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Geographic Variations in morphological shapes of the the shell of *Terebralia sulcata* from Sulu and Tawi-Tawi, Philippines

Aldren J. Jamasali, Muhmin Michael E. Manting, Mark Anthony J. Torres and Cesar G. Demayo

Department of Biological Sciences, College of Science and Mathematics MSU-Iligan Institute of technology 9200 Iligan City, Philippines

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ABSTRACT

Variations in the morphology of *T. sulcata* from four different sampling sites of Sulu and Tawi–Tawi were investigated by a landmark-based Geometric-Morphometric methodology. Twenty three anatomical landmarks along the ventral or apertural portion of the shell were used. MANOVA has shown that shell shape from the four different sampling site varies significantly. Relative Warp analysis proved that shells of different population differ in body length, body width and appertural opening. The method of relative warp analysis has shown in this study that it is a good method in describing variations in shapes of the shells. Variations in morphometry could be attributed to a lot of factors that include plasticity as affected by environmental heterogeneity, or could be genetic. However, more studies should be done that will test the influence of these factors.

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INTRODUCTION

Gastropods are groups of organisms that commonly show large amounts of phenotypic diversity. Understanding morphological variations have been explored in a number of species in relation to environmental gradients (Smith & Newell, 1955; Vermeij, 1972; Johannesson, 1986; Johannesson, Johannesson & Rola´n-Alvarez, 1993; Williams, 1995; Chapman, 1995; Reid, 1996; Johannesson & Johannesson, 1996; Chapman, 1997; Kyle & Boulding, 1998; Trussell, 1996; Trussell, 2000b; Saier, 2000; Trussell & Nicklin, 2002; Ray, 1960; Atkinson, 1994). It was also revealed in some studies that phenotypic plasticity can be induced by the effluent of both predators and damaged conspecifics in molluscs such as *Thais lamellosa* (Palmer, 1985; Appleton & Palmer, 1988), *Littorina obtusata* (Trussell, 1996; Trussell & Smith, 2000; Trussell & Nicklin, 2002) and *Mytilus edulis* (Leonard, Bertness & Yund, 1999). While many of these studies focused on the role of environmental gradients for the variations in morphology, only a few studies were explored variations in shapes of species found geographically distant from each other. In *Tenebralia* for example, despite their wide distribution, abundance and ecological importance in mangrove ecosystems, only a few studies of their general biology (Soemodihardjo and Kastoro, 1977; Barnes 2009; Shokita *et al*., 1984) including their feeding biology (Nishihira, 1983; Barnes 2009), early growth (Rao, 1938; Hashimoto and Nishijima, 1987), and historical declines in populations (Ohgaki and Kurozumi, 2000) were reported. It was therefore the objective of this study to study variations in shapes of *Tenebralia sulcata*, a locally important mangrove species used as food by local people. The study was conducted using landmark-based geometric morphometrics, a powerful quantitative tool in studying shape variation in many organisms' including gastropods) and many more.

Methodology:

T. sulcata:

samples were obtained from mangrove areas in the municipalities of Pangutaran, Laminusa**,** Maimbung and Bongao in Sulu and Tawi Tawi province in Mindanao, Philippines (Fig. 1). A total of 256 specimens were utilized in the analysis.

Corresponding Author: Cesar G. Demayo, Department of Biological Sciences, MSU-Iligan Institute of Technology, 9200 Iligan City, Philippines,
E-mail: cgdemayo@gmail.com

