

## Comparative study of putative conspecific sponge populations from both sides of the Isthmus of Panama

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A morphological, cytological and genetic comparison of putative conspecific populations of *Spirastrella* sp. cf. *mollis* (Porifera: Demospongiae) from both sides of the Isthmus of Panama revealed a very high level of genetic differentiation together with morphological and cytological differences. The main differences were the distribution of the spirasters within the choanosome, the size and shape of spirasters 1, and the size and shape of inclusions within type I cells. Consequently these two populations clearly belong to different biological species. The Atlantic one, *S. hartmani* sp. nov. corresponds to what previous authors have called *S. cunctatrix* in the Caribbean. The finding of this new species raises to three the number of *Spirastrella* spp. known from the Caribbean Sea. The Pacific species is named here *S. sabogae* sp. nov. The levels of gene divergence found between *S. hartmani* and *S. sabogae* (Nei's genetic distance  $D=2.30$ ) were as high as those found between different genera in other groups of invertebrates. Similarly exceptionally high values of gene divergence have been found between other congeneric sponge species and may be indicative either of a higher rate of molecular evolution or a very slow rate of morphological evolution in the Porifera compared to other metazoans.

### INTRODUCTION

The extremely high levels of genetic divergence found between sympatric or allopatric morphs of supposedly cosmopolitan sponge species (Solé-Cava et al., 1991a, 1992; Boury-Esnault et al., 1992; Klautau et al., 1994) indicate that the cosmopolitanism of many (if not most) sponge species can be the result of over conservative systematics. This has also been the conclusion of all recent cytological studies of cryptic or cosmopolitan species (Boury-Esnault et al., 1992, 1994, 1995) as well as precise morphological studies (Soest & Hooper, 1993; Boury-Esnault et al., 1993). A basic question in evolutionary biology and ecology is the effect of the genetic divergence resulting from geographical isolation (Jackson et al., 1993). Although populations in allopatry are expected to diverge and speciate (Mayr, 1963; Lessios, 1981; Weinberg & Starczak, 1989; Knowlton, 1993), the rate of divergence is often difficult to estimate because of the uncertainties in determining the time of their separation. A common vicariant event used to estimate that rate is the rising of the Isthmus of Panama during the Pliocene, which isolated the populations in the Caribbean Sea from those in the tropical eastern Pacific. Morphologically similar remnants of the separation of Atlantic and Pacific are presently found on both sides of the Isthmus of Panama [e.g. sea urchins (Lessios, 1981); barnacles (Laguna, 1987); isopods (Weinberg & Starczak, 1989); molluscs (Jackson et al., 1993); shrimps (Knowlton et al., 1993)]. Unlike madreporarians, for which there is almost no overlap between

genera and species of both sides of Panama (Glynn et al., 1973), a relatively high number of similar species have been reported for sponges (Laubenfels, 1936a). A recent morphological and ecological study of four of those species (*Spirastrella* sp. cf. *mollis*, *Haliclona caerulea* and two species of *Halichondria*) concluded that they were indistinguishable cautioning, however, that techniques beyond classical morphological analysis (e.g. cytology and genetics) might be necessary to confirm their identity (Wulff, 1996).

The aims of this paper, were to compare morphologically, cytologically and genetically populations of *Spirastrella* sp. cf. *mollis* from both sides of the Isthmus of Panama, to verify their taxonomic status, and to relate their levels of genetic divergence to the vicariant effect that may have been responsible for their separation.

### MATERIALS AND METHODS

#### *Collection of samples*

Two sites were chosen on the Atlantic coast of Panama (Figure 1): San Blas Islands and Galeta, close to the mouth of the canal. One site was on the Pacific coast; Saboga Island in Las Perlas Archipelago in the Gulf of Panama. Samples were collected by snorkelling or SCUBA diving on the Atlantic and Pacific coasts in July and August 1995. They were immediately fixed for cytology and frozen for allozyme work.

