

# Sipunculans associated with dead coral skeletons in the Santa Marta region of Colombia, south-western Caribbean

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*Sipunculans represent a discrete component of the coral reef ecosystem, since they live inside the calcareous structure. They are an important component in terms of biomass and number of organisms. The present study describes the diversity of sipunculans living inside massive coral skeletons. A total of 43 blocks of dead coral skeletons from Montastraea cavernosa, Montastraea annularis and Diploria strigosa were collected from nearby coral reef areas off Santa Marta, on the Colombian Caribbean coast. Using hammer and chisel, blocks of approximately 1 dm<sup>3</sup> were broken into small pieces, from which the sipunculans were extracted. A total of 381 organisms were obtained from the coral blocks comprising four families and 10 species. All the species found have been widely reported in different studies from the Caribbean region. Aspidosiphon fischeri and Phascolosoma perlucens were the two most abundant species comprising more than 60% of the total organisms with a mean density of 18.52 ± 4.64 organisms dm<sup>-3</sup>. Dead coral substrate from M. cavernosa had the greatest abundance (N = 148), followed by D. strigosa (N = 121) and M. annularis (N = 112). There were no significant differences in the abundance, richness, and diversity of sipunculans between coral skeletons; and within samples there was high variability suggesting that the skeletal substrates analysed came from coral skeletons of different unknown ages of succession. These results describe the sipunculan community structure that live inside three important massive coral skeletons, and contributes to the knowledge of the cryptobiota diversity of the Santa Marta area of Colombia.*

**Keywords:** cryptobiota, Colombian Caribbean, *Aspidosiphon*, *Phascolosoma*, marine bioerosion, dead coral skeletons

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## INTRODUCTION

Sipunculans are among the most dominant macroboring fauna living inside dead coral skeletons in coral reefs around the world (Rice & Macintyre, 1982; Hutchings, 1986; Glynn, 1997). The Sipuncula, which are exclusively marine and widely distributed in soft and hard substrata (Rice, 1976) from tropical to polar regions (Murina, 1975), are vermiform animals, also called peanut worms. A great proportion of sipunculans are tropical species accounting for more than 60% of the total, followed by temperate and polar species (Murina, 1975). According to the most comprehensive taxonomic study on sipunculans, the group is composed of two classes, four orders, six families, 17 genera and more than 160 species and subspecies (Cutler, 1994). The body is divided in two main parts: a trunk without segmentation and a retractable introvert, usually with a tentacular arrangement at the most distal part. Sipunculans present a variety of epidermal structures such as papillae, hooks, and shields that are distinctive characters of the group, and are basically

the only external morphological features used for identification (Rice, 1975; Cutler, 1994).

Sipunculans are ecologically important in marine sediments since they are responsible for the bioturbation of organic matter and serve as a food source for higher trophic levels (Murina, 1984; Cutler, 1994). They are especially common in coral reef environments where they occupy a wide variety of habitats such as sand flats, coral boulders and rubble, and in the majority of the cases they bore into the coral reef framework (Rice & Macintyre, 1982; Hutchings, 1986; Glynn, 1997). The sipunculans are one of the most abundant groups found in dead coral skeletons in terms of biomass and number of organisms (Hutchings, 1986). They have an important ecological role in coral reefs because of their capacity of *in situ* degradation of calcium carbonate, thus, being an important component in the process of bioerosion (Rice & Macintyre, 1982; Hutchings, 1986; Peyrot-Clausade & Brunel, 1990; Peyrot-Clausade *et al.*, 1992). The recruitment is mostly via pelagic larvae that metamorphose into the reef matrix where the animal develops and grows (McCloskey, 1970). The rate of recruitment depends on different biotic and abiotic factors, and should be considered variable in space and time (Davies & Hutchings, 1983; Hutchings *et al.*, 1992). Some studies have determined that the degree of sipunculan infestation (including other

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macroborers such as polychaetes) has a direct relationship with the physical characteristics of the coral skeleton, such as hardness and morphology, cover of epifauna and algae, the degree of succession in the coral skeleton (Hutchings, 1974; Hutchings & Peyrot-Clausade, 1988; Perry, 1998), and water quality among others (Hutchings & Peyrot-Clausade, 2002).

Comprehensive studies about macroborers, which emphasize the role of sipunculans in coral reef substratum, have been conducted in the Indo-Pacific (Peyrot-Clausade & Brunel, 1990; Hutchings *et al.*, 1992; Peyrot-Clausade *et al.*, 1992; Hutchings & Peyrot-Clausade, 2002), and the Caribbean region (Rice, 1975, 1976; Rice & Macintyre, 1982; Schulze & Rice, 2004; Schulze, 2005). To our knowledge there are no studies about sipunculans for the Caribbean coast of Colombia. Nevertheless, one publication about cryptobiota exists, which mentions some specimens at the family level and some at genus level (Moreno-Forero *et al.*, 1998). Rice (1975) conducted one of the most complete studies in the Caribbean including 11 stations in the Southern region such as Venezuela and Curacao. The purpose of the present study is to characterize the sipunculan community living inside massive coral skeletons of *Diploria strigosa* (Dana, 1846), *Montastraea cavernosa* Linnaeus, 1767 and *Montastraea annularis* (Ellis & Solander, 1786) in the Santa Marta area of Colombia, and to determine if there are differences in the structure of the sipunculan community between the different coral species. This work represents the first detailed study of the sipunculan community from coral reefs around Santa Marta, and contributes to the knowledge about the diversity of macroborers in the area.

## MATERIALS AND METHODS

### Study site

This study took place in a patchy reef near Santa Marta, Colombia ( $11^{\circ}10'44''$ – $11^{\circ}13'24''$ N and  $74^{\circ}14'43''$ W), which consists of

sponge dominated coral communities that develop mainly on metamorphic rocks (Díaz *et al.*, 1990). The region is influenced by a seasonal upwelling process, lowering the seawater temperatures with increments in salinity (Arévalo-Martínez & Franco-Herrera, 2008), and receives a strong input from inland waters and sediments from the Ciénaga Grande de Santa Marta, the Magdalena River and a number of rivers from the Sierra Nevada de Santa Marta (Ramírez, 1990; Franco, 2005). It is possible to find a reef development with *Diploria* Milne-Edwards & Haime, 1848, *Colpophyllia natans* (Houttuyn, 1772) and *Montastraea* de Blainville, 1830 as predominant species.

