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## ANATOMICAL STUDY ON *MYOFORCEPS ARISTATUS*, AN INVASIVE BORING BIVALVE IN S.E. BRAZILIAN COAST (MYTILIDAE)

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### ABSTRACT

*The bivalve Myoforceps aristatus (Dillwyn, 1817), also known as Lithophaga aristata, have been recently collected in the coasts of Rio de Janeiro and São Paulo, Brazil; a species that bores shells of other mollusks. This occurrence has been interpreted as an invasion of this species, originally from the Caribbean. The distinguishing character of the species is the posterior extensions of the shell crossing with each other. Because specimens with this character have also been collected in the Pacific Ocean, they all have been considered a single species. However, it is possible that more than one species may be involved in such worldwide distribution. With the objective of providing full information based on Atlantic specimens, a complete anatomical description is provided, which can be used in comparative studies with specimens from other oceans. Additional distinctive features of M. aristatus are the complexity of the incumbent siphon, the kidney opening widely into the supra-branchial chamber (instead of via a nephropore), and the multi-lobed auricle.*

KEYWORDS: *Myoforceps aristatus*, biological invasion, boring bivalve, Brazil, anatomy, systematics.

### INTRODUCTION

*Myoforceps aristatus* (Dillwyn, 1817), previously known as *Lithophaga aristata*, is a small bivalve that bores into calcareous hard substrata, mainly shells of other mollusks. In the western Atlantic, the species is known from North Carolina to Florida, the Gulf of Mexico and the northern Caribbean Sea. The species is easily identified by pointed tips at the posterior ends of the valves, which cross like fingers (Abbott, 1974) and give the common name of the species as “scissor datemussel”.

Samples belonging to *Myoforceps aristatus* have been collected in the southeastern coast of Brazil in the last two years, far outside of the normal geographic range of the species. The samples were found in shells of larger size, including cultivated scallops (Pectinidae), and attracted attention as an invading bivalve causing possible damage to native species, because the datemussels perforate living shells, causing deformation of the host and even its death.

Only one species of the closely related genus *Lithophaga* Röding, 1798, is commonly found on the

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S.E. Brazilian coast. *Lithophaga bisulcata* (Orbigny, 1842) is of larger size, normally inhabits soft rocks and corals, and it is not usually found boring into shells.

This paper reports the first occurrence of *Myoforceps aristatus*, another invasive species on the Brazilian coast, and provides new data on its morphology and anatomy. The geographic distribution of the *M. aristatus* includes the Pacific (e.g., Turner & Boss, 1962; Abbott, 1974), as samples of *Myoforceps* with crossing posterior ends of the shell have also been collected in that ocean. This paper provides anatomical information that can be used in future comparative studies with samples from other oceans.

## MATERIAL AND METHODS

The available specimens were preserved in 70% EtOH. They were dissected by standard techniques with the specimen immersed in alcohol. Examination and dissections were done with the aid of a stereomicroscope, and the drawings with the aid of a camera lucida.

The following abbreviations are used in the figures: af, anal fold; am, anterior adductor muscle; an, anus; au, auricle; bf, byssal furrow of foot; cv, ctenidial (efferent) vessel; dd, ducts to digestive diverticula; dg, digestive diverticula/gland; di, inner demibranch; do, outer demibranch; ef, excurrent siphon transverse fold; es, esophagus; ex, excurrent siphon; fg, gill food groove; fm, posterior foot retractor muscle; fr, anterior foot retractor muscle; ft, foot; gf, ventral gastric fold; gi, gill ciliary connection to mantle; go, gonad; gp, gill suspensory stalk; gs, gastric shield; gt, gastric transverse furrow; gv, gill ciliary connection to visceral sac; in, intestine; ip, inner hemipalp; ki, kidney; mb, mantle border; mg, pallial mucous gland; mi, inner fold of mantle edge; mm, middle fold of mantle edge; mo, mouth; mt, mantle; om, outer fold of mantle edge; op, outer hemipalp; pa, posterior adductor muscle; pc, pericardium; pf, pallial fold; pp, palp; sa, gastric sorting area; sh, shell; si, incurrent siphon; ss, style sac; st, stomach; uf, projection from fusion of mantle (separating siphons); um, fusion between left and right mantle lobes between siphons; vc, cerebro-visceral connective; ve, ventricle; vg, visceral ganglia.

Abbreviations of institutions: FMNH, Field Museum of Natural History, Chicago, USA; MZSP, Museu de Zoologia da Universidade de São Paulo, Brazil.

