



Morphological variations of the shell of the bivalve *Lucina pectinata* (Gmelin, 1791)

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ABSTRACT

In Martinique, the species *Lucina pectinata* (Gmelin, 1791) is called "mud clam, white clam or mangrove clam" by bivalve fishermen depending on the harvesting environment. Indeed, the individuals collected have differences as regards the shape and colour of the shell. The hypothesis is that the shape of the shell of *L. pectinata* (*P. pectinatus*) shows significant variations from one population to another. This paper intends to verify this hypothesis by means of a simple morphometric study. The comparison of the shape of the shell of individuals from different populations was done based on samples taken at four different sites. The standard measurements (length (L), width or thickness (E - *épaisseur*) and height (H)) were taken and the morphometric indices (L/H; L/E; E/H) were established. These indices of shape differ significantly among the various populations. This intraspecific polymorphism of the shape of the shell of *P. pectinatus* could be related to the nature of the sediment (granulometry, density, hardness) and/or the predation. The shells are significantly more elongated in a loose muddy sediment than in a hard muddy sediment or one rich in clay. They are significantly more convex in brackish environments and this is probably due to the presence of more specialised predators or of more muddy sediments.

Keywords

Lucina pectinata, bivalve, polymorphism of shape of shell, ecology, mangrove swamp, French Antilles.

Academic Discipline and Sub-Disciplines

Ecology, zoology

SUBJECT CLASSIFICATION

Bivalve ecology

TYPE (METHOD/APPROACH)

Experimental

1. INTRODUCTION

The shell of the molluscs is a calcified exoskeleton which performs the functions of support and protection (Akberali & Trueman, 1985; Alyakrinskaya, 2005; Sälgeback, 2006). Its characteristics are determined by genetics and by the environment (Hynd, 1960; Wada, 1986). Intra- or inter-population variations in the morphology of the shell of bivalves have been observed by several authors around the world. The intraspecific diversity of the shape of the shell has been studied, for example, in the following bivalves: *Venerupis rhomboides* (Holme, 1961; Eagar et al., 1984); different species of Sphaeridae (Holopainen and Kuiper, 1982); *Spisula solidissima* (Jarne, Berrebi, and Guelorget, 1988; Cerrato and Keith, 1992); *Mytilus edulis* (Stirling and Okumus, 1994); *Dreissena bugensis* (Claxton et al., 1998); *Ruditapes decussatus* (Ben Ouada et al., 1998); *Chamelea gallina* (Palmer et al., 2004); *Ameghinomya antiqua* (Márquez et al., 2010; Boretto et al., 2014); *Ensis macha* (Márquez, & Van Der Molen, 2011); *Ensis siliqua* (Rufino et al., 2013); *Tawera gayi* (Gordillo et al., 2011); *Saxidomus purpuratus* (Kim et al., 2006); *Ruditapes philippinarum* (Caill-Milly et al., 2012); *Pinctada imbricata radiata* (Kwon et al., 1999; Derbali, Jarbou, and Ghorbel, 2012; Rajaei et al., 2014); *Pinus nobilis* (Moreteau & Vicente, 1980); *Mactra isabelleana* (Signorelli et al., 2013); *Mytilus chilensis* (Krapivka et al., 2007, Valladares et al., 2010); *Unio delphinus* (Morais et al., 2013). No study was found on this subject on *Lucina pectinata*.

This endogeoic bivalve, which is also named *Phacoides pectinatus* (Blanville, 1825 in Frenkiel et al., 1996) is a Lucinidae (Veneroida order) found from North Carolina to Brazil (Rios, 1994). The species lives in shallow coastal areas (Warmke and Abbott, 1962; Abbott, 1974). Like all the Lucinidae (Kraus, 1995; Taylor & Glover, 2000), *L. pectinata* lives in symbiosis with sulphide-oxidising bacteria (Frenkiel et al., 1996) and they generally withstand great variations in temperature, salinity and confinement (Jackson, 1972). Moreover, this Lucinidae seems to be one of those which, according to Jackson (1972), tolerates a wide range of granulometries. Indeed, its presence has been noted in the muddy sediments of mangrove swamps by Frenkiel et al., 1985, and Rondinelli and Barros, 2010, and lagoon or estuary areas (Guelorget et al., 1990; Rathier, 1993). This species has also been observed in less muddy sediments in peripheral areas of the mangrove (marine fringe) (Barroso & Matthews-cascon, 2009). Rondinelli and Barros (2010) studied it in three types of muddy sediments in Brazilian lagoons. Several authors have described the influence of environmental factors on the intraspecific polymorphism of bivalve shells. For example, the morphology of a species' shell may vary according to the nature of the sediment (Gérard, 1978; Newell and Hidu, 1982; Eagar et al., 1984; Claxton et al., 1998; Funk and Reckendorfer, 2008), the characteristics of the seagrass bed (Combelles et al., 1986), the hydrodynamics (McLachlan, 1995; Kakino, 1996; Fuiman et al., 1999; García-March et al., 2007), the degree of exposure to waves or to the tide (Akerson & Martel, 2000; Steffani and Branch, 2003; Funk and Reckendorfer, 2008), the density of the population (Ohba,

1959; Seed, 1968; Bertness and Grosholz, 1985; Cigarria and Fernandez, 1998; Alunno-Bruscia et al., 2001; Briones and Guinez, 2005), the predation (Reimer and Tedengren, 1996; Reimer and Harms-Ringdahl, 2001; Beadman et al., 2003; Caro and Castilla, 2004), the depth (Holme, 1961; Claxton et al., 1998) and the trophic conditions (Watanabe and Katayama, 2010; Caill-Milly et al., 2014).

In Martinique, an island of the Lesser Antilles located between the island of Dominica and that of Saint Lucia, there is little data on bivalves. The species *Lucina pectinata* is called "mud clam" or "white clam or mangrove clam" by the fishermen. Indeed, there appear to be differences in the shape and colour of the shell of this bivalve depending on its living environment. The shells sampled at the level of the roots of mangrove trees appear whiter and more convex than those collected on the edge of mangrove swamps. The hypothesis is that the shape of the shell of *L. pectinata* shows significant variations from one population to another. From the perspective of the preservation of the biodiversity and knowing that the coastal marine biocenoses suffer permanent damage (Adey, 1977; Bouchon and Laborel, 1986; Smith et al., 1996; Legrand, 2010), it would be useful to distinguish between the influence of natural factors and the effects of anthropisation. This requires the collection of information on the biology and the ecology of the marine species.