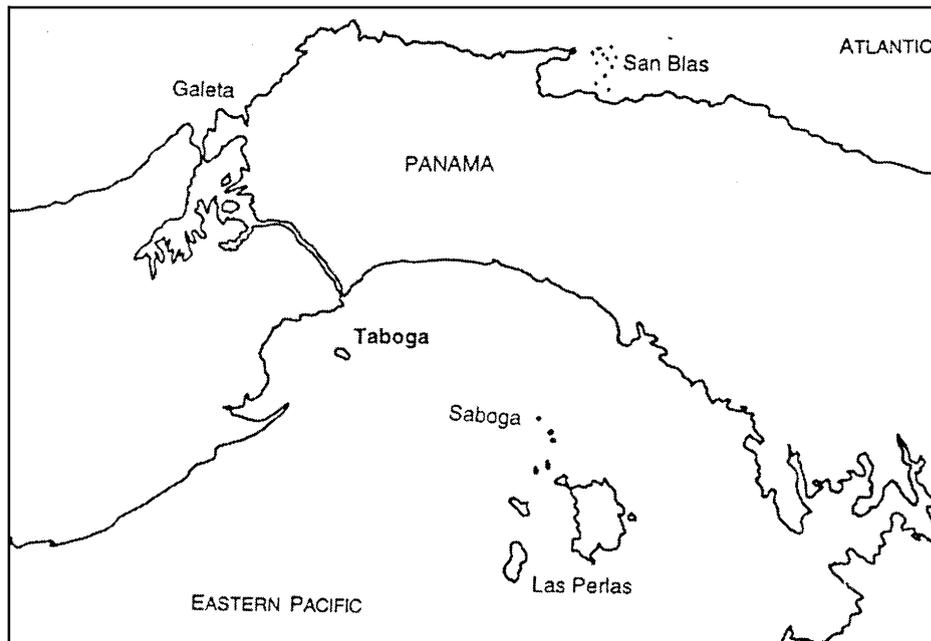


Figure 1. Map of collecting sites in Panama.

#### *Morphology*

Detailed morphology of the spicules was observed by scanning electron microscopy (SEM). Clean dehydrated spicules coated with gold-palladium were examined through a Hitachi S570 scanning electron microscope. For each population, spicule measurements (minimum 50 per spicule type) were obtained for five different specimens. Size range, as well as the mean and standard deviation, were calculated for all types of spicules. For spirasters, a histogram of length frequency was made using the algorithm for frequency classifications of Doane (1976). For the study of the architecture of the skeleton, specimens were embedded in Araldite and prepared as polished thin sections.

#### *Cytology*

For cytology, specimens were fixed as previously described (Boury-Esnault et al., 1984): glutaraldehyde 2.5% in a mixture of 0.4M cacodylate buffer and seawater (4:5 V:V; 1120 mOsm) and post fixed in 2% osmium tetroxide in seawater. For light and transmission electron microscopy (TEM) the specimens were embedded in Araldite. Semithin sections were stained with toluidine blue. Thin sections of two specimens per population, contrasted with uranyl acetate and lead citrate, were observed under a transmission electron microscope (Hitachi Hu 600).

#### *Electrophoresis*

Samples were homogenized with an equal volume of 0.01M Tris, 0.001M EDTA, 0.01M maleic acid, 0.001M  $MgCl_2$ , pH 7.4, and analysed by horizontal 13% starch gel electrophoresis, using a 0.1M Tris, 0.01M EDTA, 0.1M maleic acid, 0.001M  $MgCl_2$ , pH 7.4 buffer (for further details see Boury-Esnault et al., 1992; Solé-Cava et al., 1992). Twenty enzyme systems were assayed, of which

seven (coding for a total of eight gene loci) gave reproducible results. These were acid phosphatases (ACP; E.C. 3.1.3.2), adenylate kinase (AK, E.C. 2.7.4.3), catalase (CAT; E.C. 1.11.1.6),  $\alpha$ -esterases (EST; E.C. 3.1.1.X), glucose 6-phosphate dehydrogenase (G6PDH; E.C. 1.1.1.49), hexokinase (HK, E.C. 2.7.1.1) and phosphoglucose isomerase (PGI, E.C. 5.3.1.9). Enzyme stain recipes and nomenclature were based on Manchenko (1994). Gene frequencies, heterozygosity levels and genetic identities (Nei, 1978) were calculated with the BIOSYS-1 program (Swofford & Selander, 1981).