## Systematics

### *Myoforceps aristatus* (Dillwyn, 1817)

(Figs. 1-18)

For synonymy see Turner & Boss (1962:106). Complement:

*Lithophaga (Myoforceps) aristata*: Dall, 1898:800; Turner & Boss, 1962:105-108 (pls. 69-72); Abbott, 1974:434 (fig. 5083); Merlano & Hegedus, 1994:52 (fig. 52).

*Lithophaga aristata*: Morton, 1993:609-619 (figs. 1-6 + pls. 1-2); Redfern, 2001:202; Valentich-Scott & Dinesen, 2004:343-344 (figs. 9-11).

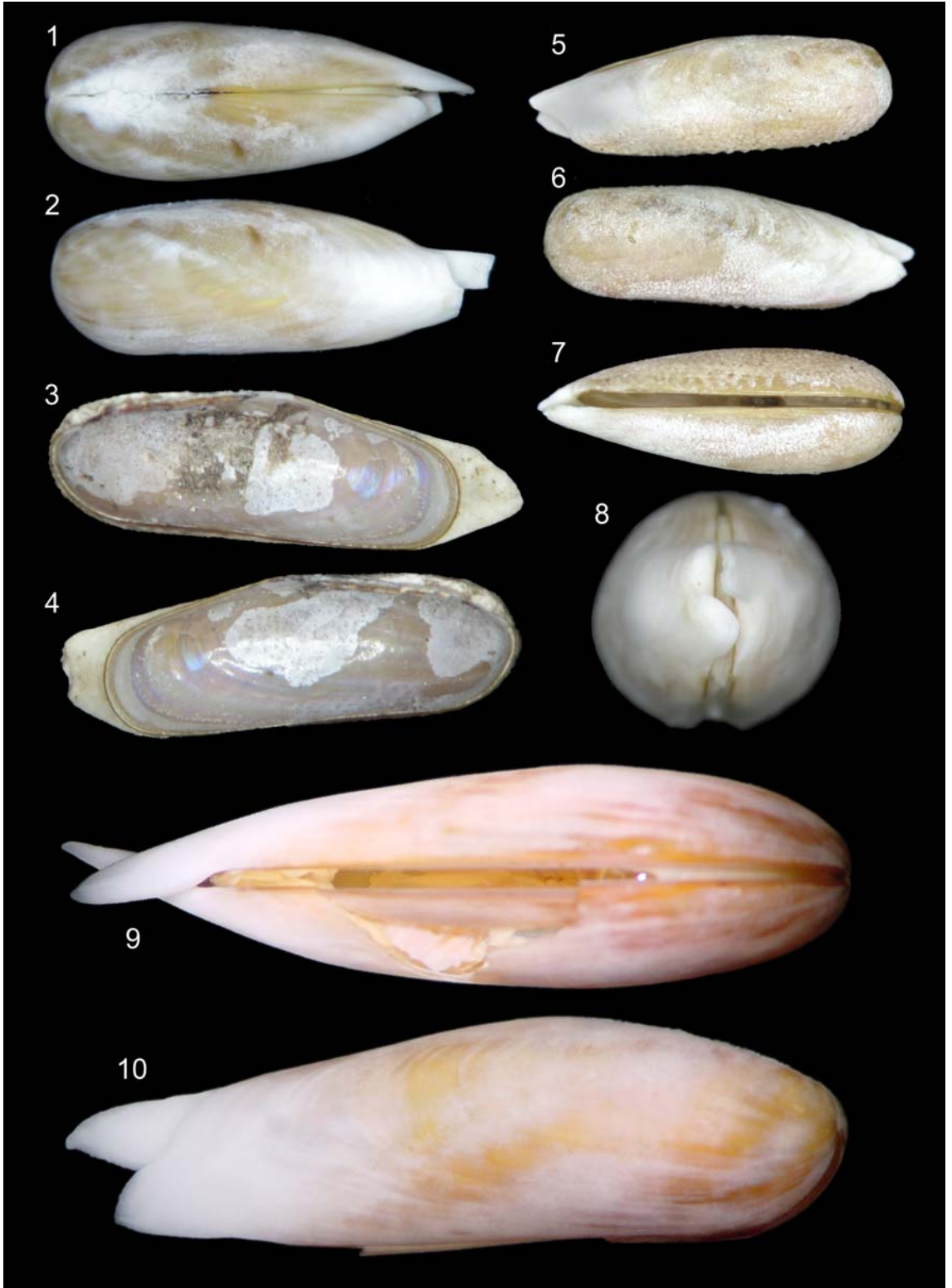
*Types*: See information by Turner & Boss (1962:106).