### Field sampling

Using SCUBA, samples were collected in nearby coral reefs around Santa Marta (Gaira Bay) between March and April 2005 (Figure 1). Dead portions of corals *Diploria strigosa* ( $N = 14$ ), *Montastraea cavernosa* ( $N = 15$ ), and *Montastraea annularis* ( $N = 14$ ) that at the time of the collection looked superficially similar (covered with filamentous algae) (Figure 2), were sampled at 10 m depth. To determine the coral species, each sample was superficially scraped *in situ* to observe basic structures like shape and size of the calyx, which were later corroborated in the laboratory. Coral species identification was performed according to Reyes & Santodomingo (2002) taking into consideration the following characteristics: *Diploria strigosa* has long continuous valleys of 6–9 mm wide (Veron, 2000) with 15–20 septa  $\text{cm}^{-2}$  (Reyes & Santodomingo, 2002); the colonies are hemispheric meandroids (Veron, 2000). Colonies of *Montastraea cavernosa* form massive boulders and domes (Veron, 2000) with corallites protruding from the skeleton. It has rounded calyces of 5–7 mm in diameter with 48 septa; 24 of them complete and connected to the columella (Reyes & Santodomingo, 2002). *Montastraea annularis* grows in clusters of thick columns with dome-like tops, and the corallites are somehow projected from the coral matrix with calyces



Fig. 1. Study site in the Santa Marta region. Arrows indicate the sampling location.



**Fig. 2.** Skeletal samples analysed. (A–B) *Montastraea annularis* (Ellis & Solander, 1786) samples; (C–D) *Diploria strigosa* (Dana, 1846); (E–F) *Montastraea cavernosa* Linnaeus, 1767.

between 2 and 2.7 mm in diameter. It has 24 septa per calyx and 12 are connected to the columella (Reyes & Santodomingo, 2002).

By means of hammer and chisel coral samples were taken randomly along several 50 m belt transects after preliminary identification of coral species. A chunk of approximately 1 dm<sup>3</sup> (Peyrot-Clausade, 1974; Hutchings, 1981) of dead coral was extracted from the reef matrix and taken to the surface in plastic bags, where they were fixed with 10% buffered formaldehyde, for a posterior extraction and analysis of the sipunculans in the laboratory. Specimens were preserved in 70% ethanol. Because of the irregularity of the coral samples, the volume was recorded by measuring the changes in water displacement, introducing each portion of coral skeleton in a 4000 ml beaker. Using hammer and chisel, dead coral samples were broken up in small pieces where the extraction was performed. After this, sipunculans embedded in the coral matrix were extracted with fine-tipped forceps to minimize damage. Some specimens (particularly small ones) were destroyed in the extraction process and were not quantified; however this accounts for less than 5% of the total individuals. Every species had several relaxed individuals showing the entire introvert, on which the full identification was done. When specimens were contracted, only other characteristics, such as the type of band muscles and/or characteristics on the anal shield and papillae, were taken in consideration. The identification was performed according to Cutler (1994) and one individual of each species was sent for confirmation to Dr G. Kawauchi, a specialist taxonomist for the group.

## Sample treatment

To carry out the description of the sipunculan community, a list of the species found for this study was created for each skeletal substrate where the absolute abundance (number of organisms), relative abundance (%), and mean density (organisms dm<sup>-3</sup>) ± standard error (SE) were calculated. To characterize the assemblage of sipunculans between coral skeletons, species richness (S), Shannon–Wiener diversity (H'<sub>Ln</sub>), and Pielou evenness (J') were calculated with PRIMER<sup>®</sup>V5 (Clarke & Warwick, 2001). For all the calculations the samples were categorized according to the coral skeleton (*D. strigosa*, *M. cavernosa*, *M. annularis*). To test for statistical differences in abundance, species richness, and diversity, one-way ANOVAs were applied after data met the assumptions of homogeneity of variances (tested by Bartlett's test) and normality (as shown by the Kolmogorov–Smirnov test with Lilliefors's correction). For evenness, arcsin square root transformation was applied to the raw data as recommended for percentages and proportions (Quinn & Keough, 2002; Zar, 2010). Data of dead coral samples (1 dm<sup>3</sup>), within species, were analysed as replicates. Values were considered statistically significant when  $P < 0.05$ .

## RESULTS

### General overview

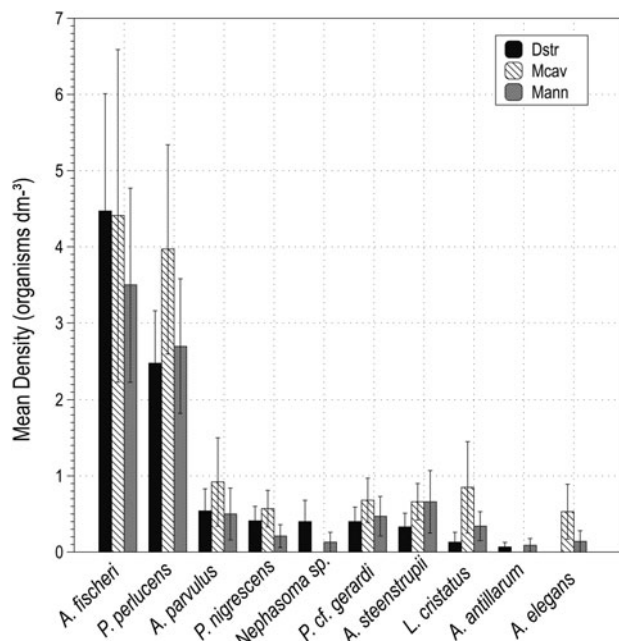
A total of 381 sipunculans ( $10.69 \pm 1.00$  organisms dm<sup>-3</sup>) living inside dead skeletons of *Dipoloria strigosa*, *Montastraea cavernosa* and *Montastraea annularis* in approximately 36 dm<sup>3</sup> were found. Sipunculans were distributed in four families and ten species. *Aspidosiphon fischeri* ten Broeke, 1925 and *Phascolosoma perlucens* (Baird, 1868) were the most abundant and frequent species, followed by *Aspidosiphon parvulus* Gerould, 1913, *Aspidosiphon steenstrupii* (Diesing, 1859), *Phascolion* cf. *gerardi* Rice, 1993, *Lithacosiphon cristatus* (Sluiter, 1902), *Phascolosoma nigrescens* (Kefterstein, 1865), *Aspidosiphon elegans* (Chamiso & Eysenhardt, 1891), *Nephasoma* sp. and *Antillesoma antillarum* (Grube & Oersted, 1858). Values of the total number of organisms, mean density ± SE and frequency of occurrence are given in Table 1. Dead skeletons of *M. cavernosa* had the greatest abundance with 148 sipunculans (38.85%) with a mean density of  $12.63 \pm 2.78$  organisms dm<sup>-3</sup>, and were distributed in three families and eight species. Organism abundance ranged between two and 38 individuals across samples and the species richness ranged between 1–5 species. Skeletons of *D. strigosa* contained a total of 121 sipunculans (31.76%) with a mean density of  $9.92 \pm 2.04$  organisms dm<sup>-3</sup>, and were distributed in four families and nine species. Organism abundance ranged between one and 28 individuals across samples and the species richness ranged between one and seven species. Skeletons of *M. annularis* contained a total of 112 organisms (29.39%) with a mean density of  $9.38 \pm 1.48$  organisms dm<sup>-3</sup> distributed in four families and 10 species. Organism abundance ranged between one and 22 individuals across samples and the species richness ranged between one and five species. Figure 3 shows the mean densities (sipunculans dm<sup>-3</sup>) for each species in each skeletal substrate. A one-way ANOVA