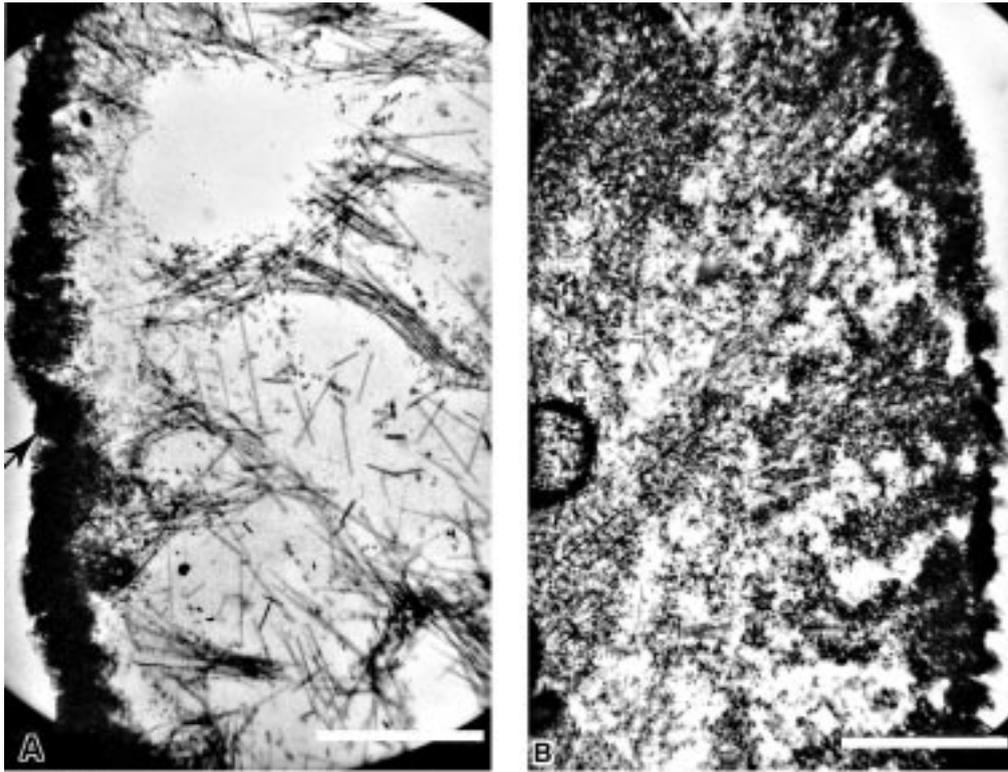
## RESULTS

#### *Ecology*

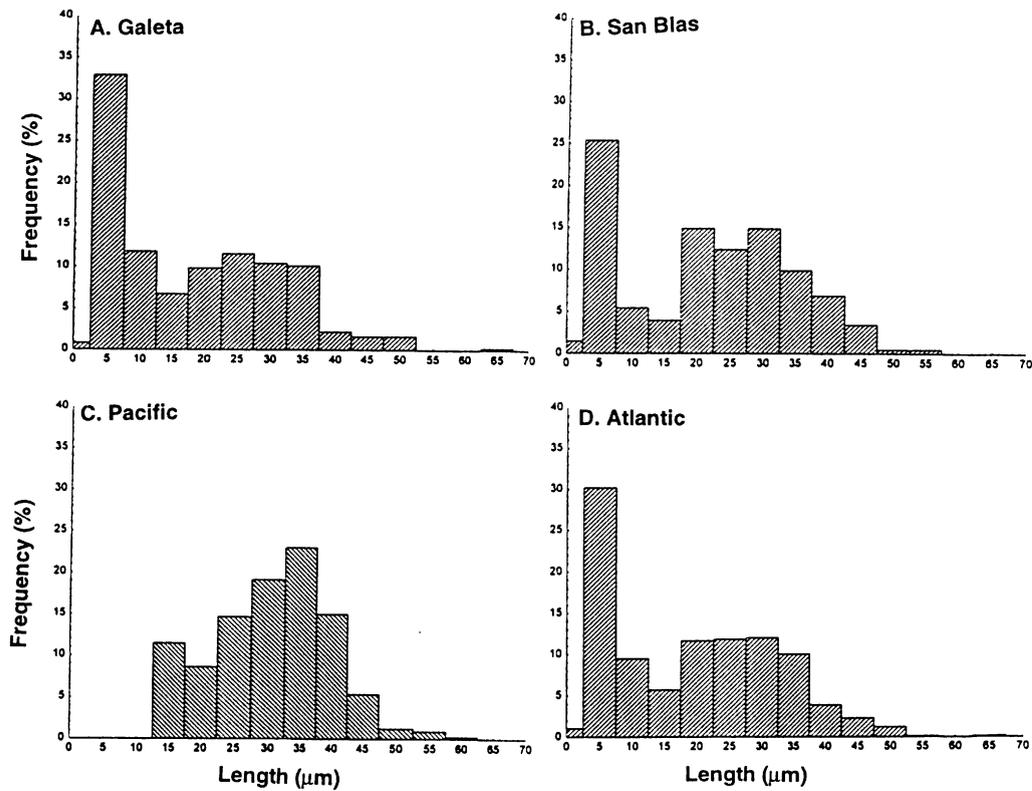
San Blas and Galeta specimens were collected between 1 and 3 m depth in sea grass beds. They were found fixed on small pebbles. The Saboga specimens were collected on coral reefs in the low intertidal zone. Both species appear to be well protected against predators except from some sponge-specialist fish (Wulff, 1994, 1995).

#### *Morphology*

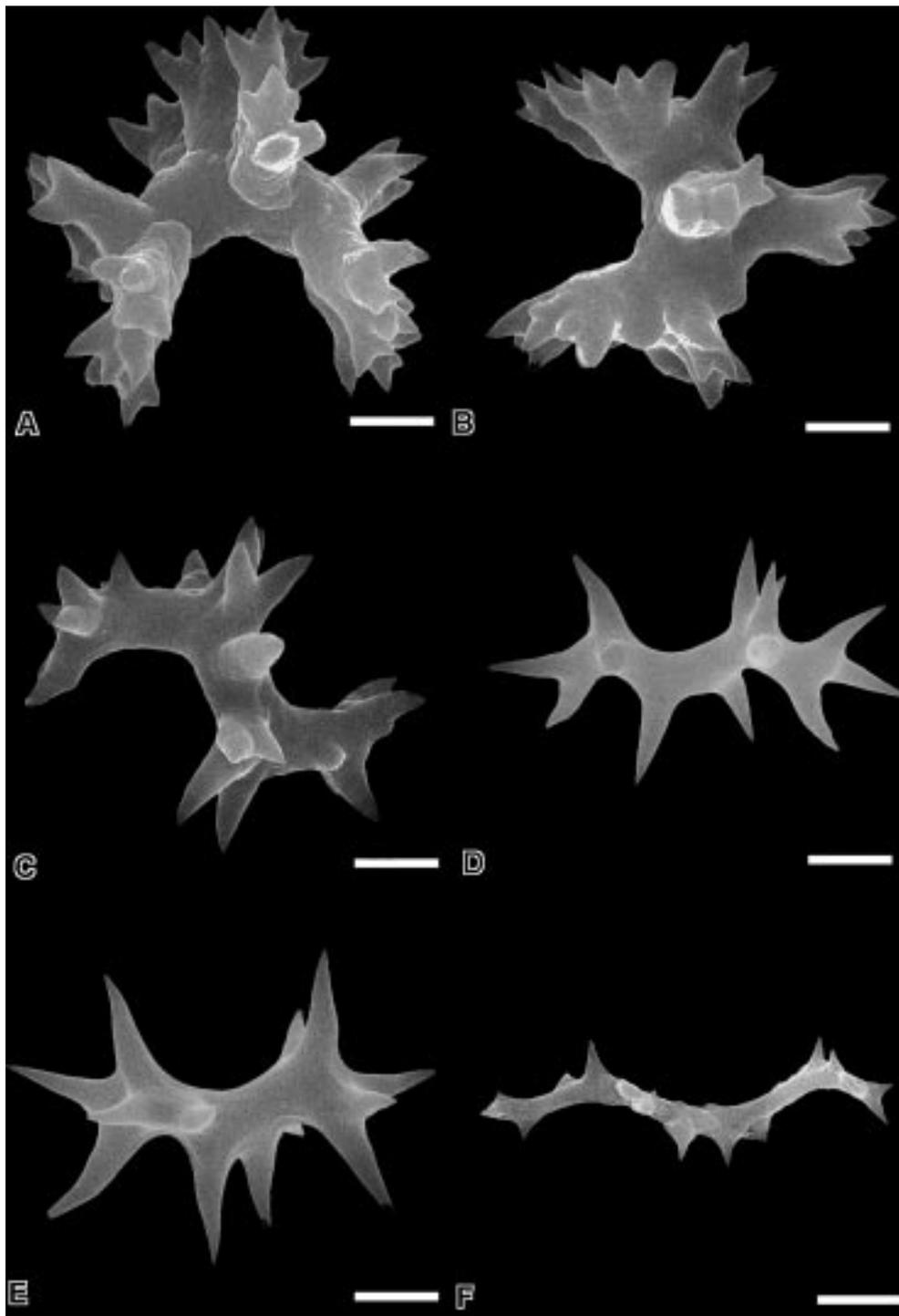
Both Atlantic and Pacific populations of *Spirastrella* spp. collected share the same general aspect. They are encrusting sponges with large visible exhalant canals. They are dull salmon-brown at the surface and brick coloured inside. The skeleton consists of tracts of tylostyles perpendicular to the substrate diverging in bouquets at the surface, and ectosomal layers of spirasters. In the Atlantic (San Blas and Galeta) populations the spirasters are densely packed in the ectosome and in a basal layer near the substrate whereas they are scattered in the choanosome (Figure 2A). In contrast, in the Pacific (Saboga) population the spirasters are densely packed not only in the ectosome and in the basal layer, but also in the choanosome (Figure 2B).