### Description

*Shell (Figs. 1-10)*: Description given by Turner & Boss (1962) adequate. Characterized by posterior extensions crossing, with left valve possessing an inferior projection (Figs. 2, 4, 6), and right valve a superior projection (Figs. 3, 5), like coring fingers (Figs. 1, 7, 8), however, some specimens are contrary (Figs. 9, 10). No clear pallial sinus detectable.

*Main muscle system (Figs. 15, 16)*: Anterior adductor muscle dorso-ventrally flattened, antero-posteriorly elongated (length about 1/5 of total shell length); located in ventral-anterior corner of valves, close to valve edges. Posterior adductor muscle relatively small, about half of anterior adductor muscle size; somewhat rounded in cross-section; located far from valve edges, positioned between middle and posterior thirds of animal length, and between dorsal and middle thirds of animal height. Pair of anterior foot retractors thick, originating in middle level of anterior region of valves, in an area equivalent to 3/4 of that of anterior adductor muscle and relatively far and totally detached from this adductor muscle; extending toward posterior and ventral up to pedal base, approximately in middle region of ventral animal edge. Pair of posterior foot retractors almost symmetrical to anterior retractors; originating just dorsal to posterior adductor muscle in an area equivalent to 1/4 of that of this adductor muscle; extending toward anterior and ventral, inserting in pedal base just posterior to anterior foot retractor insertion.

*Foot and byssus (Figs. 11, 15)*: Foot relatively small, of about 1/5 valve length, and approximately 4 times longer than wide. Foot base located about in middle

