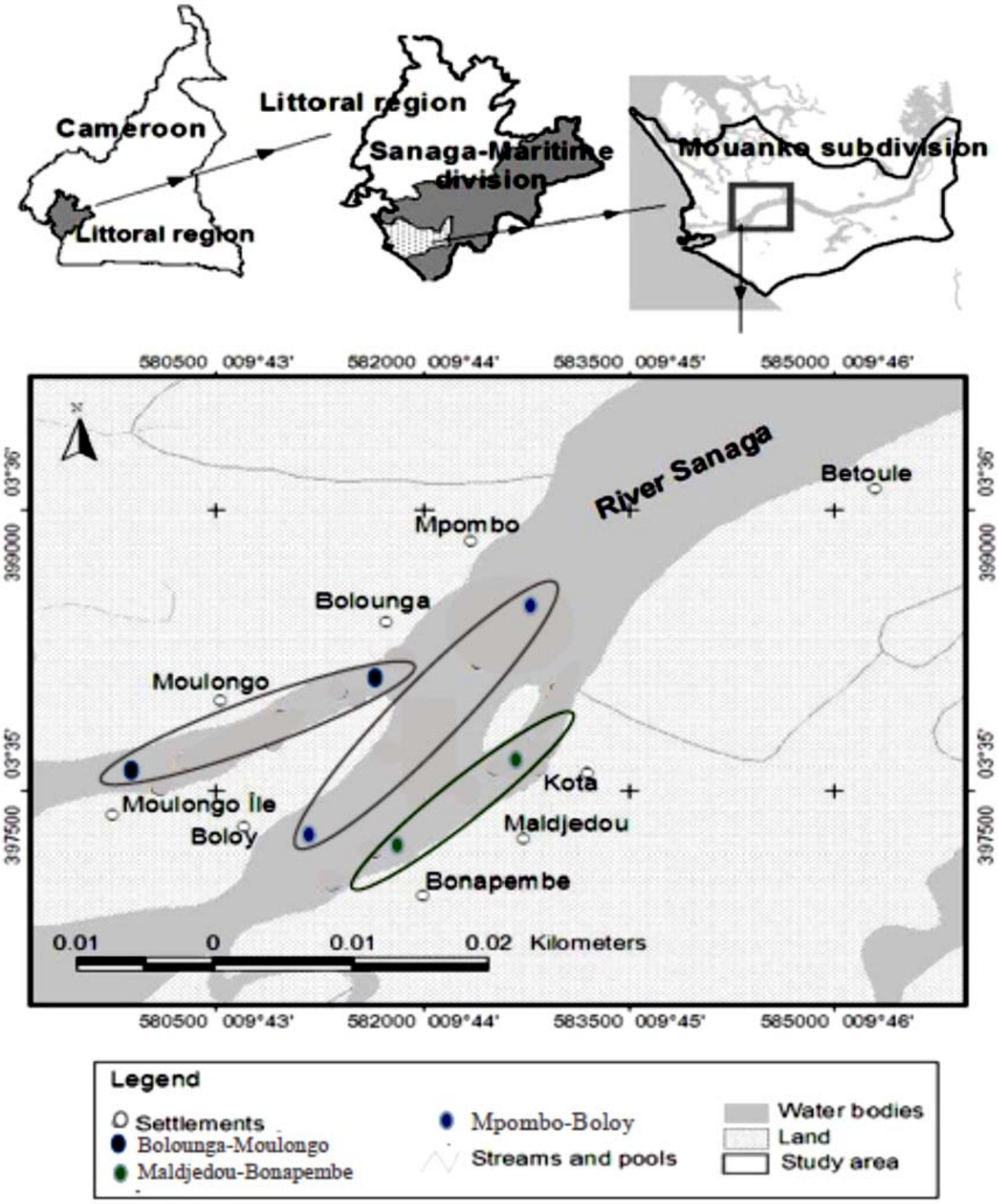

Figure 1: Maps showing the sampling locations in the lower Sanaga River, Cameroon.

manual collection, carried out at low tide by a team of professional divers. In order to avoid possible discoloration due to stress at ambient temperature, specimens were stored at 4 °C in coolers and transported to the laboratory. Once in the laboratory, the valves of each clam were opened using a knife and the flesh separated from them. Each set was drained and examined according to the protocol described by Fernández-Pato and Arnal (1977).