**Figure 2.** Polished thin section of the skeleton of (A) an Atlantic specimen where an ectosomal crust of spirasters is visible on the left of the micrograph (arrow). Spirasters are scattered in the choanosome. (B) A Pacific specimen where spirasters are densely packed in the ectosome and in the choanosome. Scale bars: A, 425  $\mu\text{m}$ ; B, 320  $\mu\text{m}$ .



**Figure 3.** Frequency histogram of size classes of spirasters I and II. Each class has an interval of 5  $\mu\text{m}$ .

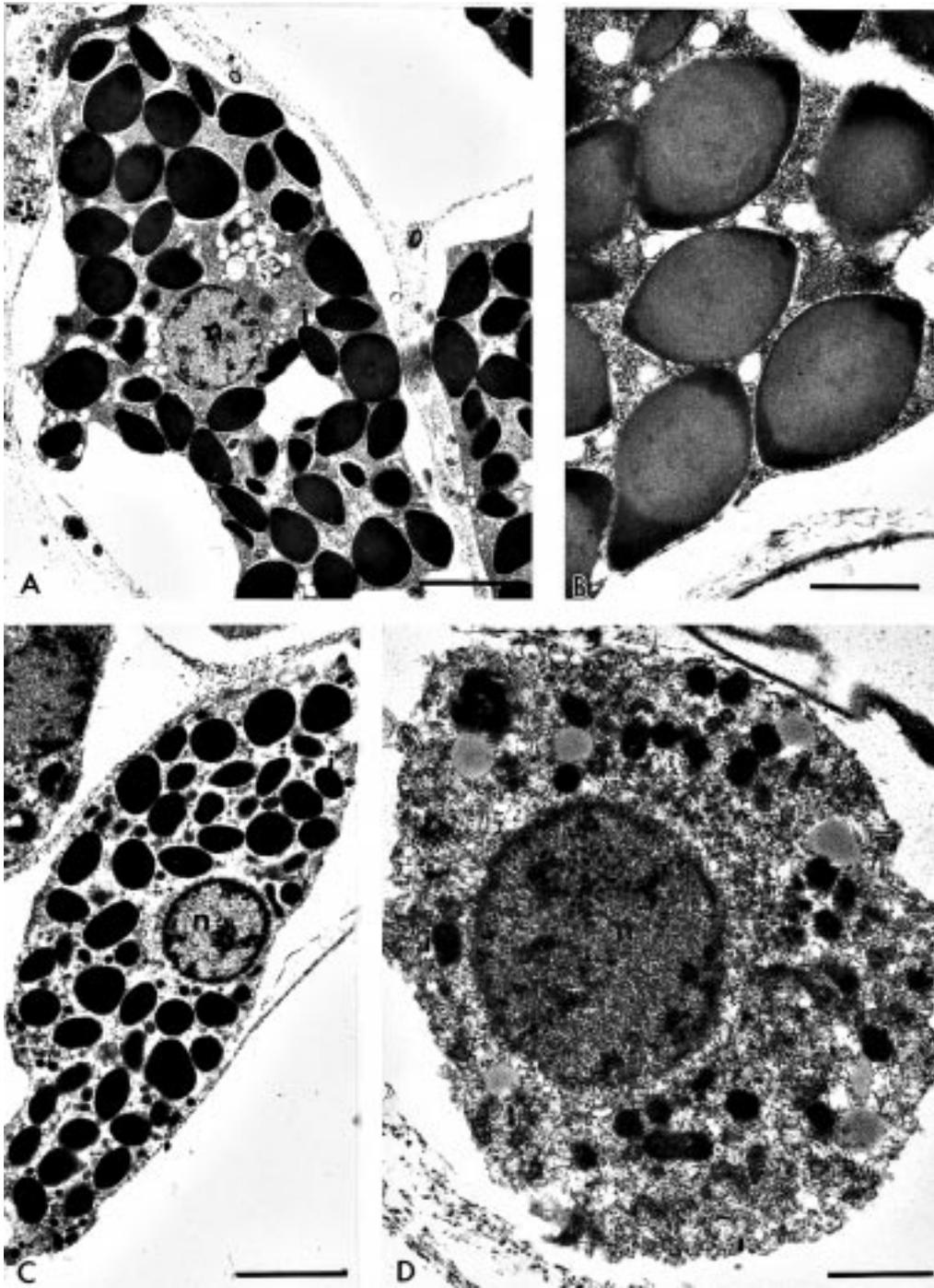


**Figure 4.** Electron micrographs of: (A) spiraster I San Blas specimen; (B) spiraster I Galeta specimen; (C) spiraster I Saboga specimen; (D) spiraster II San Blas specimen; (E) spiraster II Saboga specimen; (F) young form of spiraster II. Scale bars: A, 1.5  $\mu\text{m}$ ; B, 1.4  $\mu\text{m}$ ; C, 2.3  $\mu\text{m}$ ; D, 8  $\mu\text{m}$ ; E, 5.2  $\mu\text{m}$ ; F, 5.7  $\mu\text{m}$ .

Tylostyles of the San Blas and Galeta populations are straight and slightly fusiform. The largest width is not immediately below the head but at a certain distance beyond it. The head is spherical, sometimes irregularly shaped, with an annular swelling below the neck. The sharp point is slightly stepped and often blunt or rounded. Spicule dimensions (length  $\times$  width) in both populations were: San Blas 223–541  $\times$  5.3–15.9  $\mu\text{m}$  (mean 400  $\times$  9.9  $\pm$  52  $\times$  2) and Galeta 307–546  $\times$  5.3–15.9  $\mu\text{m}$  (mean 429  $\times$  9.7  $\pm$  62  $\times$  2.6). The head of the tylostyles in

the San Blas and Galeta populations measured, respectively, 6.8–15.3  $\mu\text{m}$  (mean 11.2  $\pm$  1.7) and 8.5–15.3  $\mu\text{m}$  (mean 11.3  $\pm$  1.9). The difference of tylostyle size between the Atlantic populations was not significant (Student's *t*-test:  $P < 0.05$ ).