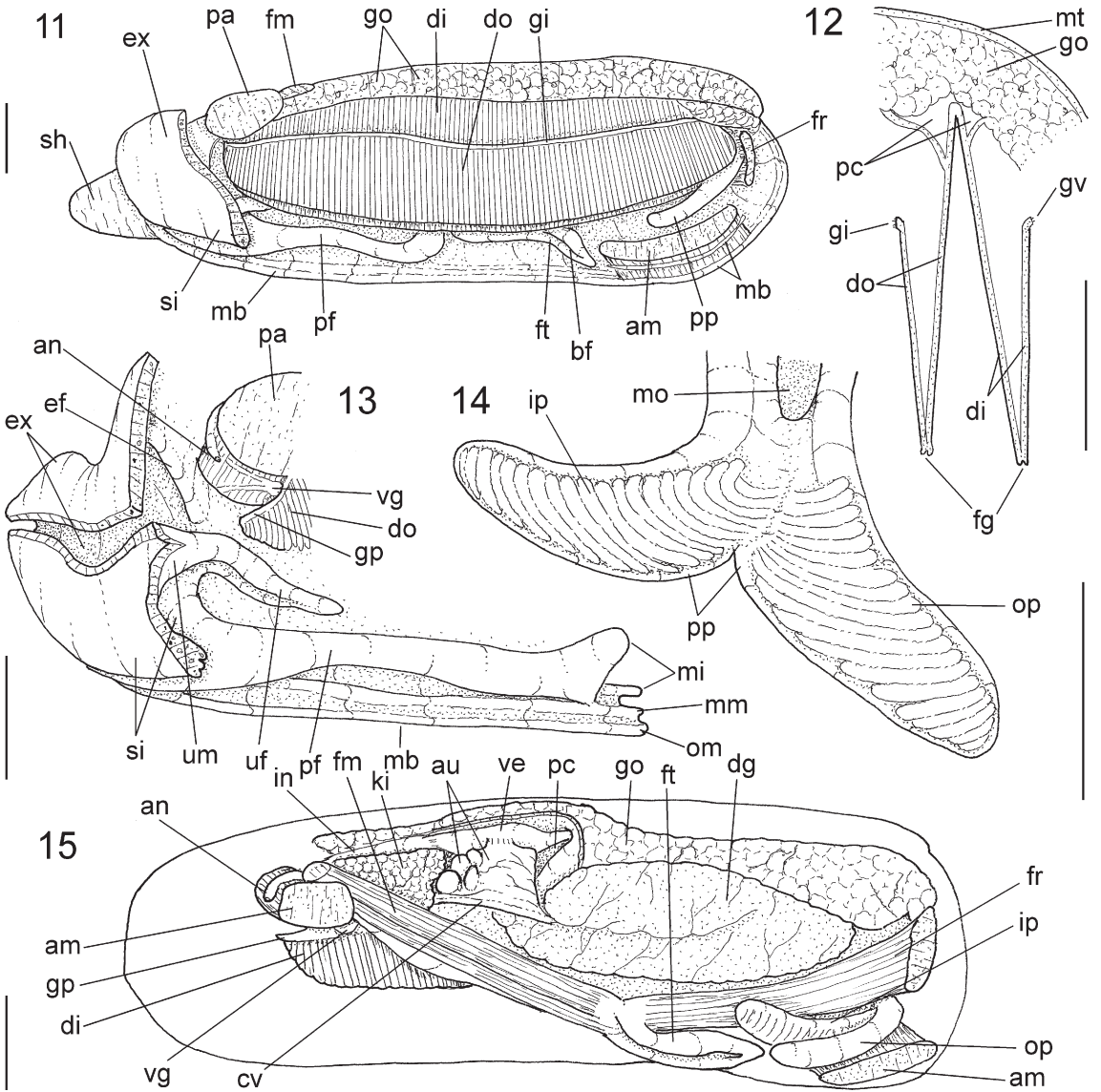


**FIGURES 1-8.** *Myofoveops aristatus* shells: 1-4) MZSP 48274 #1 (from Ubatuba, SP), 1) dorsal view; 2) left view; 3) right valve, inner view; 4) left valve, inner view; total length = 14.8 mm; 5-8) MZSP 48275 #1 (from Arraial do Cabo, RJ); 5) right view; 6) left view; 7) ventral view; 8) posterior view, showing characteristic crossed posterior projections; total length = 11.1 mm; 9-10) FMNH 311641 (from Florida), ventral and right views, specimen with contrary crossed posterior projections, total length = 24.1 mm.

region of ventral surface of visceral mass. Byssal furrow extending all along foot ventral surface, in median line, relatively deep (about half of foot thickness). Byssus not seen.

*Mantle* (Figs. 11, 13): Mantle edges of both lobes mostly free from one another. Three folds of mantle edge similarly sized, circular in section, well-separated from one another. Siphonal region restricted to posterior end, marked by gradual muscular enlargement of

mantle thickness. Incurrent and excurrent siphons separated by thick transverse connection between mantle lobes, of about 1/6 animal length. This connection possessing a flap extending toward anterior (Fig. 13: uf), projecting inside infrabranchial pallial cavity, dorso-ventrally flattened, narrowing gradually to bluntly pointed tip, length equivalent to that of siphons. Inner mantle edge folding abruptly, becoming larger and wider from middle level to incurrent siphonal base (Fig. 13: pf); anterior end of this en-



**FIGURES 11-15.** *Myoformiceps aristatus* anatomy: 11) whole right view, right valve and mantle lobe removed (except for a short portion related to the siphons); 12) transverse section in middle region of gill, with some adjacent structures also shown; 13) posterior region, right view, with special emphasis on siphonal structures, with excurrent siphon sectioned longitudinally and most right structures removed, pallial flap covering siphons removed; 14) right palp, ventral view, both hemipalps deflected to show inner surfaces; 15) whole right view, with most right structures removed, and special emphasis on visceral structures and main muscles seen as in situ. Scales = 1 mm.