**Table 1.** Total species list with the values of the total abundance (N), density (organisms  $\text{dm}^{-3} \pm$  standard error), and frequency of occurrence (F.O. %) found in each skeletal substrate.

Species	<i>D. strigosa</i> (N = 14)			<i>M. cavernosa</i> (N = 15)			<i>M. annularis</i> (N = 14)		
	N	Density	F.O. (%)	N	Density	F.O. (%)	N	Density	F.O. (%)
<i>Aspidosiphon fischeri</i>	59	4.80 $\pm$ 1.63	85.71	52	4.42 $\pm$ 2.19	40.00	48	3.75 $\pm$ 1.34	71.43
<i>Aspidosiphon parvulus</i>	7	0.59 $\pm$ 0.31	28.57	10	0.92 $\pm$ 0.48	20.00	7	0.54 $\pm$ 0.37	21.43
<i>Aspidosiphon steenstrupii</i>	5	0.36 $\pm$ 0.20	21.43	8	0.67 $\pm$ 0.24	40.00	7	0.71 $\pm$ 0.44	28.57
<i>Aspidosiphon elegans</i>	—	—	—	6	0.54 $\pm$ 0.37	13.33	2	0.16 $\pm$ 0.16	7.14
<i>Lithacosiphon cristatus</i>	2	0.14 $\pm$ 0.14	7.14	12	0.86 $\pm$ 0.61	20.00	4	0.37 $\pm$ 0.21	21.43
<i>Phascolosoma perlucens</i>	30	2.66 $\pm$ 0.71	64.29	45	3.97 $\pm$ 1.37	53.33	33	2.90 $\pm$ 0.93	64.29
<i>Phascolosoma nigrescens</i>	5	0.45 $\pm$ 0.21	28.57	7	0.58 $\pm$ 0.94	33.33	3	0.23 $\pm$ 0.16	14.29
<i>Antillesoma antillarum</i>	1	0.07 $\pm$ 0.07	7.14	—	—	—	1	0.10 $\pm$ 0.10	7.14
<i>Nephasoma</i> sp.	6	0.43 $\pm$ 0.31	13.3	—	—	—	2	0.14 $\pm$ 0.14	6.66
<i>Phascolion</i> cf. <i>gerardi</i>	6	0.43 $\pm$ 0.20	28.57	8	0.69 $\pm$ 0.29	33.33	5	0.47 $\pm$ 0.28	21.43
<b>Total</b>	<b>121</b>			<b>148</b>			<b>112</b>		

showed that there were no significant differences in the abundance ( $F_{2,40} = 0.23$ ,  $P = 0.79$ ) or species richness ( $F_{2,40} = 0.18$ ,  $P = 0.83$ ) among coral skeletons (Figure 4A, B). Skeletons of *M. cavernosa* had the highest Shannon–Wiener diversity index values ( $H' = 1.70$ , confidence interval 1.57–1.84 nits), followed by *M. annularis* ( $H' = 1.61$ , confidence interval 1.42–1.80 nits), and *D. strigosa* ( $H' = 1.53$ , confidence interval 1.35–1.71 nits). The evenness was slightly higher in skeletons of *M. cavernosa* ( $J' = 0.82$ ) than *M. annularis* ( $J' = 0.70$ ) and *D. strigosa* ( $J' = 0.69$ ) but it had the lowest species richness ( $S = 8$ ). Likewise, no significant differences were found for these indices among coral skeletons (Shannon–Wiener:  $F_{2,30} = 0.106$ ,  $P = 0.89$ ; Pielou:  $F_{2,30} = 0.644$ ,  $P = 0.53$ ) (Figure 4C, D).



**Fig. 3.** Values of density (organisms  $\text{dm}^{-3}$ ) for each species found in skeletons of *Diploria strigosa* (Dstr) (Dana, 1846), *Montastraea cavernosa* (Mcav) Linnaeus, 1767, and *M. annularis* (Mann) (Ellis & Solander, 1786). Values are expressed as mean  $\pm$  standard error.

