Shell morphometrics in four species of Gadilidae (Mollusca, Scaphopoda) in Southwestern Atlantic Ocean, Brazil

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ABSTRACT. Six morphometric shell direct measurements of the Gadilidae species *Gadila acus* (Dall, 1889), *Cadulus braziliensis* Henderson, 1920, *Cadulus parvus* Henderson, 1920 and *Polyschides tetraschistus* (Watson, 1879) were carried out and used to build three morphometric indices in according to the proposition of Shimek (1989): LI, relating total shell length to length from the dorsal aperture to the maximum width; WI, relating maximum shell diameter to apertural diameter; and Ws, whorl expansion rate (*sensu* Raup 1966). Direct measurements and morphometric indices were tested as discriminating tools among the four species. None of the morphometric indices, alone, were able to discriminate among all species. Among then, Ws is not an effective discriminating morphometric index because it fails in all pairwise comparisons, LI and WI are fairly efficient ones, since they have got effective discriminations in three out six pairwise comparisons. The combined use of direct measurements ones was more efficient than the indices ones when dealing with relatively small samples, as ours. Although both descriptors can be combiningly used; since the direct measurements descriptors are easier to obtain and understand than the more complex indices, they should be recommended as main tools.
KEY WORDS. *Cadulus*, conchology, *Gadila*, marine mollusks, *Polyschides*.

RESUMO. **Morfometria da concha de quatro espécies de Gadilidae (Mollusca, Scaphopoda) no Brasil, sudoeste do Oceano Atlântico.** Seis medidas morfométricas tomadas diretamente da concha dos seguintes gadilideos: *Gadila acus* (Dall, 1889), *Cadulus braziliensis* Henderson, 1920, *Cadulus parvus* Henderson, 1920 e *Polyschides tetraschistus* (Watson, 1879) foram realizadas e utilizadas na construção de índices morfométricos em concordância com Shimek (1989): LI, razão entre o comprimento total da concha e o comprimento entre a abertura dorsal até o ponto de máximo diâmetro; WI, razão entre o diâmetro máximo da concha e o diâmetro da abertura; e Ws, taxa de expansão dos anfractos (*sensu* Raup 1966). Tanto as medidas tomadas diretamente das conchas como os índices morfométricos foram testados como instrumentos de discriminação entre as quatro espécies. Nenhum índice morfométrico, quando considerado isoladamente, foi capaz de discriminar entre todas as espécies. Ws teve o pior desempenho, falhando na discriminação de todas as comparações par-a-par, LI e WI se saíram melhor, desde que discriminaram, corretamente, três das seis comparações par-a-par. A utilização combinada das medidas diretas da concha foi mais eficiente que os índices morfométricos, ao menos ao se tratar de amostras pequenas como as nossas. Embora ambos tipos de descritores possam ser utilizados, a maior simplicidade e facilidade de obtenção das medidas diretas as habilitam como os principais instrumentos de discriminação conquiliológica.
PALAVRAS CHAVE. *Cadulus*, conchologia, *Gadila*, moluscos marinhos, *Polyschides*.

The shell morphometrics in molluscs are a common taxonomic tool (Kilgour *et al*. 1990, Rolán 1991, Johannesson & Johannesson 1996, Ward *et al*. 1997, Wullschleger & Jokela 2002) that has been used to show local or regional conchiological variations, other times the same techniques are utilized to explore ecological relationships, usually linking morphological variations to a specific set of environmental conditions (Branch & Marsh 1978, McMahon & Whitehead 1987, Lam & Calow 1988, Denny 2000). These kinds of studies are focused on gastropods (Branch & Marsh 1978, Llop *et al*. 1991, Trussell 2000) and on pelecypods (Kilgour *et al*. 1990, McDonald *et al*. 1991, Villalaz 1994, Kafanov *et al*. 1997, Tanaka & Magalhães 1999). Apparently, the scaphopods have been neglected from this kind of approach probably because they show constant profile (tubular-conic)

and the absence of conspicuous ornaments in the shell surface. Shimek (1989) established three morphometric indices based on new morphometric measures that separated the shells of *Cadulus aberrans* Whiteaves, 1887; *Cadulus perpusillus* Sowerby 1832 and *Siphonodentalium quadrifissatum* (Pilsbry & Sharp, 1898) very well. Nothstanding the higher objective power of these morphometric indices in discriminating among scaphopods, there was no posterior utilization of them until Shimek & Moreno (1996) described a new species of *Fissidentalium* Fischer, 1885 utilizing his methodology of morphometric characterization. So, moved by the potential discriminatory power of Shimek's (1989) morphometric indices, we decided to apply them on four taxa from Brazilian continental shelf, Southwestern Atlantic Ocean.