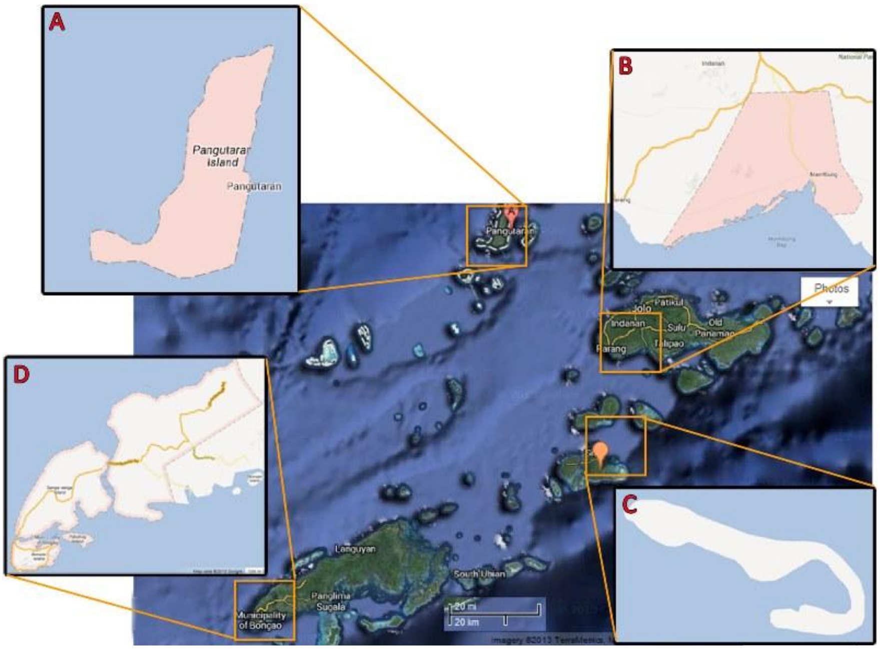

Fig. 1: Map showing the study area. A. Pangutaran, B. Maimbung, C. Laminusa Sulu, and D. Bongao Tawi-tawi, Philippines.

Shells were photographed using a digital camera. Images of the shell were always in the same position with the columella at 90^0 of the x-axis in an aperture view or in the orientation in which the apex is visible. Obtained images were then subjected to geometric morphometric methods. The shell of the *T. sulcata* is spherical having three to five sutures with narrow oval aperture. Digital images (vental) were taken for each sample using standardized procedure (Figure 2).

Shell shape was studied using a landmark-based methodology that eliminates the effect of variation in the location, orientation, and scale of the specimens. Twenty three anatomical landmarks along the ventral or apertural portion of the shell were used (Fig. 2). This was made possible using an image analysis and processing software TpsDig freeware 2.12 (Rohlf 2006). TpsDig facilities the statistical analysis of landmark data in morphometrics by making it easier to collect and maintain landmark data from digitized images.

Landmarks 1, 2 and 3 are positioned at the right body line of the shell, Landmark 4 is at the apical top, landmarks 5, 6, 7, 8 and 9 are at the left body line, landmarks 10, 11, 12, 13, 14, 15, 16, and 17 are located at the outer aperture while landmarks 18 to 23 lines the inner aperture.

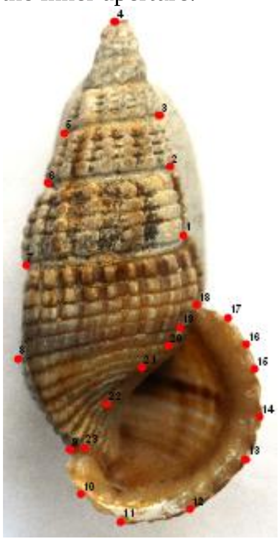

Fig. 2: Landmarks used to describe the shape of the ventral view of the shell *T. sulcata*

The coordinates were then transferred to Microsoft Excel application for organization of the data into groups. The two-dimensional coordinates of these landmarks were determined for each shell specimen. Then the generalized orthogonal least squares Procrustes average configuration of landmarks was computed using generalized Procustes Analysis (GPA) superimposition method. GPA was performed using software tpsRelw, ver. 1.46 (Rohlf 2007). After GPA, the relative warps (RWs, which are principal components of the covariance matrix of the partial warp scores) were computed using the unit centroid size as the alignment-scaling method. Histogram and box plots were generated using PAST software from the relative warps of the shell shapes. Histogram and box plots are a powerful display for comparing distributions. They provide a compact view of where the data are centered and how they are distributed over the range of the variable. Canonical Variances Analysis (CVA) was also used in order to compare patterns of population variation. Multivariate Analysis of Variance (MANOVA) test was used to analyze whether or not the species differ significantly with regards to its shell shape. All statistical procedures were done using the PAST software (Hammer *et al* 2001).

RESULT AND DISCUSSION

Relative warp analysis describes the variations observed in *T. sulcata.* This is presented in Table 1 and graphically presented in Fig. 3. It can be seen from the results the amount and nature of variations between the four populations. The distribution of individual snails in a scatterplot from the canonical variance analysis show the type of shapes of their shells (Fig. 4). Multiple analysis of variance (Table 2) and cluster analysis (Fig. 5) revealed significant differences between populations.