## Species characterization

### ASPIDOSIPHON FISCHERI

This was the most abundant and frequent species in the study. It was more abundant and frequent in skeletons of *D. strigosa* > *M. annularis* > *M. cavernosa* (Table 1). *Aspidosiphon fischeri* is commonly found in shallow coral rock in the southern Caribbean boring into coral skeletons (Cutler, 1994) (Figure 5D). Material examined: UNIANDES-IM 1685, south-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

### ASPIDOSIPHON PARVULUS

This was the third most abundant species. It was more abundant in skeletons of *M. cavernosa* > *M. annularis* = *D. strigosa*, and more frequent in skeletons of *D. strigosa* (Table 1). All bore into coral skeletons (Cutler, 1994) (Figure 5B, C). Material examined: UNIANDES-IM 1687. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

### ASPIDOSIPHON STEENSTRUPII

This was the fourth most abundant species of the study. It was more abundant in skeletons of *M. annularis* > *M. cavernosa* > *D. strigosa*, and more frequent in skeletons of *M. cavernosa* (Table 1). *Aspidosiphon steenstrupii* has a distinctive anal shield where it is common to see externally deposited calcium carbonate, and it has bidentate hooks disposed in rings, which are between 30 and 70  $\mu\text{m}$  tall (Cutler, 1994) (Figures 5H, I and 6D). It has a circumtropical distribution and bores into coral skeletons (Cutler, 1994). Material examined: UNIANDES-IM 1686. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

### ASPIDOSIPHON ELEGANS

Although this is one of the most common and widespread tropical sipunculans, it was under-represented in our study. *Aspidosiphon elegans* was present in three samples, and was absent from skeletons of *D. strigosa*. It appeared in two samples of *M. cavernosa* with three sipunculans in each sample, and in *M. annularis* we found two individuals in

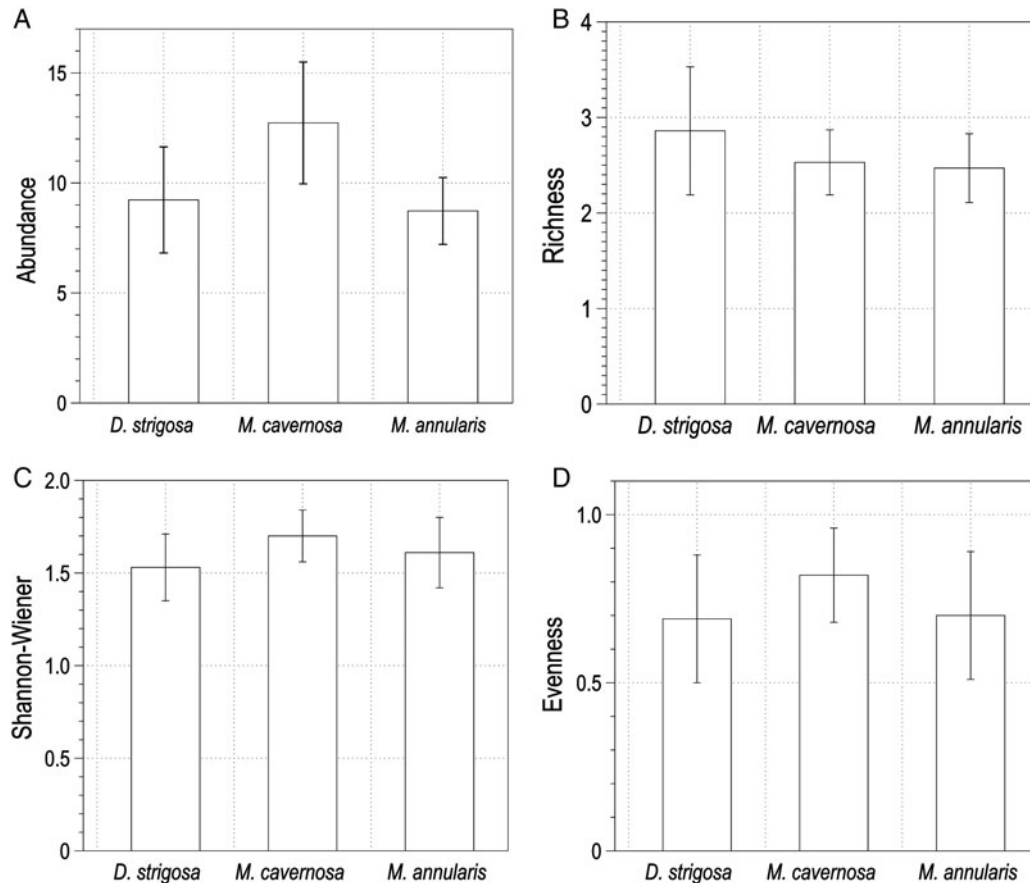


Fig. 4. Values for (A) abundance, (B) species richness, (C) diversity of Shannon–Wiener, and (D) evenness of Pielou of the sipunculans found in the three skeletal substrates. Mean  $\pm$  standard error in (A) and (B), mean  $\pm$  confidence intervals in (C) and (D).

only one sample (Table 1). All specimens were small in size, smooth and white in colour with bidentate compressed hooks (Figure 5A). They are common dwellers of live and dead coral skeletons in shallow waters (Cutler, 1994). Material examined: UNIANDES-IM 1688. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

#### LITHACROSIPHON CRISTATUS

It was more abundant in skeletons of *M. cavernosa* > *M. annularis* > *D. strigosa*, and more frequent in skeletons of *M. annularis* and *M. cavernosa* than *D. strigosa*, which appears in only one sample (Table 1). It has an anterior, distinctive, calcareous cone-shaped anal shield that has parallel grooves, which is typical of the genus (Figure 5G). *Lithacrosiphon cristatus* has wide tropical distribution (Cutler, 1994), and has been collected from coral rock in shallow areas from different locations in the Caribbean (Rice, 1975). Material examined: UNIANDES-IM 1689. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

#### PHASCOLOSOMA PERLUCENS

This was the second most abundant and frequent species. It was more abundant in skeletons of *M. cavernosa* > *M. annularis* > *D. strigosa*, and less frequent in *M. cavernosa* (eight samples) than *D. strigosa* and *M. annularis* (nine samples each) (Table 1). This middle size species is characterized for