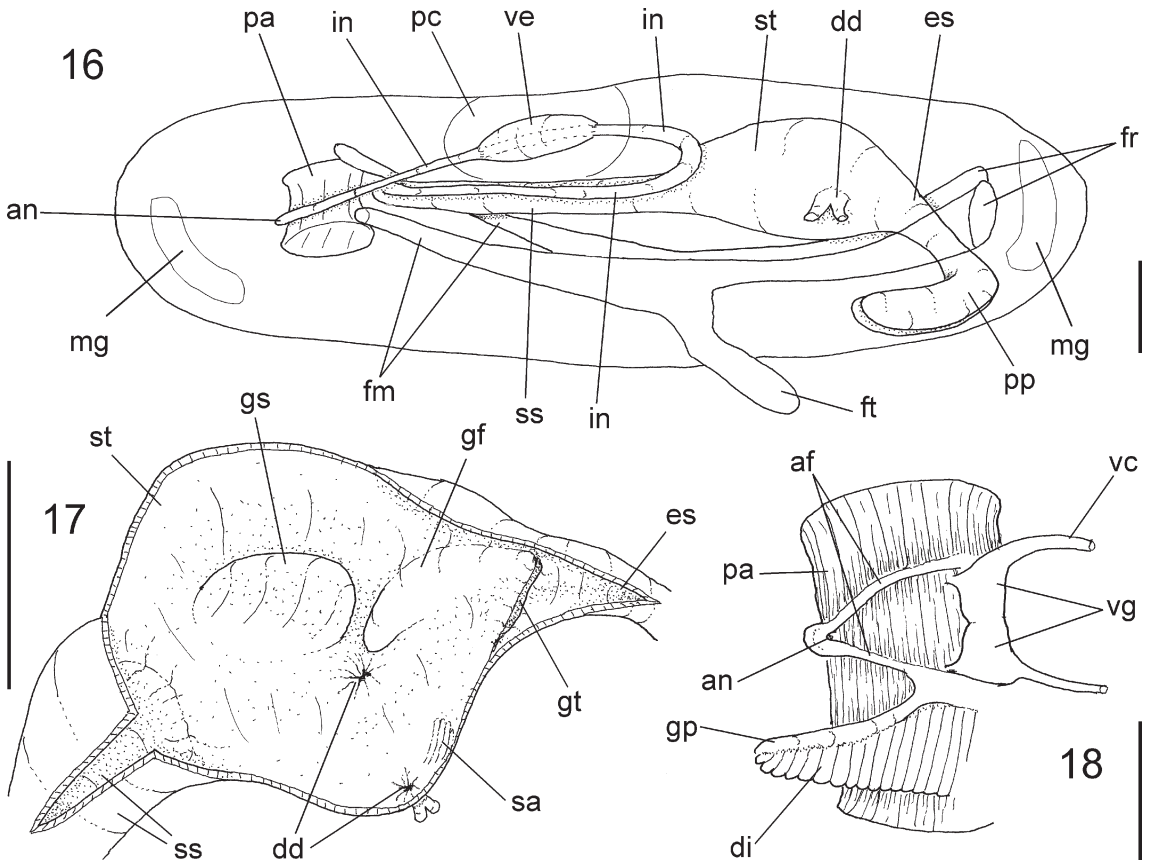


largement shortly projecting inwards, tip rounded; remaining region of this enlargement uniform; in siphonal base abruptly expanding, becoming part of incurrent siphonal wall. Incurrent siphon anatomically open along ventral edge, but edges of both sides contacting each other, producing a tube. Incurrent siphonal edges smooth and thick. Excurrent siphon totally fused with incurrent siphon, being only internally separated, as described above, by septum-like, transverse branchial septum; dorsal wall totally fused, anatomically forming a tube. Transverse, low flap in dorsal and lateral regions of base of excurrent siphon, at same level of posterior end of branchial septum. Excurrent siphonal tip with smooth edges. Pairs of pallial glands that secrete a calcium-binding mucoprotein for boring into calcareous (Jaccarini *et al.*, 1968) whitish; anterior pair located in anterior end of mantle, at short distance from mantle edge, just anterior to origin of both anterior retractor muscles of foot; pos-

terior pair located in posterior-ventral corner, at short distance from mantle edge (Fig. 16: mg)

Gonad filling most regions of mantle lobes, being very thick dorsally (Figs. 11, 12), becoming thinner ventrally, reaching region close to mantle edges (more details below).

*Pallial cavity* (Figs. 11-14, 18): Palps relatively small, of about 1/20 valve area; antero-posteriorly elongated. Palp external surface smooth. Palp internal surface (Fig. 14) with about 20 transverse folds; more distal folds, close to free end, gradually becoming oblique and longer toward proximal end; proximal to connection of hemipalps folds gradually becoming smaller, suddenly disappearing at a distance equivalent to half of hemipalp free region. Inner palp folds with rounded ends, at some distance from palp edges, producing smooth margin. With a smooth furrow between hemipalps. Gills (ctenidia) occupying about 3/4 of



**FIGURES 16-18.** *Myofoveops aristatus* anatomy: 16) whole right view, semi-diagrammatic representation of digestive tract and topology of main muscles, mucous gland (mg) and pericardium; 17) stomach right view, longitudinal section along gastric right wall; 18) ventral region of posterior adductor muscle (pa), with most integument and right gill removed, and topology of some adjacent structures shown. Scales = 1 mm.

pallial cavity (Fig. 11); inner and outer demibranchs of approximately same size; gill anterior end just posterior to origin of anterior retractor muscle of foot, rounded; gill posterior end with about same shape as anterior end, at level posterior to posterior adductor muscle. Posterior end of gill connected to middle region of posterior adductor muscle ventral surface by short, weakly muscular, suspensory stalk (Figs. 13, 15, 18: gp). Gill filaments connected with each other by aligned rows of ciliary junctions. Ventral edge of each demibranch bearing shallow food groove (Fig. 12: fg). Inner lamella of inner demibranch and outer lamella of outer demibranch of approximately same size, connected respectively to visceral sac and to mantle via ciliary junctions; outer lamella of inner demibranch and inner lamella of outer demibranch about twice longer than inner lamella of inner demibranch and outer lamella of outer demibranch, connected to dorsal structures via tissue junctions (Fig. 12). No clear vessels present in demibranch extremities, except in region between demibranchs connected to pericardium (Fig. 12: pc). No clear connection between lamellae of each demibranch. Flap extending from septum between siphons (described above) (Fig. 13: uf) lying between posterior regions of left and right gills.