Frequency of phenotypic characteristics

The phenotypic data were identified with the naked eye on the shell of each individual using Bernardi (1860) and FAO (2016) identification keys and included the interior and exterior valve color (Html color code: https://htmlcolorcodes.com/fr), the presence or absence of patterns on the shell and their number on left valve, the type of pallial sinus and the color of the mantle.

Absolute frequency is considered as the observation number of phenotypic descriptors. The relative frequency of the phenotypic descriptor was calculated as follows:

RF= (ON d ÷TN) × 100

Where *RF*: Relative Frequency, d: phenotypic Descriptor, *ON*: Observation Number of descriptor *d* and *TN*: Total Number of individuals studied.

Table 1: Formula and description of some indices of form measured in *Egeria* clams from the lower Sanaga River, Cameroon.

Indices	Formula	Description
Elongation index *(Ei)*	*H/L*	*Ei*< 1.5 Oval shape, 1.5 < *Ei* < 2 elliptical shape
Compacity index *(Cmi)*	*W/L*	Rapid increase in *W* compared to *L*, globular form. If *W* is > 50% *L* and therefore *Cmi*> 0.5, compact bivalve
Convexity index *(Cni)*	*W/H*	If *W* is > 50% of *H* and therefore *Cni*> 0.5, convex bivalve

L: length (mm), *W*: width (mm), *H*: height (mm) (Nedeau et al., 2009; Caill-Milly et al., 2012).

Shape indices

The shape indices used in clams are summarized in Table 1. In order to calculate these indices, metric data were collected on each individual using a Stainless steel electronical digital caliper with an accuracy of 0.01 mm. These metrics were length (*L*: greatest measurement in the antero-posterior lateral direction), height (*H*: from the dorsal hinge to the ventral edge in the lateral view) and width or inflation (*W*: maximum thickness in the ventral view) (Fig. 2) (Fernández-Pato and Arnal, 1977; Caill-Milly et al., 2012; 2014; FAO, 2016).

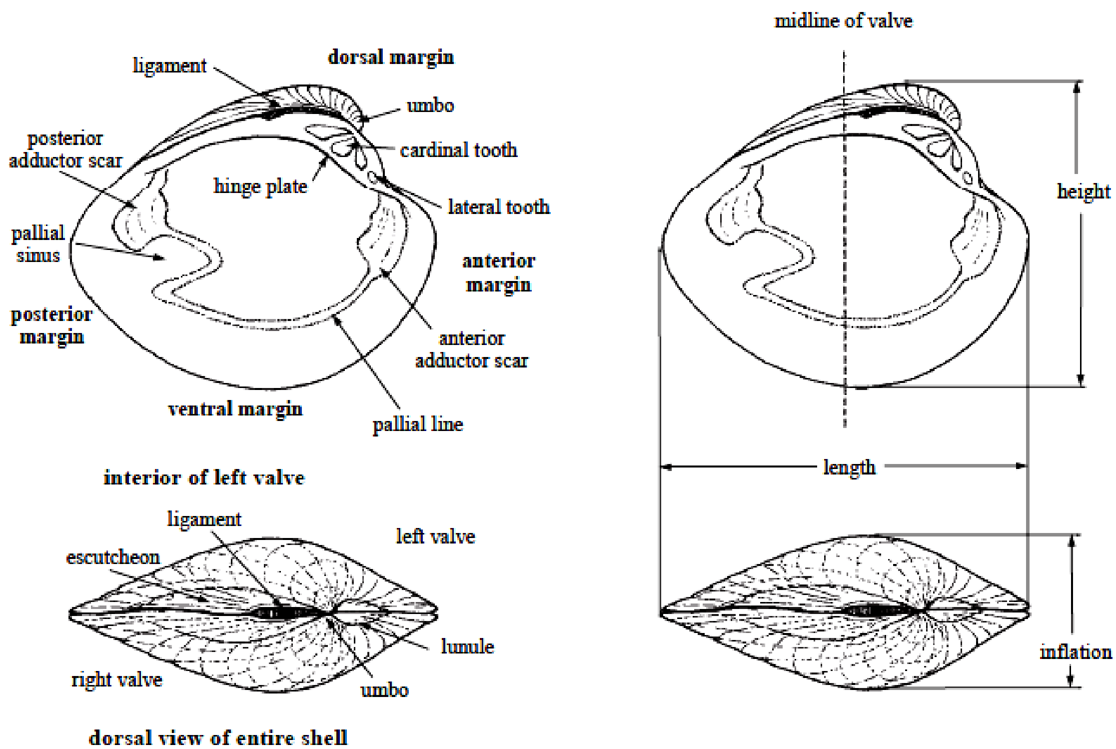

Figure 2: Technical terms and measurements of clam shells (FAO, 2016).