MATERIAL AND METHODS

Abbreviations

(CF VII) Oceanographic Operation Cabo Frio VII collected by Oceanographic Vessel Almirante Saldanha (NOAS); (IBUFRJ) Instituto de Biologia, Universidade Federal do Rio de Janeiro; (IEAPM) Instituto de Estudos Almirante Paulo Moreira; (PITA) Projeto Intregrado de Treinamento de Alunos; (REVIZEE) Recursos Vivos da Zona Econômica Exclusiva.

Experimental material examined (Figs 1-4)

All specimens studied (only empty shells available) are deposited at the collection of molluscs of the Instituto de Biologia from the Universidade Federal do Rio de Janeiro (IBUFRJ) and came from the Southeastern-Northeast coast of Brazil (15° to 24°S), according to the list below (number inside brackets indicate number of shells in each lot):

Gadila acus (Dall, 1889); IBUFRJ 12854 # C76 REVIZEE, 15°53'82S, 38°31'9W, 66 m, 30/IV/1996 [30].

Cadulus braziliensis Henderson, 1920; IBUFRJ 7037 CF VII # 6196, 24°14'8S, 44°18'3W, 150 m, III/1983 [12]; IBUFRJ 2397 CFVII # 6199, 23°17'S, 44°15'W, 48 m, 03/1983 [1]; IBUFRJ 2401 CFVII # 6165, 23°02'8S, 42°46'W, 56 m, III/1983 [1]; IBUFRJ 2398 CFVII # 6198, 23°32'S, 44°15'3W, 65 m, III/1983 [1]; IBUFRJ 3110 PITA # 12, 22°24'30"S, 41°33'30"W, 38 m, 02/V/1993 [13]; IBUFRJ 1205 Geocosta Rio II # B2, 23°00'19S, 42°02'32W, 65 m, 20/III/1986, Aviso de Pesquisa Oceânico "Suboficial Oliveira" do IEAPM [1]; IBUFRJ 6477 PITA # 1, 22°31'30"S, 41°45'25"W, 38 m, 01/V/1993 [1].

Cadulus parvus Henderson, 1920: IBUFRJ 7075 CF VII # 6194, 24°03'6S, 44°07'6W, 134 m, III/1983 [3].

Polyschides tetraschistus (Watson, 1879): IBUFRJ 7066 CFVII # 6144, 22°39'5S, 44°39'5W, 52 m, III/1983 [2]; IBUFRJ 7066 CFVII # 6147, 22°53'7S, 41°50'5W, 50 m, III/1983 [3]; IBUFRJ 7066 CFVII # 6165, 23°02'8S, 42°46'W, 56 m, III/1983 [10].

Morphometric analysis

Each specimen was drawn in camera lucida. On these sketches, shell measurements (milimeters) and morphometrics were made on only unbroken adult shells. Since shell orientation is important for shell measurements we followed exactly Shimek's (1989: 237, fig. 2) methodology. The specimens were measured for total length (LTot), the interior ventral aperture width (ApW), the maximum width (Wm), length from the most anterior position of the ventral aperture of the shell to the widest portion of the shell (LWm), the maximum arc (arc), and length from the ventral aperture to the place of maximum arc (Larc). The morphometric indices of shell shape used were: LI, relating total shell length to length from the dorsal aperture to the maximum width; WI, relating maximum shell diameter to apertural diameter; and Ws, whorl expansion rate (Raup 1966). For details about morphometric indices' formulae see Shimek (1989: 237). The means and standard deviations of the measurements and derived indices were computed and compared among the species. Since the number of specimens varied among the taxa and, we are not sure about the distribution of these data, we'd rather use a distribution-free (non-parametric test as the Kruskal-Wallis) test to assess morphometrics differences.

RESULTS

The morphometric data and indices (Tab. I) showed that *G. acus* has the lowest relation between the length to point of maximum width and shell total length, making it the more slender species. *C. parvus* has a more middled bulged shell and is the less acuminate one. *P. tetraschistus* shows a higher whorl expansion rate and proportion between aperture width and total width, which is evident in the almost cylindrical profile – the shell slender very little towards apical aperture. Finally, *C. braziliensis* has no extreme values, being relatively acuminate, but not so much as in *G. acus*; and the maximum width is about 1/4 shell length toward aperture, while in *G. acus* it is nearest the aperture (around 1/6 shell length from the aperture).