In order to verify the existence of significant differences in the shape of the shell of *L. pectinata* in Martinique, this paper intends to compare some characteristics of the shells (shape and external colour) of individuals gathered by the fishermen and at different sites. The purpose of this study is:

- (1) to establish and compare the biometric ratios of the *Lucina pectinata* shells based on their morphometric characteristics (height, length and width) in different samples collected by the fishermen.
- (2) to collect samples from within different populations of *L. pectinata* from three intertidal sites corresponding to the fishing zones and then to establish and compare their biometric ratios with those of individuals from fishing catches.
- (3) to formulate hypotheses on the influence of environmental factors on the diversity of the shape of the shells.

2. MATERIAL AND METHODS

2.1. Origin of the samples:

2.1.1 The study area:

The island of Martinique is bordered to the east by the Atlantic Ocean and to the west by the Caribbean Sea. Located between 60° 50' and 61° 15' west longitude and at a north latitude of between 14° 23' and 14° 53', it has 350 km of coastline. The study area (fig 1) is located on the south side of the Caribbean coast of Martinique between the bay of Céron and Saint Anne. This portion of the southern coast of Martinique, bordered by fringing reefs of purely coral origin (Bouchon and Laborel, 1986), is dotted with bays and coves, the beds of which are taken up by seagrass and/or mangrove swamps. These seagrass beds consist broadly of mixed populations of varying densities of *Thalassia testudinum* and *Syringodium filiforme* (Laborel-Deguen, 1984).



Figure 1: Localisation of the study area. The sampling points are in white and red, the sampling areas in green.

2.1.2 The sampling sites

The individuals were gathered between July and November 2012 in three sites, two of which were located at the level of the areas of colluvial mangrove swamps (Joseph, 2006) of the Bay of Céron and of Trois-Rivières (fig. 1). The last site is located at the Meunier cove, in the bay of Marin. It is part of a lagoon area back from the beach and it is characterised by the presence of a mangrove swamp of 35.68 ha on clay-sandy sediment (Acer-Campestre, 2007). The Trois-Rivières site is located behind a fringing reef in a depression (of about 80 cm deep) (Brugneaux/OMM, 2006) bordered by a mangrove

swamp on clay-sandy sediment of 31.04 ha (Acer-Campestre, 2007). In this site, the urban waste (freshwater input) is significant because of the presence of an area which is quite urbanised and of a small fishing port. The bed of the site is made up of very sparse seagrass or by bare sediments (Brugneaux/OMM, 2006) colonised by a quite sparse population of *Rhizophora mangle*. In the site of the bay of Céron, a deeper (>1m), less exposed area, the waters are calm, the confinement is greater and the populations of *Rhizophora mangle* and marine phanerogams are denser.

The sampling areas and the sampling points (see maps fig.1) were chosen according to the indications of the fishermen because of their accessibility (the height of the water, the absence of danger), the density of the roots of the mangroves and the known presence of clam beds. The individuals were collected manually and with feet mainly by one or two fishermen. Up to eight sampling points were placed within each area according to the size of the areas. From each sampling point, a 10m line was drawn parallel and at 1m from the front of the *rhizophora mangle*, using a rope which thereby allowed the two transects to be delimited - the one 1m in width in the clayey-muddy sediment in which the roots of *rhizophora mangle* are buried, the second in a muddy sediment rich in sand, over a width of 2m in relation to the line. Within each transect, two or three sampling units of 1m² are randomly delimited using sticks embedded vertically in the sediment. In the event of the absence of bivalves in a unit, a replicate was made. The Céron site was sampled twice, the other two, only once. In the Meunier site, a third habitat located in a mangrove swamp where the most common species are *Avicennia germinans* and *Laguncularia racemosa* was able to be distinguished. It was explored differently by way of the random gathering of samples in the channels and among the roots of the mangrove trees.

The individuals at the Vauclin site were harvested by other fishermen during a study on the fishing methods in August 2012. This site is located on the Atlantic coast in a cove of Pointe Athanase at a coastal mangrove swamp with coarse sediments, rich in biogenic calcareous elements. The shells collected among the roots of *R. mangle* and at the edge of the sea showed no difference in shape and had thick valves. During this study, the granulometry of the sediments was visually assessed, while the water temperature and salinity were measured with a refractometer (Milwaukee MA887 of accuracy ± 2 psu). In Céron, the salinity was between 36 psu (at the bottom of the bay) and 43 psu (towards the exterior of the bay). At Meunier, the salinity ranges between 38 and 40 psu.

The individuals collected in the field are placed in nets labeled according to their origin and stored in sea water in an isothermal box.

2.2 Statistical analysis and processing

2.2.1 Biometric study of the shells

The identification of the shells was made based on the data of several authors including Warmke & Abbott (1962) and Abbott (1974). The batches of shells collected in the restaurant were grouped into two batches according to the fishermen's indications: mud clams and white clams (harvested among the roots of *Rhizophora mangle*). The external colouration of all the shells was noted. As for the individuals harvested in the field, after measuring their total mass (with scales of 0.01 g accuracy), the flesh is removed and weighed for further study. Next, all the shells were air-dried for three days and then weighed. The length (L = the largest measurement in the antero-posterior axis), the maximum thickness of the two joined valves (E=thickness) and the height (H = the largest measurement perpendicular to the length) of each shell were measured with a caliper (0.1 mm) (fig. 2). Then, according to the methods of Kuiper (1949) in Holopainen and Kuiper (1982) or Babin (1966), the morphometric indices such as elongation (H/L), compactness or roundness (E/L) and convexity (E/H) were established for each individual with the various previous biometric parameters.

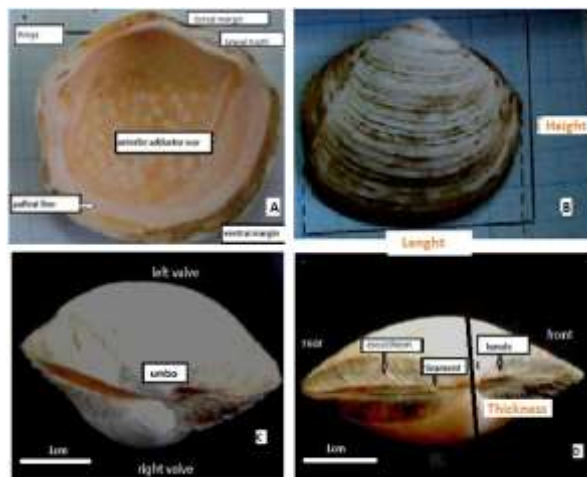


Fig.2: Different measurements taken and external (A) and internal (B) morphology of shell of *L. pectinata*. Dorsal views of a white clam (C) and an orange clam (D).