Statistical analysis

The comparison of the abundance averages of phenotypic traits and the shape indices according to the seasons and the sites was made by a 2-way ANOVA test. The analysis of the shape indices proportions was made using the Chi-square test at a 5% significance level.

Results

General characteristics

The 2340 clam specimens collected had the following biometric characteristics: length (21.68–97.12 mm), width (3.93–50.17 mm) and height (5.84–73.67 mm).

Phenotypic characteristics

The phenotypic characteristics observed in the clams of the lower Sanaga River are illustrated in Figure 3. On the outer surface of the shell, coloring varies from dark brown, yellow, lighter brown to pink (Fig. 3a-d). The type of exterior valve patterns observed are the absence of stripes (Fig. 3e), barely visible stripes (e.g. only one stripe on one valve) (Fig. 3f) and clearly visible stripes (≥ 2 stripes on each valve) (Fig. 3g). On the interior valve surface, the coloring is either white-purple, white-pink or white (Fig. 3h-j).

The type of pallial sinus is either regularly rounded (Fig. 3k) or dorsally angular (Fig. 3l). All the pallial sinuses were dorsally ascending and were shallow. The mantle color is either orange or whitish. In a few individuals, a shade of white-pink was observed in the mantle. In general, individuals with dark coloration on the exterior surface of the shell present shades of purple on the inner side. The number of stripes observed on the exterior of the left valves ranged from 0 to 39. The internal surface of the valves was smooth in all individuals.

Abundance of phenotypic characteristics

The absolute and relative abundances of phenotypic characteristics of the clams from the lower Sanaga River, according to the season and the site are summarized in Table 2. In general, it appears that the proportions of each characteristic observed did not present any site or seasonal specificity.

Four colors on the exterior face of the shell were recorded (yellow, dark brown, light brown and pink). Individuals with the yellow exterior color were most represented (66.0%), and those with a pink color were fewest (0.2%), regardless of the site or the season. When the seasons were considered independently of the sites, the highest percentage of individuals with a yellow color was observed during the light dry season (LDS), and the smallest percentage during the short rainy season (SRS). When sites were considered independently, the highest percentage of the yellow exterior color (79.7%) was observed at Bolounga-Moulongo and the lowest (50.3%) at Maldjedou-Bonapembe.

The individuals presenting the white color on the interior surface of the shell were dominant (89.4%), followed by those presenting the white-purple (10.5%) and finally the white-pink (0.1%) in all the sites and throughout the year. When only the seasons are taken into account, the proportions of individuals with white internal color were more (91.7%) and less (87.2%) abundant in the SDS and the SRS, respectively; and inversely for those with white-purple color, respectively. White-pink individuals were only recorded in the LDS. With respect to sites only, Maldjedou-Bonapembe and Bolounga-Moulongo recorded, respectively, the highest (92.2%) and lowest (86.3%) proportions of individuals of white internal color; and the reverse for those with white-purple internal coloration. Individuals with white-pink internal coloration were only recorded at Maldjedou-Bonapembe.

The individuals with barely visible stripes (number of stripes = 1) were the least represented, followed by those absent any stripes and finally those with multiple visible stripes (number of stripes ≥ 2 on each valve) regardless of the site and the sampling season. Regardless of the seasons, the proportions of individuals with no stripes were highest (20.4%) and lowest (17.0%) during the SRS and LDS, respectively; those individuals with barely visible stripes during the SDS (24.2%) and HRS (22.4%), respectively; and those individuals with multiple visible stripes during the LDS (59.6%) and SRS (55.4%), respectively. Depending on the sites, the proportions of individuals with stripes absent were highest (23.3%) and lowest (16.3%), respectively, in Maldjedou-Bonapembe and Mpombo-Boloy; those individuals with barely visible stripes in Bolounga-Moulongo and Maldjedou-Bonapembe, respectively; and those individuals with multiple visible stripes in Mpombo-Boloy and Maldjedou-Bonapembe.