The results of table II show that the performance of the morphometric indices was not very good. Ws has failed in all pair-wise discriminations attempts while LI and WI has attained success in 50% of the attempts. None of them was able to discriminate between *C. parvus* and *C. braziliensis*. Such results could suggest that there are strong overpositions among them in terms of shell shape.

On the other hand, table II also shows that the multiple pair-wise comparisons among the four species utilizing the direct measurements produced a much better result and, considering all of them together, the four species could be discriminated. All of them were able to discriminate 4 out of 6 pair-wise comparisons in different combinations. The discrimination between *C. parvus* and *C. braziliensis* was effected through arc and Larc.

DISCUSSION

As in Shimek's (1989) analyzed species, the relatively constant maximum sizes of *C. parvus*, *C. brazilensis* and *G. acus* suggests that they have a determinate growth pattern. Apparently, from the time the apertural narrowing occurs, growth

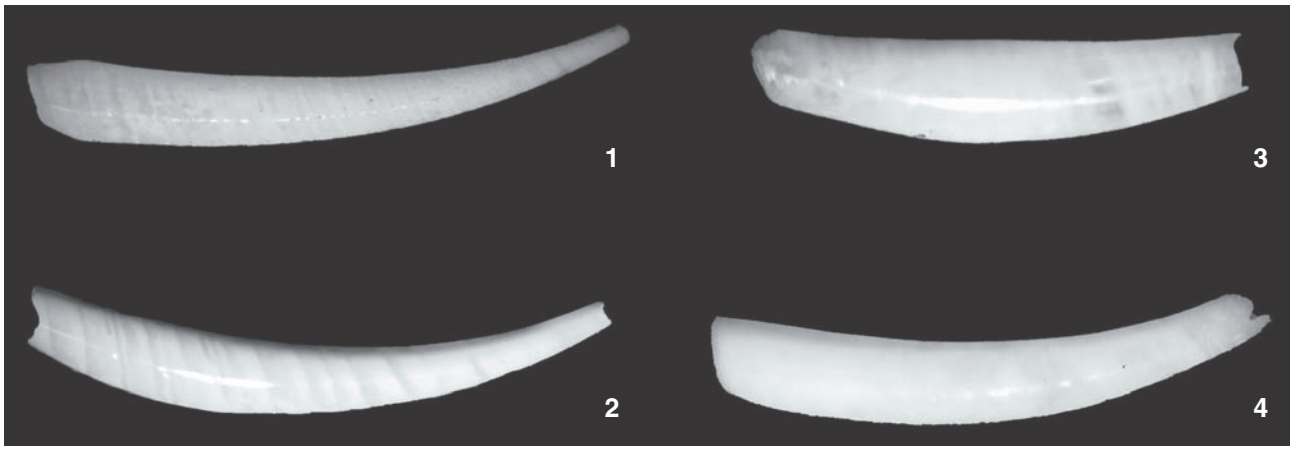

Figure 1-4: Shells of the scaphopod gadilid studied species. 1. *Gadila acus*, 9.0 mm length, IBUFRJ 12854; 2. *Cadulus braziliensis*, 7.5 mm length, IBUFRJ 6477; 3. *Cadulus parvus*, 5.0 mm length, IBUFRJ 7075; 4. *Polyschides tetraschistus*, 5.6 mm length, IBUFRJ 7066.

Table I. Direct Measurements (LTot, ApW, arc, Larc, Wm, LWm) and Morphometric Indices (LI, WI, ln(Ws)) for each studied species (Mean ± SD, in millimeters).