2.2.2 Statistical analysis of the results:

The descriptive analysis was carried out using the Xlstat or R software. The average ratios H/L (elongation), E/L (compactness) and E/H (convexity) were compared according to the origin of the shell. The normality of the distribution of the dimensions of the shell was verified. Graphs of the frequency distribution of the indices were produced for each population. The indices of compactness, derived from the other two, were not analysed. Graphs allowing us to compare the evolution of the biometric indices in terms of the size (L) of the shells according to the type (white or orange) and the origin were produced. The data were compared with those from a control sample harvested during another study on the Atlantic coast (Vauclin site).

The allometric relationships (Huxley, 1932) revealing the differences in growth variations between the different dimensions (L, E and H) of the shell were modelled. Single or multiple linear regressions were used in order to establish the relationship between the dependent variables (the indices) and the explanatory variables (the dimensions). The nonlinear relationships were adapted to a linear function in accordance with Ricker (1973). In order to estimate a and b, the relationships of formula, $y = ax^b$ (Huxley, 1924) are linearised as $Y = \ln(y) = \ln(a) + b \ln(x)$ (b = allometry exponent or the slope of the regression line). The regression equations of formula, $y = ae^{bx}$ (Céron samples) were transformed into an equation of the form $Y = \ln(y) = \ln(a) + b x$. The coefficients r^2 (determination) were obtained with the significance level (0.001). To verify that b obtained is significantly different from b = 1, a Student's t-test was done ($\alpha = 0.05$) (Sokal & Rohlf, 1987). For reasons of low significance, populations of insufficient size ($n < 30$) were not the subject of this type of previous analysis.

The average values or the distributions were compared in an attempt to differentiate between the individuals. The symmetric distributions were compared by analysing the variance of each of the indices. Previously, a test of the homogeneity of the variances (Fisher –Snedecor's F test) was carried out and then the average indices were compared by way of Student's t-test with a 95% confidence level. The non-symmetric distributions were compared by way of the Mann-Whitney-Wilcoxon or Krustal-Wallis tests. Tests (Student's t-test) of the correlation of Pearson or Spearman (allometry tests) were performed.

3-RESULTS

3.1- The variations of the shape of the shell according to their origin

3.1.1 Average morphometric indices

In total, 631 shells of sizes > 28mm were worked on. The sampling method did not permit the harvest of individuals of less than 28 mm. Broken or very deformed shells were eliminated. At the Meunier, Trois-Rivières few individuals were collected from among the roots of *Rhizophora Mangle*. These shells were not counted in this study. The minimum and maximum lengths are 28.2mm and 81.2mm respectively. The average measurements are: Length = 56.004 ± 0.65 mm, Height = 49.937 ± 0.58 mm and Thickness = 25.321 ± 0.51 mm. The characteristics of the environments, the sizes (L) and the mean ratios H/L (elongation), E/L (compactness) and E/H (convexity) of the shells according to their colour or origin are shown in Table 1 below. The shells from the Céron mangrove swamp are all externally white and chalky. The shells from the other sites are often orange but can be white. In the latter case, they are rarely chalky.

The mean indices of the white shells are greater than those of the orange shells (table 1). The shells of the clams collected at Céron among the roots of *Rhizophora mangle* (Cmangrove site) have higher indices than those that were harvested in the Céron basin. The latter have the lowest convexity and compactness indices of all the samples (see fig. 3). The Meunier lagoon site differs from the others because its shells have the highest average convexity index, combined with a high compactness index and a low elongation index.

Table 1: Average morphometric indices, environmental factors and sampling data

Type/Origin	Number of sampling units	Number of sampling points	Sampling area in m2	Type of sediment	Average salinity.	N	L average	E/H average 100 Convexity	Standard deviation (E/H)	H/L average 100 Elongation	Standard deviation (H/L)	E/L average 100 compactness	Standard deviation (E/L)
White clams	—	—	—	—	—	267	59.735	51.2896	0.038727	89.834	0.032414	46.072	0.038019
Orange clams	—	—	—	—	—	193	52.78	49.446	0.039029	88.60150	0.039093	43.7912	0.032414
Céron mangrov.swamp (C.mangrove)	14	8	1794.56	silty sandy-clayey mud	S=37.5	59	53.12	51.251	0.043342	90.61577	0.034651	46.4294	0.041663
Céron basin	26	8	3589.12	sandy mud	S=42.6	43	51.32	48.544	0.045906	86.997649	0.036686	42.173	0.032414
Trois-rivières	7	4	938.41	clayey-sandy mud	S=31.5	22	45.94	49.146	0.041869	90.410617	0.028001	44.398	0.032414
Meunier Habitat A(lagoon)	6	4	810	sandy-clayey mud	S=39.5	17	51.8	53.873	0.018003	86.53474	0.044693	46.616	0.032414
Meunier HabitatB (mangrove)	8	5	1292	hard clayey-muddy sand	S=38.3	18	52.18	50.606	0.040643	88.952	0.088496	45.168	0.067647
Vauclin	—	6	920.76	coarse sand rich in biological elements	S=33	12	71.18	51.502	0.032414	88.799	0.032414	45.742	0.032414
All samples						631	56.004	50.5126	0.041348	89.1985	0.038034	45.0524	0.0389