The clams of the low Sanaga River present two main colors of their mantle: orange or white. The orange color was the most represented regardless of the sites and seasons. Depending on the season, individuals with whitish mantles presented a higher proportion (39.3%) in the SRS and a lower proportion (7.6%) in the HRS; while those with orange mantles showed the opposite pattern. Considering justthe sites, Maldjedou-Bonapembe and Mpombo-Boloy recorded the highest (24.2%) and lowest (14.0%) proportions, respectively, of the whitish mantle color while Mpombo-Boloy and Bolounga-Moulongo recorded the orange mantle color as highest and lowest, respectively.

Looking at the pallial sinus, two forms were observed in individuals, a regularly rounded sinus or a dorsally angular sinus. The latter was the most (60.5%) represented in the sample. Depending on the season, the proportions of individuals with dorsally angular sinuses were highest (68.1%) and lowest (51.7%) in the SRS and LDS, respectively; while the reverse was recorded for individuals with regularly rounded sinuses in the same seasons. Considering sites only, Maldjedou-Bonapembe and Bolounga-Moulongo recorded the highest (63.5%) and lowest (56.08%) proportions respectively in terms of the dorsally angular sinus and inversely for the regularly rounded sinus proportions. No significant differences exist between sites, seasons and interactions no matter which phenotypic characteristic are considered ($p > 0.05$).

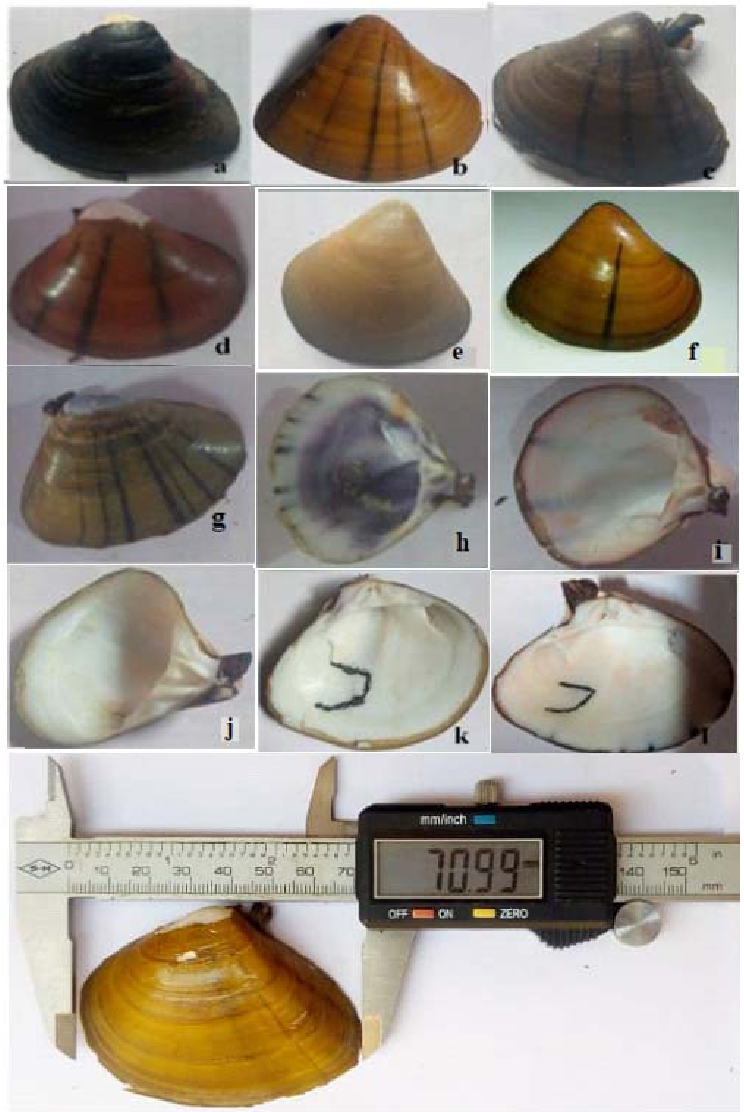

Figure 3: Phenotypic characteristics observed in clams from the lower Sanaga River, Cameroon. Outer surface (a-g): a) dark brown, b) yellow, c) lighter brown, d) pink, e) stripes absent, f) barely visible stripes (only one stripe on one valve), g) visible stripes (≥ 2 stripes on each valve). Inner surface (h-l): h) white-purple, i) white-pink, j) white, k) regularly rounded pallial sinus, l) dorsally angular pallial sinus. Scale: m) scale given by electronically digital calliper.