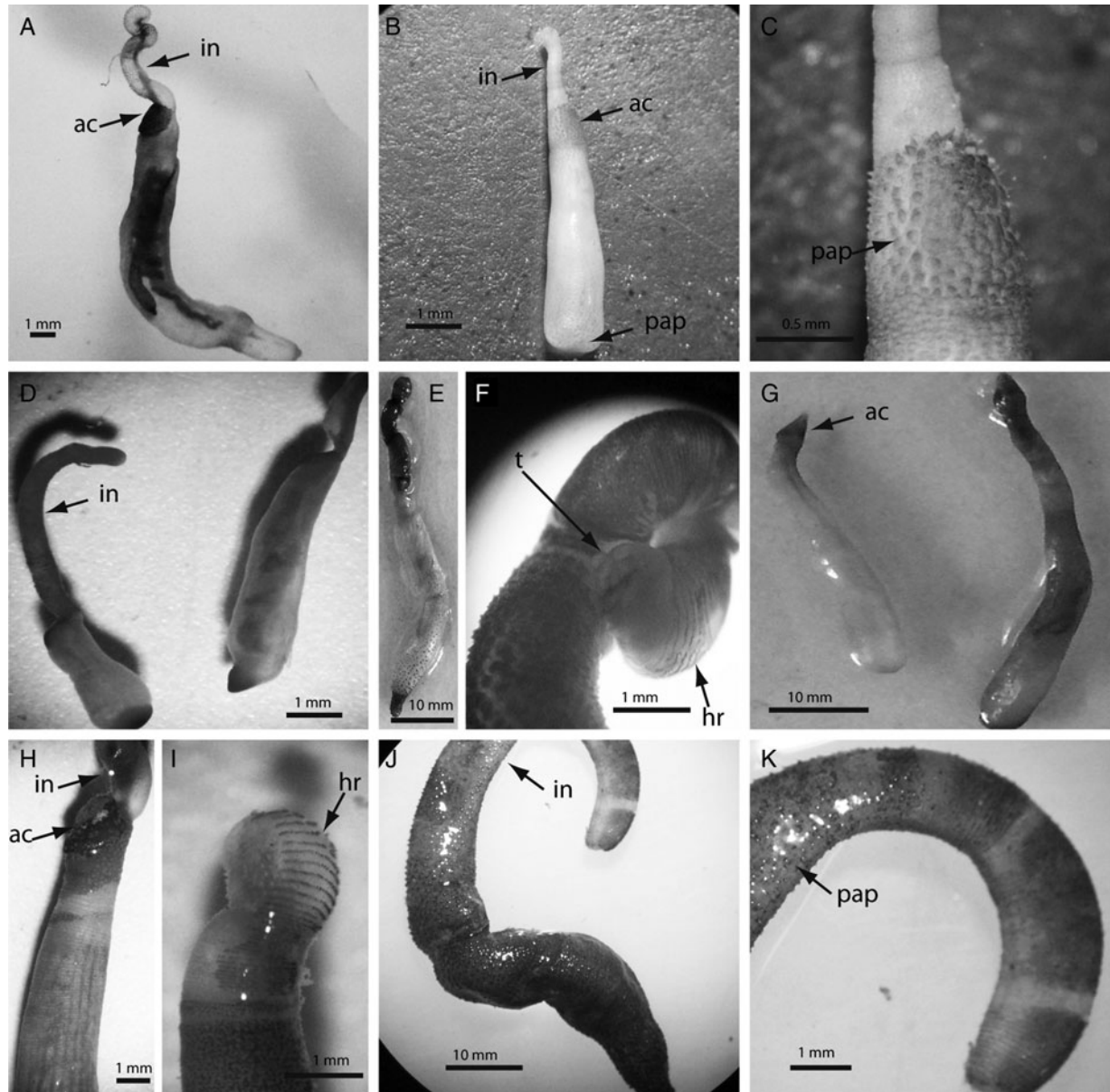
having reddish papillae concentrated at the base of the introvert, and an arrangement of tentacles at the distal end of the introvert (Figure 5E, F). It presents hooks in rings that are characterized for having a secondary tooth (Figure 6A). This species bore into coral skeletons (Cutler, 1994). Material examined: UNIANDES-IM 1692. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

#### PHASCOLOSOMA NIGRESCENS

This species was more abundant and frequent in skeletons of *M. cavernosa* > *D. strigosa* > *M. annularis* (Table 1). The trunk is usually brown with numerous papillae, and the introvert has pigmented bands (Cutler, 1994) (Figures 5J, K and 6B). This widespread species bore into coral skeletons (Cutler, 1994). Material examined: UNIANDES-IM 1693. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

#### ANTILLESOMA ANTILLARUM

This was the least abundant in the study, appearing in two samples. It was found, once each in skeletons of *D. strigosa* and *M. annularis*. The two organisms were about 25 mm each. The trunk is dark-brown with thick, dark papillae at the anterior and the posterior end of the animal. *Antillesoma antillarum* has been referenced in the literature as cosmopolitan, found in tropical and subtropical



**Fig. 5.** Photographs of the most representative sipunculans found in the present study: (A) *Aspidosiphon elegans* (Chamiso & Eysenhardt, 1891), arrows indicate the position of the anal shield (ac) and introvert (in); (B) *Aspidosiphon parvulus* Gerould, 1913, arrows pointing at the anal shield (ac), introvert (in) and papillae in the caudal shield (pap); (C) close-up of anal shield of *A. parvulus*, arrow indicates the conical papillae (pap); (D) *Aspidosiphon fischeri* ten Broeke, 1925; (E) *Phascolosoma perlucens* (Baird, 1868); (F) close-up of *P. perlucens* introvert with arrows pointing at the distal tentacles (t) and hooks disposed in rings (hr); (G) *Lithacrosiphon cristatus* (Sluiter, 1902); (H) *Aspidosiphon steenstrupii* (Diesing, 1859); (I) close-up of *A. steenstrupii* introvert, arrow indicates the introvert with the arrange of hooks in rings (hr); (J) *Phascolosoma nigrescens* (Keferstein, 1865), arrow indicates the introvert; (K) *P. nigrescens* introvert with arrow pointing at the dark papillae.

environments, boring into coral skeletons in shallow areas (Cutler, 1994).