Species	*Gadila acus*	*Cadulus parvus*	*Cadulus braziliensis*	*Polyschides tetraschistus*
Measurements				
LTot	9.06 ± 0.51	5.86 ± 0.68	8.18 ± 0.66	4.74 ± 0.54
ApW	0.92 ± 0.08	0.85 ± 0.12	0.84 ± 0.11	0,68 ± 0.11
arc	0.60 ± 0.11	0.18 ± 0.06	0.66 ± 0.11	0.28 ± 0.07
Larc	3.27 ± 0.38	1.95 ± 0.61	3.28 ± 0.52	2.02 ± 0.50
Wm	1.27 ± 0.10	1.30 ± 0.09	1.29 ± 0.07	0.82 ± 0.10
LWm	1.08 ± 0.28	2.51 ± 0.59	2.25 ± 0.25	1.15 ± 0.37
Indices				
LI	0.33 ± 0.06	0.71 ± 0.11	0.56 ± 0.04	0.49 ± 0.10
WI	0.80 ± 0.03	0.73 ± 0.05	0.80 ± 0.07	0.87 ± 0.07
ln(Ws)	22.68 ± 5.24	26.74 ± 10.37	26.74 ± 10.37	20.82 ± 10.28
Number examined	30	3	30	1

Table II. Comparative Indices Shell Morphometrics. Kruskal-Wallis with Dunn's Multiple comparisons test. n.s. non significant ($p > 0.05$); * statistically significant ($p < 0.05$); ** statistically very significant ($p < 0.01$); *** statistically highly significant ($p < 0.001$).

Species	Direct measurements						Morphometric indices		
	LTot	ApW	arc	Larc	Wm	LWm	LI	WI	ln(Ws)
C. parvus x *C. braziliensis*	n.s.	n.s.	**	*	n.s.	n.s.	n.s.	n.s.	n.s.
C. parvus x *P. tetraschistus*	n.s.	***	n.s.	n.s.	***	*	n.s.	***	n.s.
C. parvus x *G. acus*	**	n.s.	*	*	n.s.	*	***	n.s.	n.s.
G. acus x *C. braziliensis*	***	*	n.s.	n.s.	***	***	*	n.s.	n.s.
P. tetraschistus x *C. braziliensis*	***	**	***	***	**	**	n.s.	***	n.s.
P. tetraschistus x *G. acus*	***	***	***	***	***	n.s.	***	***	n.s.

in length effectively stops. Shimek (1989) found that *Cadulus tolmei* showed a large variance in the measurements but the growth pattern remmained the same. *P. tetraschistus* shows systematically the lowest or the second lowest values from all conchiological measurements. The partial overposition of *P. tetraschistus* on all other tree species in a Shimek's (1989) di-

mensional morphometric index space seems to be a reflex of the proportionally broad variances showed by *P. tetraschistus* morphometrics including the Shimek's morphometric indices. This variability seems to be an intrinsic characteristic from this population (or from this species) because those variations cannot be attributed to the interpopulational variations, since all specimens came from the same region (only tree site-samples were used). In the Shimek (1989) study this kind of variation was attributed to the juvenile-adult shell morphology as well as to inter-populational differences

The use of the length (LI) and width (WI) indices can adequately separate only three out of four species. The rate of whorl expansion (Ws) index was ineffective in doing this kind of separation. Shimek (1989: 242) says that the rate of whorl expansion (Ws) "is more variable, and consequently less useful on its own as a discriminating agent" and this was confirmed here. On the other hand, the width index (WI), a good discriminating in Shimek's study, is only partially effective here, probably reflecting differences in the shell shape among species studied by Shimek (1989) and the those studied here. In fact, there is little variation in width measurements (p.a. Wm) but, more importantly, the variance of this variation is higher than that Shimek (1989) found in his study.

Since the morphometric indices were not working as well as we expected from the Shimek (1989) example, we decided to try to distinguish these four species through their direct measurements. This approach was used but not shown by Shimek (1989) because it did not work (R.L. Shimek pers. comm.).

All six direct measurements were more effective than Shimek's (1989) morphometric indices in discriminating our four species. Each one was able to discriminate four out of six pair wise comparisons against three out of six (the best performance) of the morphometric indices. While all three of the morphometric indices have failed in discriminating between *C. parvus* x *C. braziliensis*, arc and Larc were able to distinguish between them.

Despite the difficulties to work with a relatively variable species as *P. tetraschistus* the combined use of the primary descriptors, that are easier to obtain and understand than the more complex indices suggested by Shimek (1989) could adequately separate all species here considered. Apparently, the greater variability in shape that we have documented coupled with the small sample size could be the reason for the morphometric indices to be unreliable. These factors probably increased the variance so much that the statistical analyses couldn't separate them, particularly with distribution-free tests. So, in comparisons involving relatively few samples of variable species, the statistical variance of the secondary discriminators may be too large to allow the separation of the species.