*Visceral mass* (Figs. 11, 12, 15, 16): General form somewhat triangular (foot positioned as ventral angle). Both pairs of foot retractor muscles forming ventral border of visceral sac (Fig. 15: fm, fr). Digestive diverticula (gland) greenish-beige in preserved specimens, occupying almost entire middle and anterior thirds of visceral sac. Gonad occupying dorsal region of middle and anterior thirds of visceral sac, extending throughout mantle lobes as described above. Reno-pericardial structures (described below) occupying posterior third of visceral sac. Visceral integument poorly muscular.

*Circulatory and excretory systems* (Figs. 15, 16): Heart occupying little more than half of entire reno-pericardial volume. Auricles connected directly to gills by pericardium in their middle-posterior quarter (Fig. 12: pc). Each auricle weakly triangular, its posterior surface with irregular, relatively large lobes (Fig. 15: au); anterior surface simple. Auricular connection to ventricle narrow and lateral to ventricle. Ventricle surrounding intestine, about as long as pericardium. Kidneys solid, whitish, located in lateral surfaces of reno-pericardial posterior region. Kidneys amply opened to supra-branchial chamber, by long fissure of somewhat same length

as kidney; inner folds of renal glands exposed through renal aperture.

*Digestive system* (Figs. 16, 17): Palps described above (Fig. 16). Mouth elliptical, located at short distance from median end of palp folds; flanked by smooth surfaces, anterior and posterior tips relatively thick (Fig. 14: mo). Esophagus short and wide, of about 1/10 shell length, passing between anterior pedal retractor muscles, close to their anterior end; esophagus totally free from anterior adductor muscle. Esophageal inner surface smooth. Transition of esophagus and stomach marked by oblique, deep furrow (Fig. 17: gt), located in ventral and left surfaces; inner surface of this furrow with low, narrow, well-spaced folds parallel to furrow longitudinal axis. Stomach occupying about 1/3 of visceral sac volume and 1/4 of total animal length; located at anterior region of visceral sac, below umbos, just posterior and dorsal to esophagus (Fig. 16: st); general form elliptical. Inner surface (Fig. 17) mostly smooth; low, broad, arched fold located at left side (Fig. 17: gf), as continuation of posterior edge of furrow located between esophagus and stomach, anteriorly low, posteriorly weakly taller and rounded, close to left duct to digestive diverticula. Small sorting area in dorsal-right surface (Fig. 17: sa), opposed to previous described fold; composed by oblique, low, narrow folds close to each other. A pair of narrow ducts to digestive diverticula (Figs. 16, 17: dd), located at anterior region of gastric ventral surface, one on each side. Gastric shield of about 1/4 gastric surface (Fig. 17: gs); located at left, slightly dorsal and posterior to left duct to digestive diverticula. Intestine and style sac totally fused and nearly indistinguishable; both separated from gastric chamber by low, transverse fold (Fig. 17, preceding ss). Style sac extending directly toward posterior, narrowing gradually, reaching anterior surface of posterior adductor muscle; length slightly longer than that of stomach. Intestine continuing after style sac end, marked by abrupt 180° curve (Fig. 16); extending dorsally, slightly at right along style sac surface; close to stomach posterior surface, performing wide loop to left, returning toward posterior, extending more dorsal and away from preceding loop; passing through pericardium, and along dorsal surface of posterior adductor muscle. Anus a low, simple, small aperture located at anterior region of adductor muscle ventral surface (Figs. 13, 16, 18: an).

*Genital system*: Not seen in total detail. Gonad, as described above, covering dorsal region, reaching mantle

lobes close to mantle edges (Figs. 11, 12, 15: go). Color cream or brown in preserved specimens. No genital apertures observed.

*Central nervous system:* Cerebral and pedal ganglia not seen in detail. Visceral ganglia (Fig. 18: vg) located just anterior to ventral surface of posterior adductor muscle; widely fused to one another in median line (Fig. 13); volume approximately 1/10 of posterior adductor muscle. Cerebro-visceral connectives relatively thick, extending through digestive diverticula.