Table 1: Variance and description of variations in the ventral shell of *T. sulcata* as explained by significant relative warps.

RW % Variation	Apertural Shell	POPULATION			
		Tawi-Tawi	Pangutaran	Maimbung	Laminusa
1 37.86	variation is greatly caused by the relative distance within and between apical landmarks and between apical and body landmarks determining whether the body length is shorter or longer, and how wide the aperture.	the shell has a more globose shell aperture, wider body width and shorter body length.	shells have less pronounced and narrower shell opening, narrower body width and longer body length.	the apertural opening is neither too wide nor too narrow, body width neither too wide nor too narrow, body length neither too long nor too short	shell has wider opening, wider body width and shorter body length than the shells of Maimbung and Pangutaran.
2 14.83	The values between apical landmark and body landmark, outer apertural landmarks, inner apertural landmarks is shown to contribute to significant variation in RW2. Body length and apertural width and shape are the variations specified.	the shells have half-oblongated aperture.	that the appertural shape is neither half-oblongated nor half-circular.	appertural shape of the shells is half-circular.	some shells have half-oblongated shell opening while some have half circular shell opening.
3 13.35	distances between right body landmarks with inner apertural landmarks and also left body landmarks with apertural landmarks determining the relative body width of the samples.	shells have pronounced body curve	Shells show a straighter or less curved body shape	body curves of this shell is less pronounced compared to shells from Tawi-Tawi .	some shells have straight body while others are curved.
4 8.23	distance between apical landmark and outer apertural landmarks left body landmarks and apertural landmarks determining body width, body length and apertural size and shape.	the shell has shorter body length. Wider body width and half-circular aperture.	shell body length is neither too short nor too long, shell body width neither too wide nor too narrow and appertural opening is neither half-circular nor half-oblongated as compared to the rest of the populations.	there are shells that have longer body length, narrower body width and half-oblongated circular opening.	some shells have shorter body length, wider body width and half circular appertural opening compared with the rest of the shells in other population.
5 5.22	shape of the aperture; Shells in the positive RW has a narrow distance between the inner and outer lip compared to a wider distance between the inner and outer lip of shells in the negative RW.	some shells have narrower appertural opening. This is determinded by outer appertural landmarks 10 and 11 with inner appertural landmarks 20, 21, and 22.	shells have wider appertural opening.	shells have neither too narrow nor too wide appertural opening.	shells have wider appertural opening compared to the shells in other populations.