CONCLUSION

The present data suggest that, although there can be some regional variability in the efficiency of the morphometric indices, the direct measurements have showed a better performance in discriminating these slender gadilids scaphopods than the morphometric indices. So, they should be recommended as the main tools.

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REFERENCES

Branch, G.M.& A.C. Marsh. 1978. Tenacity and shell shape in six *Patella* species: adaptive features. **Journal of Experimental Marine Biology and Ecology**, Amsterdam, **3**: 111-130.

Denny, M.W. 2000. Limits to optimization: fluid dynamics adhesive strength and the evolution of shape in limpet shells. **Journal of Experimental Biology**, Cambridge, **203**: 2603-2622.

Johannesson, B. & K. Johannesson. 1996. Population differences in behavior and morphology in the snail *Littorina saxatilis*: phenotypic plasticity or genetic differentiation. **Journal of Zoology**, London, **3**: 475-493.

Kafanov, A.I.; D.D. Danilin & A.V. Moshchenko. 1997. Morphological analysis of taxonomical characteristics of bivalve mollusks of the genus *Macoma*. **Russian Journal of Marine Biology**, Moscow, **23** (6): 298-307.

Kilgour, B.W.; D.H. Lynn & G.L. Mackie. 1990. Use of shell morphometric data to aid classification of *Pisidium* (Bivalvia: Sphaeridae). **American Malacological Bulletin**, Houston, **7** (2): 109-116.

Lam, P.K.S. & P. Calow. 1988. Differences in the shell shape of *Lymnaea peregra* (Müller) (Gastropoda: Pulmonata) from lotic and lentic habitats: environmental or genetic variance? **Journal of Molluscan Studies**, London, **54**: 197-207.

Llop, I.; J. Martinell & M. Renzi. 1991. *Bittium reticulatum* s.l. en comunidades fósiles y actuales. 2. Estudio del crescimento. Alometria y isometria. **Iberus**, Madrid, **10** (1): 49-58.

McMahon, R.T. & B.E. Whitehead. 1987. Environmental induction of shell morphometric variation in the European stream limpet, *Ancylus fluviatilis* (Muller) (Pulmonata: Basommatophora). **American Malacological Bulletin**, Houston, **5** (1): 105-124.

McDonald, J.H.; R. Seed & R.K. Koehn. 1991. Allozymes and morphometric characters of three species of *Mytilus* in the Northern and Southern Hemispheres. **Marine Biology**, Berlin, **111**: 323-333.

Raup, D. 1966. Geometric analysis of shell coiling: general problems. **Journal of Paleontology**, Iowa, **40**: 1178-1190.

Rolán, E. 1991. El género *Amphitalamus* Carpenter, 1864 en

Cuba (Mollusca, Gastropoda, Rissoidae), com la descripción de tres nuevas especies. **Iberus**, Madrid, **10** (1): 131-141.

Shimek, R.L. 1989. Shell morphometrics and sytematics:A revision of the slender, shallow-water *Cadulus* of the North-eastern Pacific (Scaphopoda: Gadilida). **The Veliger**, Santa Barbara, **32**: 233-246.

Shimek, R.L. & G. Moreno. 1996. A new species of eastern Pacific *Fissidentalium* (Mollusca: Scaphopoda). **The Veliger**, Santa Barbara, **39** (1): 71-82.

Tanaka, M.O. & C.A. Magalhães. 1999. Morphometric species recognition in *Brachidontes darwinianus* and *Brachidontes solisianus* (Bivalvia: Mytilidae). **The Veliger**, Santa Barbara, **42** (3): 267-274.

Trussell, G.C. 2000. Phenotypic clines, plasticity, and morphological trade-offs in an intertidal snail. **Evolution**, Lawrence, **54**: 151-166.

Villalaz, J.R. 1994. Morphometric and biochemical changes in two classes of the tropical scallop, *Argopecten ventricosus*, under laboratory conditions. **American Malacological Bulletin**, Houston, **11** (1): 67-72.

Ward, P.I.; C.P. Goater & M. Mikos. 1997. Shell variation in sympatric freshwater *Lymnaea peregra* and *L.ovata* (Gastropoda: Lymnaeidae). **Biological Journal of the Linnean Society**, London, **61**: 139-149.

Wullschleger, E.B. & J. Jokela. 2002. Morphological plasticity and divergence in life-history traits between two closely related freshwater snails; *Lymnea ovata* and *Lymnaea peregra*. **Journal of Molluscan Studies**, London, **68**: 1-5.

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