Abundance of indices of form

The relative abundance of the three indices of form from the three sites studied is presented in Table 3. The majority ofindividuals presented oval shapes (> 99%) for the elongation index and convex shapes (> 99%) for the convexity index. The compactness index showed predominance (52.7%) of the compact form compared to the non-compact form.

In Bolounga-Moulongo, no elliptical shaped shells were observed, but they were observed in Mpombo-Boloyat 0.4% in the LDS and in Maldjedou-Bonapembe at 0.4% in the LDS and 1.1% in the SRS. The non-convex shape was observed only in the LDS in Bolounga-Moulongo while in Mpombo-Boloy and Maldjedou-Bonapembe, it was observed in the LDS and the SRS. The non-compact form was more (59.6%) and less (33.7%) dominant in Maldjedou-Bonapembe and Mpombo-Boloy, respectively, regardless of season. It was, however, more dominant in Bolounga-Moulongo in the HRS and the LDS.

Whatever the axis, the proportions of shapes were not significantly influenced by seasons (elongation: $\chi^2 = 3.591$, df = 3, $p > 0.05$; compactness: $\chi^2 = 4.165$, df = 3, $p > 0.05$; convexity: $\chi^2 = 3.379$, df = 3, $p > 0.05$) orsites (elongation: $\chi^2 = 3.504$, df = 2, $p > 0.05$; convexity: $\chi^2 = 2.006$, df = 2, $p > 0.05$). However, the compactness index significantly influenced the proportions by site ($\chi^2 = 105.798$, df = 2, $p < 0.05$).

Table 2: Absolute and relative abundance of phenotypic characteristics depending on the site and the season in *Egeria* clams from the lower Sanaga River, Cameroon.