#### PHASCOLION CF. GERARDI AND NEPHASOMA SP.

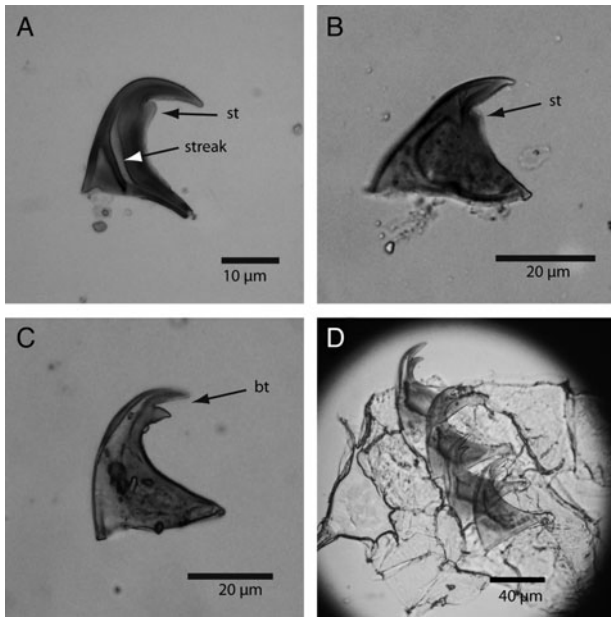
These were found in the three different coral skeletons, with the exception that *Nephasoma* sp. was not present in *M. cavernosa*. *Phascolion* cf. *gerardi* was more abundant and frequent in skeletons of *M. cavernosa* > *D. strigosa* > *M. annularis* (Table 1). *Nephasoma* sp. was more abundant and frequent in skeletons of *D. strigosa* than *M. annularis*. Although these two species are commonly found in coral skeletons or empty mollusc shells that they use as shelter, they are not considered borers like aspidosiphonids or phascolosomatids since they usually use pre-

existing spaces (Cutler, 1994). Material examined *Phascolion* cf. *gerardi*: UNIANDES-IM 1691. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi. Material examined *Nephasoma* sp.: UNIANDES-IM 1690. South-western Caribbean Sea, Gaira Bay off Santa Marta, Magdalena, Colombia, 10 m depth. ID revised by G. Kawauchi.

#### DISCUSSION

The present study shows that the sipunculans fauna of *Diploria strigosa*, *Montastraea cavernosa*, and *Montastraea annularis* is





**Fig. 6.** Photomicrographs of hook types: (A) *Phascolosoma perlucens* (Baird, 1868) showing the characteristic rounded secondary tooth (st) and the streak; (B) *Phascolosoma nigrescens* (Keferstein, 1865), arrow pointing at the secondary tooth; (C) *Aspidosiphon fischeri* ten Broeke, 1925, arrow pointing at bidentate hook (bt); (D) row file of bidentate hooks of *Aspidosiphon steenstrupii* (Diesing, 1859).

relatively homogeneous in terms of abundance and number of species in the study site. The species found in the Santa Marta area are well known coral reef dwellers, and have been reported as typical organisms from dead coral substrate from the Caribbean and many other regions of the world (Murina, 1975; Rice & Macintyre, 1982; Peyrot-Clausade *et al.*, 1992; Hutchings & Peyrot-Clausade, 2002; Schulze, 2005; Fonseca *et al.*, 2006). Although only few studies have been carried out on sipunculans in detail, different authors have reviewed the ecological importance of this group in coral reef environments (Hutchings, 1986; Glynn, 1997).

More than 90% of the specimens found living inside the coral skeletons of *D. strigosa*, *M. cavernosa* and *M. annularis* were bioeroders with the exception of *Phascolion* cf. *gerardi* and *Nephasoma* sp., which usually use pre-existing spaces (Cutler, 1994). The most important sipunculans reported as dead coral skeletons dwellers are the species of *Phascolosoma* Leuckart, 1828 *Aspidosiphon* Diesing, 1851 and *Lithacosiphon* Shipley, 1902 (Rice, 1976; Cutler, 1994). *Aspidosiphon fischeri* and *Phascolosoma perlucens* were the most abundant and frequent species in all three skeletal substrates analysed, comprising 73% of the total fauna found in the present study. Rice (1975) reported *Aspidosiphon fischeri* as especially abundant in the Southern Caribbean, and this species has also been reported on the Pacific coast of Panama and the Galapagos Islands (Cutler, 1994). Likewise, *P. perlucens* has been considered one of the most abundant rock boring species in the great Caribbean, and its dominance may be related to the prolonged breeding season (Rice, 1975). It has been reported to have circumtropical distribution (Cutler, 1994); however, a recent study has suggested that it could be a complex of cryptic species (Kawauchi & Giribet, 2010). *Aspidosiphon parvulus* and *Aspidosiphon steenstrupii* were found in small proportions in the three skeletal

substrates and have a low frequency of occurrence. *Aspidosiphon parvulus* has only been reported in the Western Atlantic and Caribbean region in reefs from Belize (Schulze & Rice, 2004), and Panama (Collin *et al.*, 2005; Schulze, 2005) where it is very common. On the other hand, *A. steenstrupii* is a worldwide-distributed species that has been reported as one of the dominant species in reefs from the Great Barrier Reef (Hutchings & Peyrot-Clausade, 1988), the Tropical Eastern Pacific (Cantera *et al.*, 2003; Fonseca *et al.*, 2006), and the Caribbean (Rice & Macintyre, 1982). Hutchings & Peyrot-Clausade (1988) found that this species was one of the most abundant sipunculans at Lizard Island (Great Barrier Reef), reaching higher densities in shallow areas. *Aspidosiphon elegans* made up only a small percentage of the total abundance in this study; it was absent from *D. strigosa* and rare in samples of *M. cavernosa* and *M. annularis*. Notwithstanding, it is another widespread species, also found in reefs from the Western Pacific and the Indian Ocean. In Moorea, French Polynesia, studies have found that this species is the most abundant sipunculan in samples of dead *Porites* Link, 1807 (Hutchings & Peyrot-Clausade, 1988, 2002) and Rice & Macintyre (1982) have reported very high densities from the barrier reef of Belize. Other species like *Phascolosoma nigrescens*, *Nephasoma* sp., *Phascolion* cf. *gerardi*, *Antillesoma antillarum* and *Lithacosiphon cristatus* appeared only in a small number of samples and at low densities. The later was distributed in the three different coral skeletons analysed, and has been reported in the Caribbean as synonymous of *L. alticonus* or *L. gurjanovae*, also reaching high densities in reefs from Belize (Rice & Macintyre, 1982).