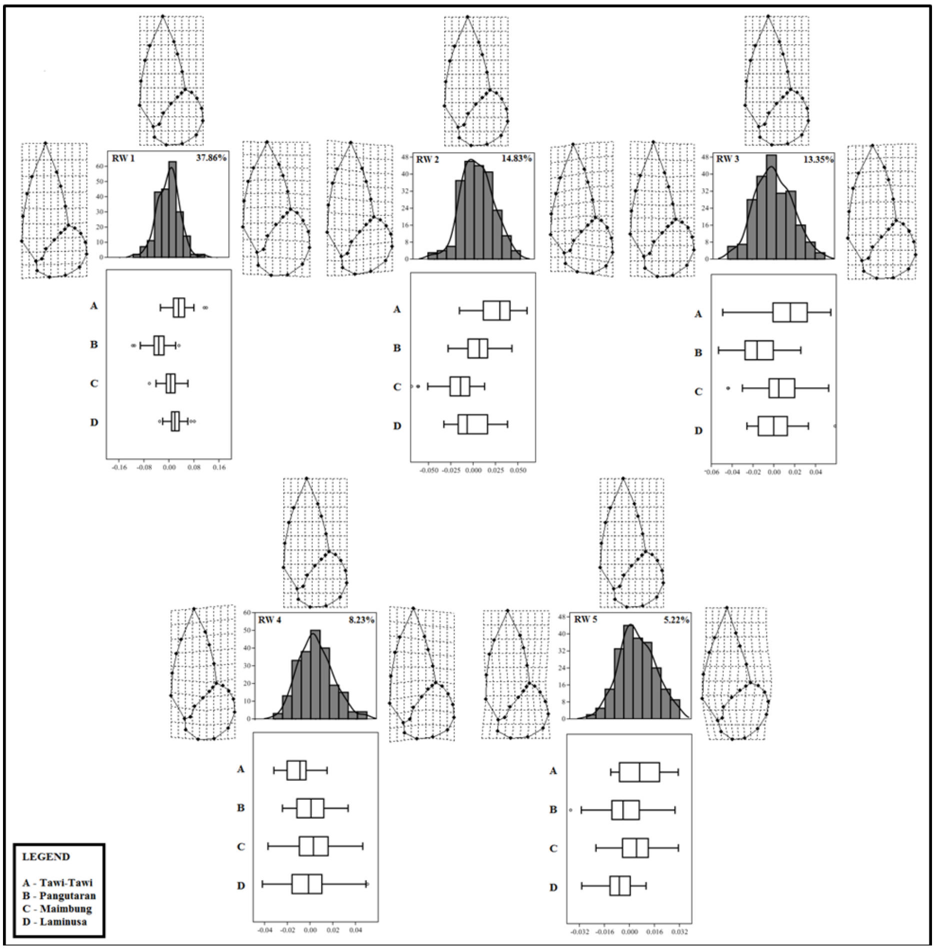

Fig. 3: Relative warp box plot and histogram showing variations in the shape of the ventral shell portion of *T. sulcata* found in different area. (A) Tawi-tawi, (B) Pangutaran, (C) Maimbung, (D) Laminusa.

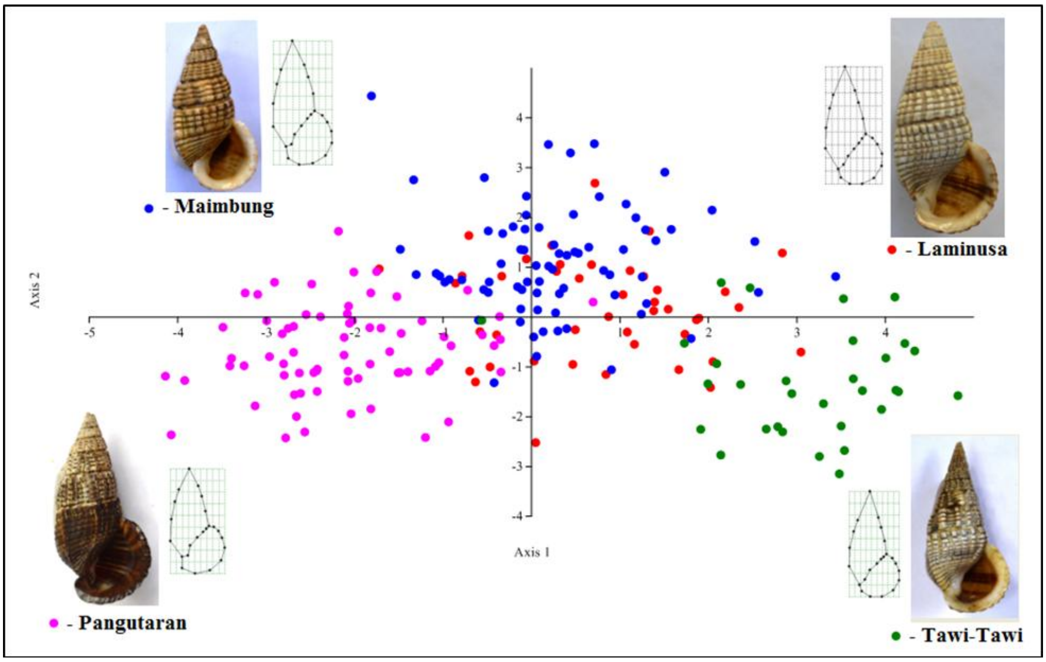

Fig. 4: CVA scatter plot of the apertural shell of the seawater shell *Terebraia sulcata* showing samples from four different sampling sites.

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Table 2: p- values generated from MANOVA showing significant differences between the shell shapes of four populations of *T. sulcata*.