Site	Season	F	Ext-col					Ext-nbr-stp-l				In-col-shl				In-col-man			In-sin		
			yl	bw	pk	dk	Total	Sab	Sbv	Sv	Total	wt	wpk	wpp	Total	wt	or	Total	and	rr	Total
Site 1	**HRS**	**AF**	180	41	0	19	**240**	45	61	134	**240**	208	0	32	**240**	15	225	**240**	145	95	**240**
		RF (%)	75	17.1	0	7.9	**100**	18.8	25.4	55.8	**100**	86.7	0	13,3	**100**	6.3	93.8	**100**	60.4	39.6	**100**
	LDS	**AF**	218	12	0	10	**240**	32	58	150	**240**	213	0	27	**240**	29	211	**240**	96	144	**240**
		RF (%)	90.8	5	0	4.2	**100**	13.3	24.2	62.5	**100**	88.8	0	11,3	**100**	12.1	87.9	**100**	40	60	**100**
	SRS	**AF**	110	61	3	6	**180**	30	48	102	**180**	151	0	29	**180**	68	112	**180**	130	50	**180**
		RF (%)	61.1	33.9	1.7	3.3	**100**	16.7	26.7	56.7	**100**	83.9	0	16,1	**100**	37.8	62.2	**100**	72.2	27.8	**100**
	SDS	**AF**	114	3	0	3	**120**	24	26	70	**120**	101	0	19	**120**	0.0	120	**120**	72	48	**120**
		RF (%)	95	2.5	0	2.5	**100**	20	21.7	58.3	**100**	84.2	0	15,8	**100**	0.0	100	**100**	60	40	**100**
Site 2	**HRS**	**AF**	149	80	0	11	**240**	43	45	152	**240**	208	0	32	**240**	13	227	**240**	166	74	**240**
		RF (%)	62.1	33.3	0	4.6	**100**	17.9	18.8	63.3	**100**	86.7	0	13.3	**100**	5.4	94.6	**100**	69.2	30.8	**100**
	LDS	**AF**	180	54	0	6	**240**	33	58	149	**240**	223	0	17	**240**	39	201	**240**	126	114	**240**
		RF (%)	75	22.5	0	2.5	**100**	13.8	24.2	62.1	**100**	92.9	0	7.1	**100**	16.3	83.8	**100**	52.5	47.5	**100**
	SRS	**AF**	137	34	0	9	**180**	26	43	111	**180**	157	0	23	**180**	46	134	**180**	112	68	**180**
		RF (%)	76.1	18.9	0	5	**100**	14.4	23.9	61.7	**100**	87.2	0	12.8	**100**	25.6	74.4	**100**	62.2	37.8	**100**
	SDS	**AF**	64	53	0	3	**120**	25	32	63	**120**	113	0	7	**120**	11	109	**120**	73	47	**120**
		RF (%)	53.3	44.2	0	2.5	**100**	20.8	26.7	52.5	**100**	94.2	0	5.8	**100**	9.2	90.8	**100**	60.8	39.2	**100**
Site 3	**HRS**	**AF**	149	85	1	5	**240**	51	55	134	**240**	225	0	15	**240**	27	213	**240**	153	87	**240**
		RF (%)	62.1	35.4	0.4	2.1	**100**	21.3	22.9	55.8	**100**	93.8	0	6.3	**100**	11.3	88.8	**100**	63.8	36.3	**100**
	LDS	**AF**	115	112	0	13	**240**	57	53	130	**240**	215	2	23	**240**	40	200	**240**	150	90	**240**
		RF (%)	47.9	46.7	0	5.4	**100**	23.8	22	54.2	**100**	89.6	0.8	9.6	**100**	16.7	83.3	**100**	62.5	37.5	**100**
	SRS	**AF**	71	87	0	22	**180**	54	40	86	**180**	163	0	17	**180**	98	82	**180**	126	54	**180**
		RF (%)	39.4	48.3	0	12.2	**100**	30	22.2	47.8	**100**	90.6	0	9.4	**100**	54.4	45.6	**100**	70	30	**100**
	SDS	**AF**	57	60	0	3	**120**	20	29	71	**120**	116	0	4	**120**	24	96	**120**	66	54	**120**
		RF (%)	47.5	50	0	2.5	**100**	16.7	24.2	59.2	**100**	96.7	0	3.3	**100**	20	80	**100**	55	45	**100**
Total seasons	**HRS**	**AF**	478	206	1	35	**720**	139	161	420	**720**	641	0	79	**720**	55	665	**720**	464	256	**720**
		RF (%)	66.4	28.6	0.1	4.9	**100**	19.3	22.4	58.3	**100**	89.0	0	11.0	**100**	7.6	92.4	**100**	64.4	35.6	**100**
	LDS	**AF**	513	178	0	29	**720**	122	169	429	**720**	651	2	67	**720**	108	612	**720**	372	348	**720**
		RF (%)	71.2	24.7	0	4.0	**100**	17.0	23.4	59.6	**100**	90.4	0.3	9.3	**100**	15.0	85.0	**100**	51.7	48.3	**100**
	SRS	**AF**	318	182	3	37	**540**	110	131	299	**540**	471	0	69	**540**	212	328	**540**	368	172	**540**
		RF (%)	58.9	33.7	0.6	6.8	**100**	20.4	24.2	55.4	**100**	87.2	0	12.8	**100**	39.3	60.7	**100**	68.1	31.9	**100**
	SDS	**AF**	235	116	0	9	**360**	69	87	204	**360**	330	0	30	**360**	35	325	**360**	211	149	**360**
		RF (%)	65.3	32.2	0	2.5	**100**	19.1	24.2	56.7	**100**	91.7	0	8.3	**100**	9.7	90.3	**100**	58.6	41.4	**100**
Total Sites	**Site 1**	**AF**	622	117	3	38	**780**	131	193	456	**780**	673	0	107	**780**	112	668	**780**	443	337	**780**
		RF (%)	79.7	15	0.4	4.9	**100**	16.8	24.7	58.5	**100**	86.3	0	13.7	**100**	14.4	85.6	**100**	56.8	43.2	**100**
	Site 2	**AF**	530	221	0	29	**780**	127	178	475	**780**	701	0	79	**780**	109	671	**780**	477	303	**780**
		RF (%)	68	28.3	0	3.7	**100**	16.3	22.8	60.9	**100**	89.9	0	10.1	**100**	14.0	86.0	**100**	61.2	38.8	**100**
	Site 3	**AF**	392	344	1	43	**780**	182	177	421	**780**	719	2	59	**780**	189	591	**780**	495	285	**780**
		RF (%)	50.3	44.1	0.1	5.5	**100**	23.3	22.7	54.0	**100**	92.2	0.2	7.6	**100**	24.2	75.8	**100**	63.5	36.5	**100**
Grand total		**AF**	**1544**	**682**	**4**	**110**	**2340**	**440**	**548**	**1352**	**2340**	**2093**	**2**	**245**	**2340**	**410**	**1930**	**2340**	**1415**	**925**	**2340**
		RF (%)	**66.0**	**29.1**	**0.2**	**4.7**	**100**	**18.8**	**23.4**	**57.8**	**100**	**89.4**	**0.1**	**10.5**	**100**	**17.5**	**82.5**	**100**	**60.5**	**39.5**	**100**