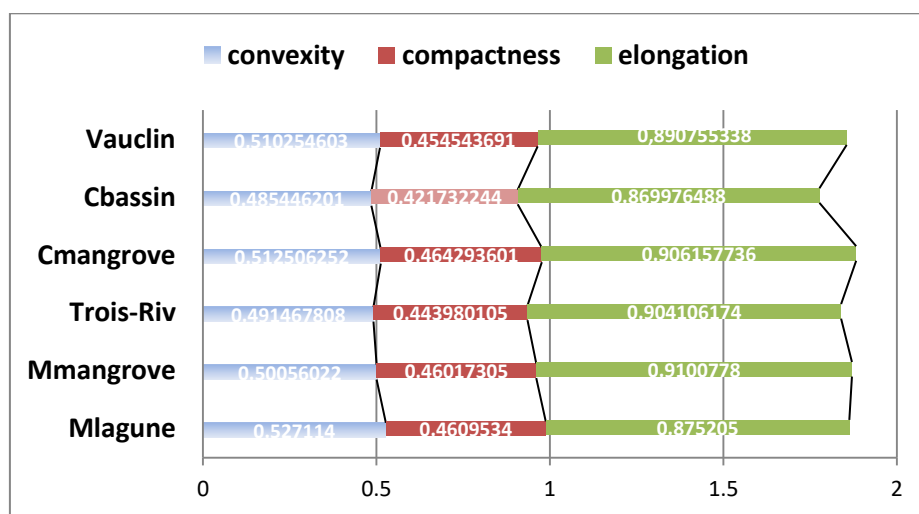


fig.3: Average morphometric indices of shells in different sites

3.1.2- Frequency distribution of the morphometric indices:

The data obtained show that it is by way of the distribution of the indices of shell convexity and elongation of that the samples differ the most.

-The distributions of the index of convexity:

The distributions (fig. 4A) are almost symmetrical for all the samples except those from the Céron basin, Meunier (disymmetrical boxplots), Trois-rivières and Vauclin. In Céron basin and Vauclin, the distribution of the convexity index spreads more towards the large values. By contrast, in Trois-Rivières this distribution is spread over the small values. The majority of the shells from Céron basin (about 75%), Trois-Rivières (70%) and Meunier mangrove (62.5%) have a convexity index < 0.5 (average index of all the samples). On the other hand, 63% of those from Céron mangrove and 85% of those from Meunier lagoon have a higher index (> 0.5). The comparison of the distribution of the convexity index of the two batches a (White) and b (Orange) by means of a Fischer test shows that the variances are homogeneous. Then, a comparison test of the averages (Student's *t*-test unilateral unpaired) shows that the average convexity index of the white shells is significantly higher than that of the orange shells ($t(384, -4.917, \alpha = 0.05)$). For the other samples harvested in the environment, with the normality of the distributions of the "Vauclin" and "Meunier" samples not having been verified, a Kruskal-Wallis test ($K = 35.433, df = 5, p\text{-value} = 1.233e-06$) was performed. It shows on the 7 samples, there is at least one of them which differ from the others per/by the distribution.

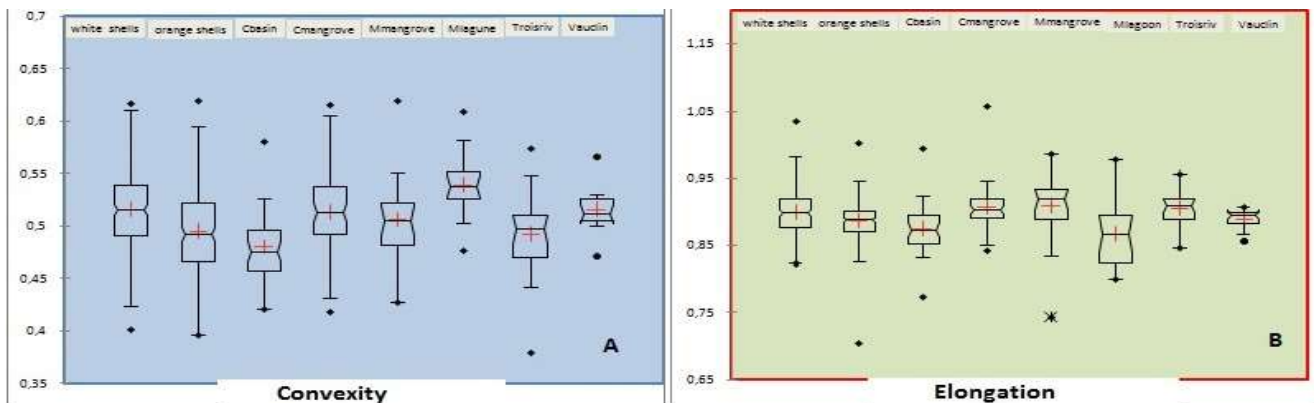


fig.4: Distributions of the index of convexity (A) and the index of elongation (B) *L.pectinata* of shells in different sites.

-The distributions of the elongation index:

Apart from the "Cbasin" sample and "white shells", the distribution of this index (fig.4 B) is slightly dissymmetrical in all the samples. For the set of the samples grouped, the average of this index is 0.89. The samples from the Céron basin, Meunier lagoon and the orange shells differ from the others by the fact that at least 75% of their individuals have an index < 0.90. The totality of the white shells and those from CéronRH has an elongation of at least > 0.8.

The distribution of the elongation index is significantly different in these two groups (batch a and batch b) ($U(193,193; 22,615, p < 0.05)$). The comparison of the other samples by way of a Kruskal-Wallis test shows that with a significance level of 0.05% there is at least one sample whose distribution differs from the others ($Q = 32.994, ddl = 5, p\text{-value} = 3.775e-06$).

3.2. The dimensions and shape of the shell of *L. pectinata*

3.2.1- Allometric relationships between the dimensions of the shell:

The graphical representation of the relationships between the dimensions of the shell for the 631 individuals shows an interdependence between them (fig.5).

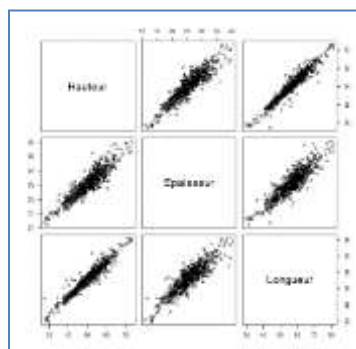


Fig.5: Relationships between the dimensions of shell
(Hauteur=height; Longueur=Length, Epaisseur= thickness)

These relationships are all highly significant (pvalue < 2.2e-16) and positive. The variable dimensions each follow a normal distribution, the linear correlation coefficient of Pearson (r) perfectly characterises the connection between them. However, since this coefficient is slightly overestimated because of the presence of exceptional points, the Spearman coefficient (rho) in this case better indicates the intensity of the relationship.