The relatively homogeneous structure of sipunculans found among coral skeletons in this study confirms that the type of coral played a minor role in conditioning the assemblage, and other factors are more important in structuring the community. Physical conditions of the skeleton at the time of collection directly affect the density of different macroborers including sipunculans. The dynamics of sipunculan colonization of dead coral skeletons is spatially and temporally variable (Davies & Hutchings, 1983; Kiene, 1988). Davies & Hutchings (1983) have indicated that sipunculans are not a pioneer community, and two or three years after the death of the colony the substrate could become suitable for colonization by this group. Generally, this infestation follows a succession pattern, in which the time when the skeleton became available is important. Our dead coral samples were taken *in situ*, directly from the reef matrix that at the moment of the collection looked superficially similar (covered by filamentous algae). There is no information about the time when the coral died and the skeleton began a succession process. Despite the data being homogeneous across the different coral species, between samples it was highly variable and exhibited marked differences in abundance and composition. It can be suggested that this variability is due to collection of coral skeletons of different ages and degrees of succession. Marked variation, within and between samples of dead coral substrates collected *in situ*, has also been mentioned (Hutchings & Peyrot-Clausade, 1988; Peyrot-Clausade & Brunel, 1990), and it has been attributed to samples at different stages of development (succession pattern) that are determined by the time since the coral colony died. Generally, the macroboring community develops over time increasing in abundance and richness (Hutchings & Peyrot-Clausade, 2002). In reefs from

Madagascar, Peyrot-Clausade & Brunel (1990) have found that the level of infestation was more correlated with the degree of coral degradation than the type of coral, since sipunculans were less abundant in new dead heads (undamaged) than in old ones.

The values of the present study are low compared to reefs in other places of the Caribbean. The only study on the Caribbean coast of Colombia was done by Moreno-Forero *et al.* (1998), in skeletons of *Acropora palmata* (Lamarck, 1816) around Islas del Rosario (Cartagena, Colombia), and although they did not report the composition at the species level, they found densities up to 213 organisms dm<sup>-3</sup>, which are much higher than the values found in the present study. It appears that the sipunculan community is highly influenced by the reef zone they inhabit. Higher densities are found on or near the reef crest in shallow areas, than in other parts of the reef, where light regime and agitation of water can play an important role in influencing the distribution of sipunculans species (Rice & Macintyre, 1982). This study was conducted in a patchy fringing reef, at 10 m depth, where there is a lack of a reef crest zone. This is in contrast, to the samples from Moreno-Forero *et al.* (1998), which came from dead coral samples taken on the reef crest, off Isla Grande (Islas del Rosario). The type of coral morphology (branching vs massive), which influence the abundance and composition of cryptobiota in dead coral skeletons (Highsmith, 1981a), could be also a factor related to the low densities found in our study. Smaller coral chunks (i.e. branching species) have higher surface to volume ratio than bigger coral chunks having relatively solid centre (i.e. massive species), and branching species tend to have higher percentage of dead surface, thus supporting more organisms (Highsmith, 1981b). This statement is in accordance with the densities found by Moreno-Forero *et al.* (1998), which represents dead coral chunks from branching *Acropora palmata*.

Sipunculans found in dead coral skeletons of the massive species *D. strigosa*, *M. cavernosa* and *M. annularis* from the Santa Marta area have been reported as typical coral reef dwellers elsewhere. *Phascolosoma perlucens* and *Aspidosiphon fischeri*, the two most abundant species in this study are two of the most common species in the Caribbean. The three skeletal substrates analysed shared similar species distribution; however, the marked variability between samples may be the result of skeletal blocks of different ages and succession stages. This study contributes to the knowledge about the cryptobiota and coral reef diversity for the region.

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## REFERENCES

- Arévalo-Martínez D.L. and Franco-Herrera A. (2008) Características oceanográficas de la surgencia frente a la ensenada de Gaira, Departamento de Magdalena, época seca menor de 2006. *Boletín Investigaciones Marinas y Costeras* 37, 131–162.
- Cantera J., Orozco C., Londoño-cruz E. and Toro-Farmer G. (2003) Abundance and distribution patterns of infaunal associates and macroborers of the branched coral (*Pocillopora damicornis*) in Gorgona Island (Eastern Tropical Pacific). *Bulletin of Marine Sciences* 72, 207–219.
- Clarke K. and Warwick P. (2001) *Change in marine communities: an approach to statistical analysis and interpretation*. Plymouth: Plymouth Marine Laboratory.
- Collin R., Díaz M.C., Norenburg J., Rocha R.M., Sánchez J.A., Schulze A., Schwartz M. and Váldez A. (2005) Photographic identification guide to some common marine invertebrates of Bocas del Toro, Panama. *Caribbean Journal of Sciences* 41, 638–707.
- Cutler E.B. (1994) *The Sipuncula: their systematics, biology, and evolution*. Ithaca, NY: Cornell University.
- Davies P.J. and Hutchings P.A. (1983) Initial colonization, erosion and accretion on coral substrate. *Coral Reefs* 2, 27–35.
- Díaz J.M., Escobar L.A. and Velásquez L.E. (1990) Reef associated molluscan fauna of the Santa Marta area, Caribbean coast of Colombia. *Boletín Investigaciones Marinas y Costeras* 19–20, 173–196.
- Fonseca A.C., Dean H.K. and Cortés J. (2006) Non-colonial coral macroborers as indicators of coral reef status in the south Pacific of Costa Rica. *Revista de Biología Tropical* 54, 101–115.
- Franco A. (2005) *Oceanografía de la ensenada de Gaira: El Rodadero, más que un centro turístico en el Caribe colombiano*. Universidad Jorge Tadeo Lozano, Bogotá.
- Glynn P.W. (1997) Bioerosion and coral reef growth: a dynamic balance. In Birkeland C. (ed.) *Life and death of coral reefs*. London: Chapman & Hall, pp. 68–94.
- Highsmith R.C. (1981a) Coral bioerosion: damage relative to skeletal density. *American Naturalist* 117, 193–198.
- Highsmith R.C. (1981b) Coral bioerosion at Enewetak: agents and dynamics. *Internationale Revue der gesamten Hydrobiologie und Hydrographie* 66, 335–375.
- Hutchings P. (1974) A preliminary report on the density and distribution of invertebrates living on coral reefs. In Cameron A.M., Cambell B.M., Cribb A.B., Edean R., Jell J.S., Jones O.A., Mather P. and Talbot F.H. (eds) *Proceedings of the Second International Coral Reef Symposium, Brisbane*, Volume 1, pp. 285–296.
- Hutchings P. (1981) Polychaete recruitment onto dead coral substrates at Lizard Island, Great Barrier Reef, Australia. *Bulletin of Marine Sciences* 31, 410–423.
- Hutchings P. (1986) Biological destruction of coral reefs: a review. *Coral Reefs* 4, 239–252.
- Hutchings P. and Peyrot-Clausade M. (1988) Macro-infaunal boring communities of *Porites*: a biogeographical comparison. In Choat J.H., Barnes D., Borowitzka M.A., Joll J.C., Davies P.J., Flood P., Hatcher B.G., Hopley D., Hutchings P.A., Kinsey D., Orme G.R., Pichon M., Sale P.F., Sammarco P., Wallace C.C., Wilkinson C., Wolanski E. and Bellwood O. (eds) *Proceedings of the 6th International Coral Reef Symposium, Townsville, Australia*, Volume 3, pp. 263–267.
- Hutchings P. and Peyrot-Clausade M. (2002) The distribution and abundance of boring species of polychaetes and sipunculans in coral substrates in French Polynesia. *Journal of Experimental Marine Biology and Ecology* 269, 101–121.