F: frequency, AF: absolute frequency, RF: relative frequency, SRS: short rainy season, LDS: light dry season, SDS: short dry season, HRS: heavy rainy season, site 1: Bolounga-Moulongo, site 2: Mpombo-Boloy, site 3 : Maldjedou-Bonapembe, yl: yellow, bw: lighter brown, pk: pink, dk: darkbrown, Sab: stripes absent, Sbv: barely visible stripes, Sv: multiple visible stripes, wt: white, wpk: white-pink, wpp: white-purple, or: orange, and: angular dorsally, rr: regularly rounded, Ext-col = exterior color of the shell; Ext-nbr-stp-l = number of stripe on the outer part of the left shell; In-col-shl = color of the inner surface of the shell; In-col-man = color of the mantle; In-sin = type of pallial sinus.

Table 3: Abundance of some indices of form across the sites and the seasons studied for clams of the lower Sanaga River, Cameroon.

		Indices (%)					
		Elongation		**Compactness**		**Convexity**	
Sites/ seasons	**Form**	**Oval**	**Elliptic**	**Compact**	**Not compact**	**Convex**	**Not convex**
Site 1	HRS	100.0	0.0	40.4	59.6	100.0	0.0
	LDS	100.0	0.0	45.4	54.6	99.6	0.4
	SRS	100.0	0.0	60.6	39.4	100.0	0.0
	SDS	100.0	0.0	70.8	29.2	100.0	0.0
Site 2	HRS	100.0	0.0	74.2	25.8	100.0	0.0
	LDS	99.6	0.4	62.9	37.1	99.2	0.8
	SRS	100.0	0.0	62.2	37.8	99.4	0.6
	SDS	100.0	0.0	63.3	36.7	100.0	0.0
Site 3	HRS	100.0	0.0	48.8	51.3	100.0	0.0
	LDS	99.6	0.4	40.4	59.6	99.4	0.6
	SRS	98.9	1.1	36.7	63.3	99.4	0.6
	SDS	100.0	0.0	29.2	70.8	100.0	0.0
Total seasons	HRS	100.0	0.0	54.4	45.6	99.9	0.1
	LDS	99.6	0.4	49.6	50.4	99.4	0.6
	SRS	99.6	0.4	53.1	46.9	99.6	0.4
	SDS	100.0	0.0	54.4	45.6	100.0	0.0
Total sites	Site 1	100.0	0.0	51.3	48.7	99.9	0.1
	Site 2	99.9	0.1	66.3	33.7	99.5	0.5
	Site 3	99.6	0.4	40.4	59.6	99.7	0.3
Total		**99.8**	**0.2**	**52.7**	**47.3**	**99.7**	**0.3**

SRS: short rainy season, LDS: light dry season, SDS: short dry season, HRS: heavy rainy season, site 1: Bolounga-Moulongo, site 2: Mpombo-Boloy, site 3: Maldjedou-Bonapembe.

Discussion

The present study revealed a variety of phenotypic characteristics in *Egeria* clams. On the exterior surface, the shells presented, in decreasing proportions, yellow, lighter brown, dark brown and pink coloration. The yellow and pink colors have been compared to those of the genus *Egeria* as described by Bernardi (1860). The work of Tekou et al. (2015) and Tekou (2017) revealed similar proportions of color in the same river and in the Nkam River. No particular color was specific to any site or season. The differences in shell color could be explained either by the type of substrate, which varies across the sites where they were collected, or by inherent genetic traits. Indeed, the higher frequencies of individuals with the clear, unstriped, exterior color (yellow or pink) were mainly observed at Bolounga-Moulongo and could be due to the clear substrate and shallow depth of the waters; allowing sunlight to penetrate more easily. Conversely, the higher frequencies of individuals with dark, and striped, exterior colors (light and dark brown) were mainly observed at Maldjedou-Bonapembe where the substrate rich in silt and clay and the water depth is greater preventing sunlight from penetrating to the bottom.