In this species, *L. pectinata*, we can note that the length and the height are better correlated with one another (r = 0.958) than with the thickness of the shell (r = 0.894 and r = 0.917 respectively (fig. 5). The data and the graphs of the linear relationships or otherwise between the height, length and thickness of the *L. pectinata* shell according to origin are given in table 2. The relationships between the dimensions of the shell can vary depending on the samples. Between the length and the height, the relationships are all significantly close to isometry (gradient close to 1). The length of the shell reflects the age of the individual and was chosen as the reference dimension.

Table 2: Equations of the allometric relationships between the different dimensions of the shell of *L. pectinata* (conf = conforming model)

Simple regression	b(gradient)	intercept	equation	r ²	rho2	P-value (F-test)	a
Set : N=631							
LH	1.04966***	3.58770***	y=bx+a	0.9194		< 2.2e-16	intercept
H L	0.87591***	0.88215	i.d	0.9194		i.d	i.d
E L	0.51943***	-3.76875 ***	i.d	0.7999		i.d	i.d
L E	1.53998***	17.00968 ***	i.d	0.7999		i.d	i.d
E H	0.5832***	-3.7999***	i.d	0.8414		i.d	i.d
H E	1.44275***	13.40422***	i.d	0.8414		i.d	i.d
Cmangrove : N=59							
E L	0.007991***	0.9625999***	y=ae ^{bx}	0.6218	0.6415	1.994e-13	2.618495
HL conf	0.008338***	1.2360287 ***	i.d	0.9145	0.9010	< 2.2e-16	3.441917
E H	0.008601***	0.9732815***	i.d	0.6539	0.6540	1.635e-14	2.646615
Cbasin: N=43							
E L	1.12728***	-0.59291***	y= ax ^b	0.9092	0.8866	< 2.2e-16	0.5527165
H L conf	0.85818***	0.77842	y=bx+a	0.9689	0.9622	i.d	intercept
E H conf	1.16156 ***	-0.58294***	y= ax ^b	0.95	0.9335	i.d	0.5582547
Orange all conf : N=193							
EL	0.51135***	-3.82962	y=bx+a	0.7454	0.6892	i.d	intercept
H L	0.92343***	0.07820	y= ax ^b	0.8537	0.840	i.d	1.081339
E H	1.1818***	-0.6097 ***	i.d	0.7688	0.7633	i.d	0.5435139
White : N=266							
E L conf	1.09262 ***	-0.50234***	y= ax ^b	0.6955	0.6019	i.d	0.605113
HL conf	0.96527***	0.01491	i.d	0.9085	0.8640	i .d	1.015022
E H	1.12234***	-0.50266	i.d	0.7526	0.6832	i.d	0.6049194

***(high signification); i.d (same value)

In the Céron mangrove swamp, all the dimensions are linked to each other by an exponential factor while for the basin, the orange and the white: the relationships are either linear or exponential. For the Céron mangrove swamp these correlations are less strong than in the basin. The coefficients of determination (r²) of E by H and of H by L are respectively 0.6539 and 0.90 in the mangrove swamp as opposed to 0.9335 and 0.9689 in the basin

3.2.2- Relationships between the dimensions and the biometric indices of the shell:

The study of the relationship between each of the indices and the length of the shell for the set of the individuals shows a near absence to a very weak linear correlation (r = -0.06 to 0.30) (table 3).

Table 3: Correlation matrix (Pearson). The values in bold are all significantly different from 0 at a level of alpha = 0.05

Variables	Length	Convexity	Compactness	Elongation
Length	1	0.3032115	0.2357655	-0.06257239
Convexity	0.3032115	1	0.8805526	-0.0044171
Compactness	0.2357655	0.8805526	1	0.4679681
Elongation	-0.06257239	-0.0044171	0.4679681	1

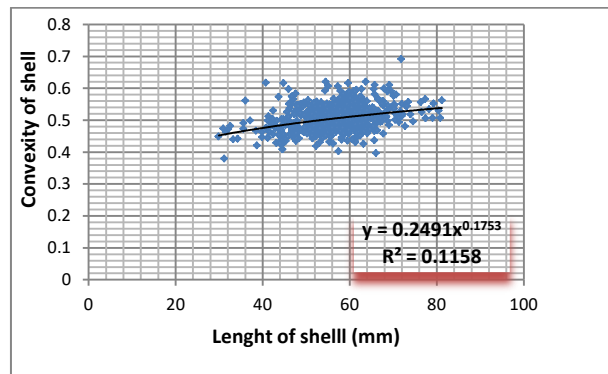


Fig.6: link between the convexity and the length

The graph of the relationship between the convexity and the length of the shell (fig. 6) for the set of the individuals shows a decline in the growth of the convexity with the increase of the length. The matrix of correlation (table 3) between the indices shows that the convexity and the compactness are better correlated (positively) among each other than with the elongation. Moreover, one notes that the elongation is very weakly and negatively correlated with the convexity.

The study of the linear regression of each of the indices by each of the shell length dimensions was done for all the samples (table 4). For all the initially non-linear and therefore linearised relations, the Spearman coefficient is indicated. The coefficients for determining the indices by the length are the weakest at the "M.lagoon" site. The index of elongation has the weakest coefficients of determination (with the exception of the Vauclin site).

Table 4: Influence of the variations of the length of the shell on those of the indices of shapes

Coefficient of determination in %	Trois-rivières	C.basin	C.mangrove	M.mangrove	M.lagoon	Vauclin
Compactness	22.99 (p<0.05)	39.54 p=0.00518	32.04 (n.s)	39.09 (n.s)	8.10(n.s)	26.85(n.s)
Convexity	58.10 (p<0.05)	50.67 p<0.001	27.89 p<0.001	19.508 (p<0.05)	0.733(p=0.0975)	34.92(p=0.06073)
Elongation	16.57(n.s)	0.1039 (n.s)	0.0289 (n.s)	2.817(n.s)	0.203(p=0.069)	36 (p=0.05618)

n.s (not significant)

The explanatory effects of the imbricating dimensions interlocking, we calculate the percentage of determination of the variations of the indices of shape of the shell by those of its three dimensions for all the samples (table 5). The values <100% are the maximum values calculated by adding the coefficients of determination of the three dimensions to each of the indices. We can note that the 'Cmangrove' and 'M.lagoon' sites have the lowest coefficients of determination.

Table 5: Total percentage of determination of the variations of the shape indices of the shell by those of its three dimensions.