*Measurements (in mm):* MZSP 48274 #1 (Figs. 1-4): 14.8 length by 5.1 height; MZSP 48275 #1 (Figs. 5-7): 11.1 by 4.2. FMNH 311641: 24.1 by 17.7 (Figs. 9, 10).

*Distribution:* North Atlantic: from Portugal to Senegal; from North Carolina to Venezuela, including the Gulf of Mexico. Now introduced to southeastern Brazilian coast. For occurrence in Pacific Ocean see Turner & Boss (1962).

*Habitat:* Boring calcareous substrata, mainly shells of other mollusks, from intertidal to 5 m depth.

*Material examined.* UNITES STATES OF AMERICA. Florida. Florida Keys, Monroe, Looe Key coral reef, 8 m depth, 24°32.8'N 81°24.8'W, 1 specimens, FMNH 311641 (Sta. FK-260; Bieler & Mikkelsen col. 10/viii/1999). BRAZIL. Rio de Janeiro; Búzios, Ossos Beach, MZSP 48275, 1 specimen (Simone *et al.* col., 19/iii/2005); Arraial do Cabo, Porcos Island, 22°57'35.5"S 41°59'47.7"W, MZSP 48276, 7 specimens [Simone *et al.* col., 19/iii/2005, in *Thais haemastoma* (Linné, 1767)]. São Paulo; Ubatuba, MZSP 48274, 10 specimens [Iris L.A. Álvares col.; iv/2005, in *Nodipecten nodosus* (Linné, 1758)].

## DISCUSSION

The geographic distribution of *Myoforceps aristatus* is regarded by some authors as almost worldwide, including the Pacific coast of South America, Red Sea, Australia, Japan, etc. (e.g., Turner & Boss, 1962; Abbott, 1974). However, this species has not been reported in the western Atlantic areas southern than Venezuela (Merlano & Hegedus, 1994); this fact demonstrates the relevance of this report from the Brazilian coast. Turner & Boss (1962:108) advocated that the original distribution of the species was tropical to temperate from

the eastern and western Atlantic and eastern Pacific, and that the remaining records are attributable to transport by ballast.

Related to the general geographic distribution of *Myoforceps aristatus*, no detailed study beyond analysis of the shell has been produced to verify whether specimens from all points of the world are really of a single species. It is possible that, actually, the species is restricted to the Atlantic, and the remaining records are merely of other cryptic species with similarly shaped shells. The following names were described to samples from the Pacific Ocean, and have been referred as synonym of *M. aristatus*: *Lithobaga caudata* Gray, 1827 (from Australia), *L. gracilior* Carpenter, 1856, *L. tumidior* Carpenter, 1856 (both Pacific coast of Mexico, described as subspecies of *L. aristata*), and *L. carpenteri* (Mörch, 1861) (Costa Rica). The species described for Atlantic samples, and also are considered as *M. aristatus* synonyms (Turner & Boss, 1962), are: *Mytilus curviroster* Schröter, 1787 (no loc.); *Mytilus lithobagus striatus* Sowerby, 1807 (London); *Mytilus aristata* Dillwyn, 1817 (Senegal); *Modiola caudigera* Lamarck, 1819 (Africa); *Mytilus ropan* Deshayes in Lamarck, 1836; *Lithobagus calyculatus* Carpenter, 1856; *Lithodomus forficatus* Ravenel, 1861 (South Carolina); *Lithodomus bipenniferus* Guppy, 1877 (Trinidad).

Since the environmental problems brought by invasive species have increased in importance, mainly related to the extinction of native species and reduction of biodiversity (e.g., Sax & Brown, 2000; Clavero & García-Berthou, 2005), the fact that *Myoforceps aristatus* is another introduced species in the Brazilian coast gains weight. Compared to Western Pacific, for example (Mooney & Hobbs, 2000), the Brazilian coast has been relatively spared from invasive species of mollusks. There are three currently detected species, one of them is the byssate bivalve *Isognomon bicolor* (C.B. Adams, 1845). Like *M. aristatus*, *I. bicolor* is regarded to have originated from the Caribbean, being transported by counterbalance water of ships (Fernandes *et al.*, 2004). Additionally, and different from *I. bicolor*, *M. aristatus* directly impacts native species; it causes damage to their shells, producing serious scars, deformations and even death. The infested specimens of the scallop *Nodipecten nodosus*, studied herein, were cultivated in a marine farm in north São Paulo coast (Ubatuba), where *M. aristatus* is considered a problem (Álvares, personal communication). Beyond *I. bicolor*, other two marine species have been considered as invasive in Brazilian waters, the mytilid *Perna perna* (Linné, 1758) (Souza *et al.* 2004) and the dreissenid *Mytilopsis*

*leucophaeta* (Conrad, 1831) (Souza *et al.*, 2005), both also possibly coming from the Caribbean.