Like all molluscs, clams have a protein layer on the outer surface of their shell, called the periostracum (Basso et al., 2015; Tripathy and Mukhopadhyay, 2015), which very likely changes color depending on the surrounding environmental conditions. The inner shell colors in decreasing proportion, were white, white-purple and white-pink, and they were similarly observed by Bernardi (1860) when he described the species in the genus *Egeria*. Indeed, the interior surface of the clam shell, called the ostracum, is rich in calcium carbonate but, deprived of proteinaceous matter (Basso et al., 2015; Tripathy and Mukhopadhyay, 2015) and therefore cannot change color as readily depending on the surrounding environment. The different internal coloration could be due to the existence of several different species in the genus or to population variation within a species. Consequently, the individuals of white-pink color approach the color exhibited by *Egeria rubicunda*, a species previously described by Bernardi (1860). However, their rarity in the current sampling could indicate either that they have a low reproductive capacity, due to environmental conditions which are not favourable for their development, or that these specimens are disappearing from, or newly introduced to the current population.

The number of stripes on the left valve of the clams studied varied widely, as did the results of the study by Tekou (2017) in the Nkam River, who observed the number of stripes varying between 0 and 20 on the left valve. Unlike other genera of clams, the existence of stripes on the exterior surface of the shell confirms that it would be the genus *Egeria* (Bernardi, 1860). In fact, Clams of the genus *Egeria* are endemic to the eastern Atlantic coast of the African continent (Bernadi, 1860; Purchon, 1963b; 1963; Daget, 1998). The word "radiata" in *Egeria radiata* comes from the presence of stripes. The shallow pallial sinus with a regularly rounded or dorsally angular shape also corresponds to the characteristic features of *Egeria*. Thus, these clam specimens studied in the lower Sanaga River, by their phenotypic characteristics, are similar to those observed in the Nkam River (Tekou, 2017) and would therefore belong to the genus *Egeria*.

The high frequency of individuals observed with an orange mantle, regardless of the site or season, would be contrary to the conclusions of Adjei-boateng and Wilson (2016) in the Volta River in Ghana, who claimed that the mantle colors would change depending on the stage of maturity of the clams and therefore by the season. Indeed, these authors observed that the color of the gonads, which is also characteristic of the color of the mantle, would present a whitish coloration in mature females and orange in immature females (Adjei-boateng and Wilson, 2016).

The maximum values of length, height and width recorded during this study (97.12 mm, 73.67 mm and 50.17 mm) are close to the description made by Bernardi (1860) (88, 71 and 44) and FAO (2016) (90–110 mm), both on the species *Egeria radiata*. The proportion of the convex shape in the populations is similar to that obtained by Tekou (2017) at 99.5%. The proportion of shapes obtained via the compactness index is contrary to those Tekou (2017) who recorded 99.2% with a compact shape. The 100% of the oval shapes obtained in the present study correspond to similar observations reported by Bernardi (1860) when he described the species of the genus *Egeria*.

The influence of environmental characteristics on the proportion of shapes on the compactness axis could be explained by both endogenous and exogenous factors. Indeed, Caill-Milly et al. (2012) explain the influence of the site on the compacity index of the clam *Ruditapes philippinarum* in the Arcachon Bay (France) by the possible existence of several cryptic species, the presence of individuals of different sizes, population densities, water depth or else the type of substrate linked to the significant variability of environmental conditions between and within sites. In addition, Watanabe and Katayama (2010) explain in *Ruditapes philippinarum* collected from various areas in Japan, that the nutritional state modifies the shape of the shell. Thus, individuals with better nutritional condition tend to have more elongate and flatter shells (Watanabe and Katayama, 2010).

In the present study, the phenotypic characteristics did not vary between sites, nor seasons and also not in comparison with the Nkam River (Tekou, 2017). Thus, the hypothesis linked to the variability of environmental conditions between and within sites would not explain the variation of shape observed in this study. This would suggest that the sources of variation could be genetic.

Conclusion

The phenotypic characteristics of the *Egeria* clams of the lower Sanaga River were not influenced by the sampling site or season. The clams studied were almost entirely oval on the shape index and convex on the convexity index. Part of the population has a compact form and the rest do not, on the compactness index, and only this. Compactness index was influenced by the site. Most of the studied characteristics converge on the species *Egeria radiata*. It would therefore be imperative to carry out a comprehensive molecular characterization in order to confirm or invalidate the species of the clam populations of the lower Sanaga River. In order to establish a solid base of information on the diversity of clams in Cameroon, in-depth studies of phenotypic and molecular variability must be carried out in all estuarine water bodies in the country.

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Conflict of interest

All the authors declare that there are no conflicting issues related to this research article.

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