	Laminusa	Maimbong	Pangutaran	Tawi-Tawi
Laminusa	-	9.09E-09	3.54E-26	9.32E-16
Maimbong		-	9.82E-34	6.82-28
Pangutaran			-	1.10E-38
Tawi-Tawi				-

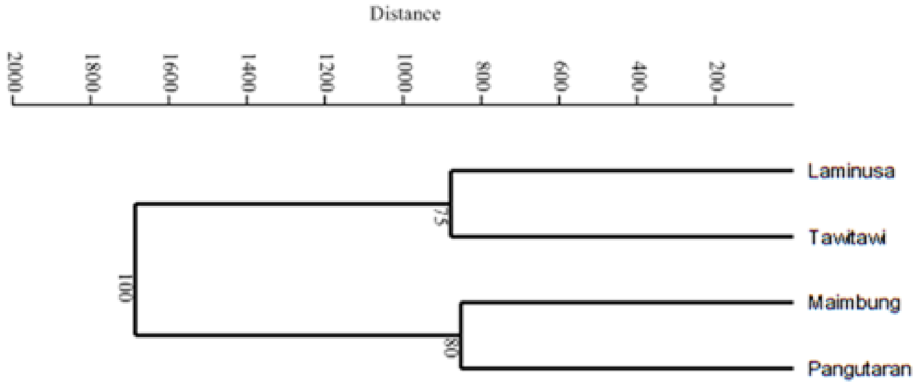

Fig. 5: Plot showing the degree of similarity of shell characters of *T. sulcata* from four different sites.

Results of this study revealed significant differences in the populations of *T. sulcata*. Variations within and between populations of the population can be due to phenotypic plasticity as shown in selected studies (Irie and Morimoto, 2013; Saunders, 2009; Vermeij, 1973; Trussel, 2000; Hollander and Butlin, 2010). The possibility of plasticity is possible because of the snail's exposure to changing environmental conditions and marine adaptation such as symbiosis, camouflage, defensive behavior, reproductive strategies, contact and communication and predation forces the organism to change behavior and shape after exposure to environment with different physico-chemical and predation factors (Minton *et al*., 2011), interspecific (Vohra, 1971) and intraspecific (Fratini, et.al., (2000) competition; contribute to phenotypic plasticity. Variations can also be argued to be due to a very large range of developmental patterns in gastropods (Scheltema, 1971, 1986; Erlandsson *et al*., 1998) or could be due to allometry as common patterns of allometric growth in gastropods include variations in the apical angle that result in doming of the shell (O'Loughlin and Aldrich, 1987), and increased thickness as an apparent antipredation adaptation (Cotton *et al*., 2004; Palmer, 1990). Spatial variations in shell morphology resulted from genetic differences and evolutionary change (Reid, 1996; Hollander *et al*., 2006; Johannesson, 1992; Johannesson *et al*., 1995; Makinen *et al*., 2008, Peterson and Fry, 1987; Janson, 1982; Makinen *et al*., 2008; Morgan, 1999; Newkirk and Doyle, 1975). Ecological factors such as food availability can also affect internal volume to shell material ratio (Kemp and Bertness, 1984) thus resulting to variations in shape of the shell. Studies on ecotypic variation of the shell of littorinids in rocky shores was related to wave action, desiccation risk and predation by crabs (Johannesson *et al*., 1993; Newkirk and Doyle, 1975; Reid, 1993; Elner and Raffaelli, 1980; Palmer, 1990). Often, more than one ecotype can coexist in the same shore at different levels, as a consequence of the steep environmental gradient associated with the vertical position on the shore, the low vagility of individuals within microhabitats that cause assortative mating (Erlandsson *et al*., 1998), and the absence of a planktonic dispersal phase (Johannesson, 2003). Effects of wave exposure, desiccation and predation in littorinids and other marine snails are correlated to a large extent (Elner and Raffaelli, 1980; Palmer, 1990). It is, however, possible that the observed spatial variation in the shell shape may also be at least partially due to non-allometric plasticity. The morphological differences observed may thus represent a plastic response but unrelated to size. Direct experimental evidence is thus necessary before we can be identify to what extent the morphologic differences in *T. sulcata* are due to local adaptation, allometry, or non-allometric plasticity.

Conclusion:

Landmark-based geometric morphometric analysis of shell shape variations in four populations of *T. sulcata* revealed significant differences in body length, body width and appertural opening. Relative warp analysis was observed to be a good method in quantitatively describing shape variations of the shells. It is hypothesized that variations in morphometry could be attributed to a lot of factors that include plasticity as affected by environmental heterogeneity, or could be genetic. However, more studies should be done that will test the influence of these factors.

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