The anatomical features of *Myofoorceps aristatus* are similar to other members of Mytilidae (Coan *et al.* 2000). The main exclusive attributes of *M. aristatus* are the complexity of the incurrent and excurrent siphons; these structures are responsible for constructing the posterior projection of the shell (Morton, 1993), which is annexed to, but it is not part of, the shell. In addition, the folds and projections of the siphons can be used in species identification; they are reasonably uniform in the examined samples; something similar, but with another conformation, is found in the boring mytilid *Botula fusca* (Gmelin, 1791) (see Yonge, 1955; Wilson & Tait, 1984, fig. 3). The kidneys are widely communicated to the supra-branchial chamber by a long aperture, rather than a small aperture, the nephropore as in most bivalves. This wide renal communication is a long opening of each renal chamber, lying along the dorsal edge of the organ; the internal folds of the renal gland are easily visible through this aperture. This feature has not been previously reported to a bivalve. The lobed posterior surface of the auricles is another uncommon feature of this species; although, the significance those lobes is unknown. Lobed auricles appears to be a shared character with *Botula fusca* (Wilson & Tait, 1984).

In agreement with typical morphological characters of Mytilidae (Coan *et al.*, 2000), *M. aristatus* has the visceral sac greatly compacted dorsally, with the internal organs, mainly the digestive tubes, compressed upwards. Another mytilid exclusivity, and possibly related to the preceding character, is the invasion of the gonad into the mantle lobes. The more typical bivalve gonad is inside the visceral sac, however, in mytilids, the gonads are only partially placed inside it, being mostly located along the mantle lobes, reaching, when fully mature, the regions close to the mantle edge (being bordered by the mantle muscles originating from the shell pallial line). The palps are also characteristically long and narrow, having transverse folds. Finally, the foot is relatively small, and operates only as a stalk for the byssus.

The anterior boring gland or pallial glands, present in some boring mytilids as, e.g., *Gregariella coralliophaga* (Gmelin, 1791) (Morton, 1982), *Botula fusca* (Wilson & Tait, 1984), and *Lithophaga lithophaga* (Linné, 1758) (Jaccarini *et al.*, 1968), were also observed in *Myofoorceps aristatus*. Those structures are responsible for the coral or rock boring, secreting, normally, a neural nucoprotein with calcium binding ability (Jaccarini *et al.*, 1968).

## CONCLUSIONS

1. *Myofoorceps aristatus* has been only recently found on the southwest Brazilian coast and is considered introduced, originally from the Caribbean.
2. There is the possibility that the worldwide distribution of *M. aristatus* is uncertain. Its distribution is possibly restricted to the Atlantic, and its occurrence in other seas can be interpreted as cryptic species with similarly shaped shells.
3. The anatomical study revealed characters common to mytilid bivalves plus possible unique features that can be used for comparison with samples from other regions.

## RESUMO

O bivalve *Myofoorceps aristatus* (Dillwyn, 1817), também conhecido como *Lithophaga aristata*, tem sido recentemente coletado nas costas do Rio de Janeiro e São Paulo, Brasil; uma espécie que perfura conchas de outros moluscos. Esta ocorrência está sendo interpretada como uma invasão de uma espécie originada do Caribe. O caráter distintivo da espécie é a região posterior da concha, com extensões que se cruzam. Como espécimes com esta característica também têm sido coletados no oceano Pacífico, eles tem sido considerados como pertencentes à mesma espécie. Entretanto, é possível que mais de uma espécie possam estar envolvidas nesta suposta distribuição mundial. Com o objetivo de fornecer informação completa baseada em material do Atlântico, uma descrição anatômica completa é dada, a qual pode ser usada em estudos comparativos com espécimes de outros oceanos. As características distintivas adicionais de *M. aristatus* são a complexidade do sifão inalante, o rim com uma abertura ampla para a câmara supra-branchial (ao invés de ser via nefróporo) e aurícula multi-lobada.

PALAVRAS-CHAVE: *Myofoorceps aristatus*, invasão biológica, bivalve perfurador, Brasil, anatomia, sistemática.

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