- Hutchings P., Kiene W.E., Cunningham R.B. and Donnelly C.** (1992) Spatial and temporal patterns of non-colonial boring organisms (polychaetes, sipunculans and bivalve molluscs) in *Porites* at Lizard Island, Great Barrier Reef. *Coral Reefs* 11, 23–31.
- Kawauchi G.Y. and Giribet G.** (2010) Are there true cosmopolitan sipunculan worms? A genetic variation study within *Phascolosoma perlucens* (Sipuncula, Phascolosomatidae). *Marine Biology* 157, 1471–1431.
- Kiene W.E.** (1988) A model on bioerosion on the Great Barrier Reef. In Choat J.H., Barnes D., Borowitzka M.A., Joll J.C., Davies P.J., Flood P., Hatcher B.G., Hopley D., Hutchings P.A., Kinsey D., Orme G.R., Pichon M., Sale P.F., Sammarco P., Wallace C.C., Wilkinson C., Wolanski E. and Bellwood O. (eds) *Proceedings of the 6th International Coral Reef Symposium Townsville, Australia*, Volume 1, pp. 449–454.
- McCloskey L.R.** (1970) The dynamics of the community associated with marine scleractinian coral. *Internationale Revue der gesamten Hydrobiologie und Hydrographie* 55, 13–81.
- Moreno-Forero S.K., Navas G.R. and Solano O.D.** (1998) Cryptobiota associated to dead *Acropora palmata* (Scleractinia: Acroporidae) coral, Isla Grande, Colombian Caribbean. *Revista de Biología Tropical* 46, 229–236.
- Murina G.V.** (1975) The geographical distribution of marine worms of the phylum sipuncula of the world ocean In Rice M.E. and Todorovic M. (eds) *Proceedings of the International Symposium on the Biology of the Sipuncula and Echiura*. Belgrade: Naucno Delo Press, Volume 1, pp. 3–18.
- Murina G.V.** (1984) Ecology of sipuncula. *Marine Ecology Progress Series* 17, 1–7.
- Perry C.T.** (1998) Macroborers within coral framework at Discovery Bay, north Jamaica: species distribution and abundance, and effects on coral preservation. *Coral Reefs* 17, 277–287.
- Peyrot-Clausade M.** (1974) Ecological study of coral reef cryptobiotic communities: an analysis of the polychaete cryptofauna In Cameron A.M., Cambell B.M., Cribb A.B., Eudean R., Jell J.S., Jones O.A., Mather P. and Talbot F.H. (eds) *Proceedings 2nd International Coral Reef Symposium*. Brisbane: Great Barrier Reef Committee, Volume 1, pp. 269–283.
- Peyrot-Clausade M. and Brunel J-F.** (1990) Distribution patterns of macroboring organisms on Tulear reef flats (SW Madagascar). *Marine Ecology Progress Series* 61, 133–144.
- Peyrot-Clausade M., Hutchings P. and Richard G.** (1992) Temporal variations of macroborers in massive *Porites lobata* on Moorea, French Polynesia. *Coral Reefs* 11, 161–166.
- Quinn G.P. and Keough M.J.** (2002) *Experimental design and data analysis for biologists*. Cambridge: Cambridge University Press.
- Ramírez G.** (1990) Distribución de nutrientes inorgánicos en las aguas costeras de la región de Santa Marta, Caribe colombiano. In VII *Seminario Nacional de Ciencia y Tecnología del Mar, Cali, Colombia*. pp. 244–254.
- Reyes J. and Santodomingo N.** (2002) *Manual de indentificación CITES de invertebrados marinos de Colombia*. Serie de documentos generales/ INVEMAR No. 8; Serie de manual de indentificación CITES de Colombia.
- Rice M.** (1975) Survey of the sipuncula of the coral and beach-rock communities of the caribbean sea. In Rice M.E. and Todorovic M. (eds) *Proceedings of the International Symposium on the Biology of Sipuncula and Echiura*. Belgrade: Naucno Delo Press, Volume 1, pp. 35–49.
- Rice M.** (1976) Sipunculans associated with coral communities. *Micronesica* 12, 119–132.
- Rice M. and MacIntyre I.G.** (1982) Distribution of Sipuncula in the coral reef community, Carry Bow Cay, Belize. In Rutzler K. and MacIntyre I.G. (eds) *The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay. Structure and community*. Smithsonian Contribution to Marine Science 12, pp. 311–320.
- Schulze A.** (2005) Sipuncula (Peanut Worms) from Bocas del Toro, Panamá. *Caribbean Journal of Sciences* 41, 523–527.
- Schulze A. and Rice M.E.** (2004) Sipunculan diversity at Twin cays, Belize with a key to the species. *Atoll Research Bulletin* 521, 1–9.
- Veron J.** (2000) *Corals of the world*. Volume 3. Townsville, Queensland: Australian Institute of Marine Sciences.
- and
- Zar J.** (2010) *Biostatistical analysis*. 5th edition. Upper Saddle River, NJ: Prentice-Hall.

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