%of determination	Trois-rivières	C.basin	C.mangrove	M.mangrove	M.lagoon	Vauclin
Compactness	100%	100%	55.879%,	100%	39.82 %	100%
Convexity	100%	77.72%	63.472%	100%	55.573%	100%
Elongation	37.68%	3,173%	11.66%	47.67%	25.79%	4.53%

Table 6: Data of regression the indices of shape by the dimensions of the shell of *L. pectinata*

	Compactness =	Convexity =	Elongation =
Set of the samples	$-7.975e-03L+1.056e-02\log H$ $+1.766e-02 E +0.4323e-01$ ($r^2=0.9771$)	$51.9827e-03\log L-1.01828e-02$ $H+1.95484e-02E+0.4283248$ ($r^2=0.974$)	$-15.8398e-03 L+1.76438 e-02$ $H+0.02399e-02 E+0.8919305$ ($r^2=0.9769$)

The search for relationships of multiple linear regressions of the indices of the set of the individuals by the dimensions (Table 6) and the origin shows that the latter has practically no effect on the variations of the indices. However, very small but significant effects on the convexity and elongation indices for the "Cbasin" samples ($p = 0.0176$, $p = 0.0240$ respectively) and "Mlagoon" ($p = 0.0302$, $p = 0.0722$ respectively) exist.

4. DISCUSSIONS

The shell of *L. pectinata* is convex, almost lenticular and slightly compressed laterally. However, the *L. pectinata* individuals collected display a diversity as regards the shape and the colour of the shell depending on their origin. This study consisted of confirming, using simple biometric parameters, the polymorphism of the shape of the shell of the *L. pectinata* individuals from different populations.

4.1-The variations in the shape of the shell

4.1.1- Comparisons of the averages and the frequency distributions of the shape indices:

As proposed by Selin (2007), if the convexity index (E/H) of a bivalve shell is > 0.5 , the shell is convex. The compactness and the "bulge" (convexity) of a shell increase respectively with the indices of compactness and convexity. On the other hand, the elongation decreases when the index of elongation increases. In *L. pectinata*, the shells possessing the three highest indices are the most rounded. The lower the index of elongation (< 0.9), the more the shells are stretched otherwise they are truncated. A convex shell is associated more significantly with a higher elongation index (e.g. C mangrove) than a weak one (e.g. those from the Meunier lagoon). The more convex a shell is, the more compact it is.

With a significance level < 0.001 , at least one sample (apart from the restaurant batches) has distributions and the mean values of the indices different from the others. The observation of the graphs and the data indicates that these are the samples from Céron and the Meunier lagoon. As regards the shape of the shell of *L. pectinata*, there is therefore an inter-population diversity. We can distinguish between three types of shape:

1°- The shells collected in the Céron basin are the flattest, the least truncated and the least round (their indices are the weakest). Their colour is often orange of varying brightness but can be white.

2°- The shells sampled in the Céron mangrove swamp have a pronounced convexity and compactness but are more truncated. They therefore have a rounder, and slightly globular, shape. They are similar in shape to the shells of the Meunier mangrove swamp, those from the "Vauclin" site and the "White" ones. However, they are all white, while those from the Meunier mangrove swamp and Vauclin can be orange of varying brightness.

3°- Those from the Meunier lagoon seem to differ from the others in terms of their shape, which is at once more obese and stretched in length. They have the strongest convexity index and the weakest elongation index. They can be of a white or orange colour of varying intensity.

Similarly, the writers Ben Ouada et al., (1998) also find three morphological types (flat, globular and truncated) in other bivalves such as the *Ruditapes decussatus* clam. In *L. pectinata*, the three types of shape do not by themselves represent the phenotypic diversity of the shell, since in the Meunier mangrove swamp the shells are particular because they are heavier. In addition, those which are orange all have an internal colouring of a very bright orange.

To explain the significant differences between the average indices of the batches of shells from the restaurant, the knowledge of the harvesters' fishing spots makes it possible to propose the following origins:

-The "orange" batch has lower average indices because it is probably mainly composed of shells from Céron basin and Trois-rivières.

-The white shells from the restaurant seem to have more diverse origins because they are similar in shape to those sampled in the other sites, except for those from the site of the Meunier mangrove swamp and from Céron basin.

The comparison of the dimensions and indices of the *L. pectinata* shells sampled in Martinique with the data from other authors shows greater differences as regards the elongation and compactness indices. The shells from Martinique have on average a lesser convexity but a more pronounced elongation than those from Brazil (Christo et al., 2016; Nogueira et al., 2002) (see Table 7). They are therefore flatter and less truncated. As a reminder, in Martinique, the lowest

compactness index (x100) is 42.173, the highest elongation index (x100) is 90.62 and the maximum convexity index (x100) is 53.87. The indices of the shells of the Céron mangrove swamp are closest to those from the data of Nogueira et al., (2002).

Table 7: Average values of the dimensions and the indices of the shells of *L. pectinata* collected by other authors

this study(Martinique)		Christo et al,2016 (Brasil)		Nogueira, et al, 2002 (Brasil)	
L=56mm	E/L*100=45.052	L=51.54± 6.91mm	E/L*100=41,28	L=44,06 mm	E/L*100 =47,16
H=43.937mm	E/H*100=50.512	H=49.62 ± 6.84mm	E/H*100=51.28	H=39.86 mm	E/H*100= 52,13
E=25.32mm	H/L*100=89.19	E=26.43 ± 4.59mm	H/L*100=96.27	E=20.78mm	H/L*100 = 90,46

The shells of *L. pectinata* studied by Christo et al. (2016) are more truncated and more compact than those studied by Nogueira et al. (2002) and come from different places.

4.2. The dimensions of the shell, the basis of its morphology

4.2.1 The allometric relationships between the dimensions

Due to the size of the samples, these observations only concern the set of the grouped samples, those from the restaurant and from Céron. The strong positive correlations between the dimensions of the shell, in particular between its length and its height, reflect the existence of geometrical constraints inherent to its structure. In *L. pectinata*, the coefficients of determination vary between 0.623 and 0.954. These coefficients confirm that the biometric variables, height and length of the shells of the samples are more connected to each other than to the thickness for the majority of the shells and in particular in the Céron mangrove swamp. Similarly, Gaspar et al. (2002) find, for 25 species of bivalves studied, a coefficient of determination of the height by the length greater than the coefficient of determination of the relationship between the thickness and the length. However, in the Céron basin, the percentages of variations in the height or in the thickness explained by those in the length are 96.89% and 88.6% respectively. In the Céron mangrove swamp, these values are somewhat lower (91.45% as opposed to 60.9%).

Gaspar et al. (2002) noted that due to a positive allometric relationship, for most of the species studied, the height and thickness of the shell increase more quickly than the length during the growth of the individual. This type of relationship is debatable in *L. pectinata* and makes it possible to distinguish between certain samples. Compared to the average of the individuals, the thickness of the shell increases slightly faster than its length during its growth in the Céron basin and for the white shells, because the allometric coefficients (b) are slightly larger (1.12 and 1.09). On average, however, with the allometric coefficients almost all lower bound (b <1), the increases in height and thickness occur more slowly with those of the length.

In the case of the shells from Céron, it is the exponential relationships which connect the two other dimensions to the length which explain the differences in shape between the shells from the mangrove swamp and from the basin. In the latter and as for the average of all the shells, a relationship which is one of power or simply linear connects these dimensions to the length. Consequently, in the Céron mangrove swamp, when the length of a shell increases by 1 mm, its height increases by 3.47 mm and its thickness increases by 2.64 mm, while in the basin, its height and its thickness increase by 1.64 mm and 0.553 mm respectively.

With the orange shells, it is a double linear relationship of a lower bound allometric coefficient that connects the thickness to the length. For a length that increases by 1 mm, the thickness of the orange shells decreases by 3.32 mm while that of the white shells increases by 0.604 mm.

These relationships between the dimensions explain the geometric shape of the shell by means of the biometric ratios (the indices of shape).

4.2.2 Influence of growth on the shape of the shell

If we assume that the length of the shell of *L. pectinata* reflects its initial growth, then its influence on the indices of shape is generally small and variable according to the population and the type of index. The shells of smaller sizes have, in general, thinner valves and are flatter in shape. During its growth, the dimensions of the shell increase and its shape is established. However, starting from a certain length, the indices of shape depend little on the age of the individual. For example, the convexity of the shell increases little from (~35 mm) and is determined only at 11% by the length (fig.9). In this species, the mature size is located in the vicinity of a length of about 30 mm according to Frenkiel (1985) and Poggio (2002).

Sousa et al., 2007, also notes that the difference in shape between the two populations of *Corbicula fluminea* studied is not related to the size of the individuals. Moreover, for *L. pectinata*, the influence of the growth is greater on the shape of the shells from Trois-rivières, Vauclin and Céron basin than on those of the other samples. The variations in length determine convexity rather strongly (+ than 50%) at Trois-rivières ($r^2 = 0.5810$, $p < 0.05$) and at Cbasin ($r^2 = 0.5067$, $p < 0.001$). For the set of the samples collected, the influence of the growth is less on the elongation than on the convexity

and of the compactness. When we compare the samples, we see that, with the exception of the Vauclin shells, the index of elongation is the one whose variations are least determined by those of the length of the shell. This can be explained by the strong isometric connection existing between the height and the length (on average =92%). These two dimensions increase with almost the same intensity and in the same direction. Moreover, whatever the samples, the index of elongation is that which is most weakly determined by the three dimensions of the shell.

During its growth, the compactness of a shell from the Céron mangrove swamp decreases with the increase in its length and its height. On the other hand, for the other shells, the compactness only decreases with the increase in length. The two sites "C. mangrove" and "M. lagoon" have no index whose variations are fully explained by the three dimensions of the shell, even when combining their effects.

In the orange shells, the less convex and more tapered shape is explained by the fact that when the height or the thickness increases, the shells are stretched in length (negative correlations with the index of elongation). In the case of the white shells, on the other hand, when the height or the thickness increases, the shells elongate less (positive correlations with the index of elongation) and retain a truncated shape. The fact that in *L. pectinata* the growth of the shells has a relatively weak influence on the shape of the mature individuals reinforces the hypothesis of an environmental influence. Krapivka et al., 2007 and Valladares et al., 2010 make the same assumptions to explain the similar results in their studies.

4.2.3. Possible influences of the habitats on the shape of the shell

The differences in the shape of the shell among the populations of *L. pectinata* may be related to the presence of different habitats. The environmental conditions (predation, nature of the sediment) may help to explain these differences in shape. For authors such as Dechaseaux, 1952 (in Piveteau, 1952) and Alyakrinskaya, 2005, the shape of the shell of a bivalve is influenced by its way of life. Standley (1970) makes the same observation when studying the morphological characteristics (except for the microstructure and the hinge) of the shell of 95 species of bivalves. The edge of the mangrove swamp and the areas beside the sea constitute different habitats due to the nature of the sediments, the presence or absence of *rhizophora mangle* roots, the salinity, the trophic conditions and the agitation of the water. The mangrove swamp is characterised by a very muddy sediment, variations in salinity and alternating periods of land emergence and flooding (Chapman, 1984). In the marine periphery of the mangrove swamp, the more sand-rich beds are bare or occupied by a phanerogamous seagrass. The substrates are less muddy and looser than in the mangrove swamp, where the content of clay and organic matter is greater. According to Stanley, 1970, *P. pectinatus* prefers fine-grained sediments. However, as with other Lucinidae such as *Austriella corrugata* and *Indo-austriella lamprelli* (Glover et al., 2008), the species can live both close to and within mangrove swamps by colonising substrates of various granulometries (Jackson, 1972). It is the amount of organic carbon present in the sediment which, according to Doty, 2015, has a strong influence on the distribution of *L. pectinata*.

In the sites which have sediments rich in fine sand (Céron basin and Meunier lagoon), the shells are more stretched whereas in the others, where the sediments are compacted or coarse, the shells are more round. This observation is not invalidated by the findings of Nogueira and Freitas (2002). Indeed, in the Mundaú lagoon in Brazil, these authors found biometric values which allowed me to establish the morphometric indices, in particular an index of elongation, slightly higher in the coarse sands than in the fine ones (see table 5). In fact, the nature of the sediment may influence the morphology of the shell (Gérard, 1978; Newell and Hidu, 1982). In the mangrove swamps of Céron and in particular of Meunier, the presence of numerous mangrove tree roots rigidifies the sediment which is clayey (Céron) or sandy-clayey and lacking in mud (Meunier). In Trois-Rivières, the sandy-muddy sediments rich in heavy clay are quite compact. In the coarse sediments of Vauclin, the size and density of calcareous debris can make the sediment less loose. In these more compact or dense habitats, the smallest stretch in length of the shell (high elongation index) may be explained by the reduction of the space available to its lateral development. In fact, *L. pectinata* positions itself with the antero-posterior axis approximately horizontal with respect to the surface of the substrate, with its hinge to the top (Stanley, 1970; Assis, 1978). In this position, it is the relative length of the shell that is reduced. Similarly, another bivalve, *Ruditapes philippinarum*, orientates its dorsal surface perpendicularly to the surface of the substrate and the height of its shell is reduced above all, according to Cigarria & Fernández (1998).

Table 8: Average values of the dimensions and indices of the shells of *L.pectinata* according to the nature of the sediments (obtained by other authors).

Fine sand: 62.26% Clayey silt: 0. 71% (Nogueira et al., 2002)	Fine sand: 44.42%, Clayey silt: 0.62% (Nogueira et al., 2002)	Fine sand: 62.34% Clayey silt: 0.15% (Nogueira et al., 2002)
E/H*100=51,804	E/H*100=51,366	E/H*100=52,35
H/L*100=88,903	H/L*100=89,12	H/L*100=91,535
E/L*100=46,056	E/L*100=45,78	E/L*100=47,92

Several explanations are proposed by the authors to explain the obese shape of the shell of certain bivalves. According to Sälgeback (2006), for a shell of a given mass, the increase in volume reduces the density and prevents sinking into the muddy sediment. The shells of *L. pectinata* are heavier in the Céron mangrove swamp and from the Meunier lagoon, their shapes are more convex. (In a subsequent study, a mass ratio of the shell over its length, much greater in the individuals



from the Céron mangrove swamp compared with those from the basin, had been observed). This relationship between the shape of the shell and the density/nature of the sediment may be confirmed by the following observations:

1. The flatter shape of the shells from the Céron basin is closer to that of *Codakia orbiculata* (Linnaeus, 1758), another Lucinidae living in seagrass beds in less muddy environments.
2. The globular shape of the shells from the mangrove swamp of Céron approximates that of *Anodontia alba* (Link, 1807), another Lucinidae living in the mangrove swamp.

On the other hand, Owen (1953) thinks that in many Lucinidae the fact that a shell is globular is not related to the type of substrate.

Other authors (Tokeshi et al., 2000) believe that in molluscs, this shape would allow an increase in their resistance to predation, particularly that of certain crabs (Boulding, 1984; Lin, 1990). After experimenting, Blundon & Kennedy (1982) and then Boulding, 1984 conclude that the convexity (the inflation) of the shell, as well as the thickness of its valves are the characteristics that increase its resistance to the crushing pressure exerted by the crab claws. The convexity of the shell would, by interfering with the grip or increasing its resistance, be a means of reducing predation by certain crabs that live in the lagoons and the mangrove swamp. Nevertheless, some crabs have claws capable of breaking shells which are globular (Tallqvist, 2001) or which are resistant (Seed & Hughes, 1995) due to the thickness or the structure of their valves. Combelles et al. (1986) found that the valves of the shell of *Pinna nobilis* become thicker with age and this provides some protection against predation. Meanwhile, in a large bivalve, in particular one with a shell with thick valves such as *L. pectinata*, a stretched and only slightly convex shape (like those from Céron basin) helps to increase its density, thereby offsetting its vulnerability to the crabs grip. Similarly, Lafrance et al. (2003) noticed that the wild individuals of the bivalve *Placopecten magellanicus*, which are subject to a more intense predation, have a shell which is less convex, denser and more resistant to mechanical pressures than those of farmed individuals. Moreover, since according to Stanley, (1970), *L. pectinata* is, like all Lucinidae, a relatively slow burrower, having a flattened shell allows for a more rapid burrowing in the presence of predators (Luttikhuisen et al., 2003).

In the mangrove swamp or the lagoon, environments which are exposed to lower water levels, given the low mobility and the burrowing depth of *L. pectinata*, in order to escape the predators, the convexity of the shell compensates for the slowness of the burrowing while ensuring a hold in a muddy sediment. In a deeper marine environment, a less convex shape would facilitate burrowing in the presence of more varied and less specialised predators.

CONCLUSIONS:

The morphological diversity of the shell of *L. pectinata* is confirmed by this study. The biometric parameters of the set of the samples are close to those found by other authors for this species. The three average indices of shape of the white shells and the orange shells are significantly different. On the other hand, the three average indices of the samples from different sites display small but significant differences. The orange and white shells appear to have been collected in part at the Céron site. This intraspecific polymorphism of the shape of the shell of *L. pectinata* may be related to the nature of the sediment (granulometry, density, hardness) and/or the predation. The elongation and convexity indices may be influenced by the characteristics of the substrate. The shells are significantly more stretched in fine sandy mud (Céron basin and Meunier lagoon) than in coarse muddy sand (Vauclin), clayey sandy mud (Céron RH and Trois-rivières) and sandy mud hardened by the roots of mangrove trees (Meunier mangrove swamp). The elongation and convexity indices may also be related to the pressure of predation. They are significantly more convex in brackish environments due to the presence of more specialised predators.

In order to confirm the polymorphism of the shell of this species, the conventional linear measurements could be supplemented on the one hand by more complex geometric methods. Rufino et al., 2013, cite the authors who used more sophisticated morphometric methods to study the morphology of the shell of the bivalves. Palmer, Pons & Linde, 2004, and more recently Rajaei et al., 2014, used the elliptic Fourier analysis to compare the shape of the shell of the bivalves, with the help of markers taken inside the valves. The imprint of the anterior adductor muscle has been used in the taxonomic descriptions of the Lucinidae by some authors (see Anderson, 2014, and the authors cited by him). The relative proportions of this imprint could vary with those of the shell and thus allow interspecific comparison. Knowing that *L. pectinata* can bind to several variants of bacterial symbionts present in its environment (Doty, 2015), a genetic analysis could be carried out so as to verify the inter-population allelic polymorphism and the possible presence of ecotypes. Indeed, according to Mahadevan (1980), within the same species of bivalve, the variations in the shape and colour of the shell may signify the presence of ecotypes. However, in Céron the variations in shape may be responses to habitat differences that can be explained by the plasticity of the shell.

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