In the Saboga population, tylostyles are straight, sometimes slightly flexuous, and the head is ovoid, sometimes irregularly shaped. The largest width is immediately below the head. The shaft gradually tapers to a sharp point. The dimensions of tylostyles



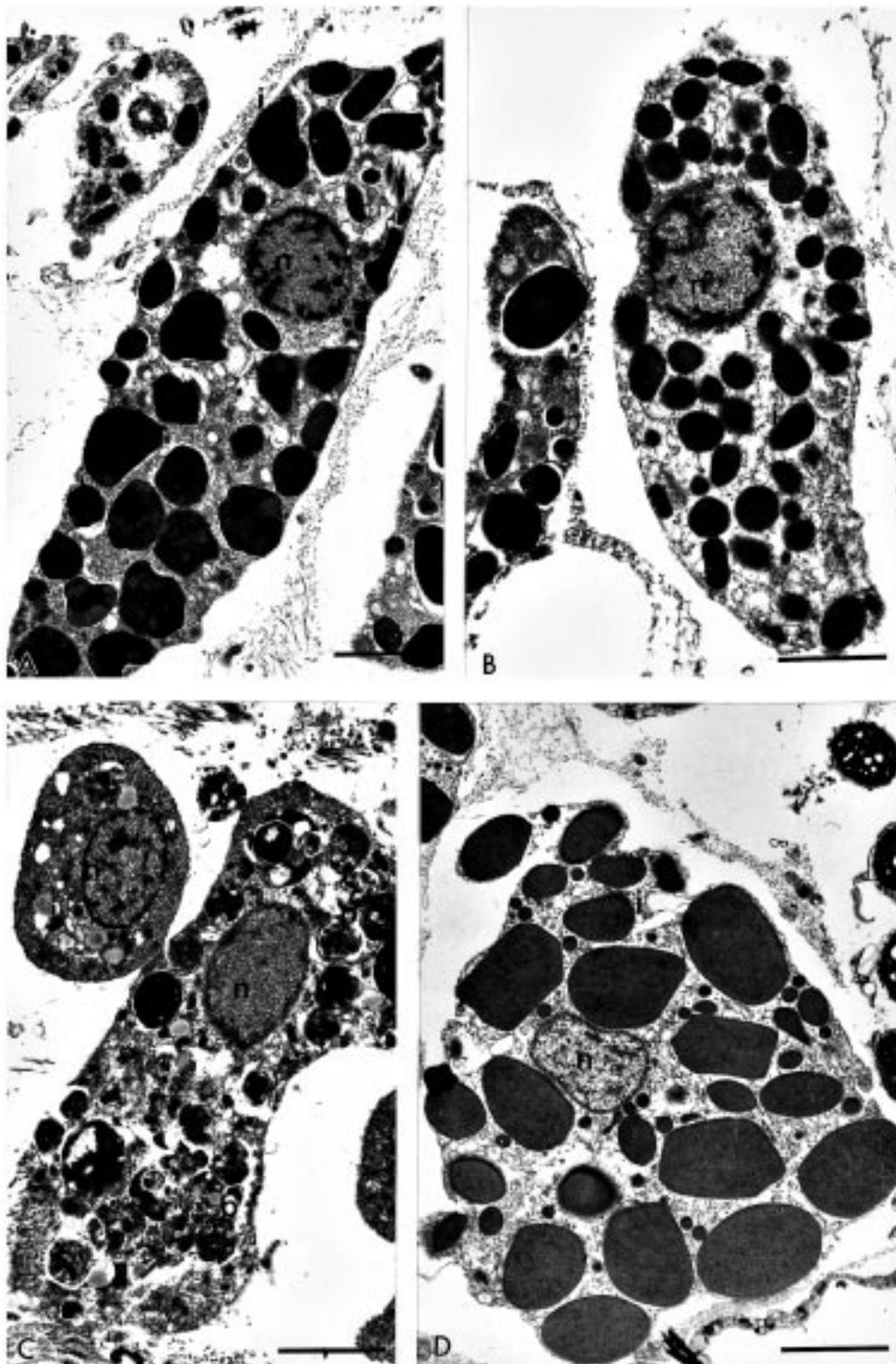
**Figure 5.** Electron micrographs showing: (A) Atlantic *Spirastrella* cell type I; (B) details of the ovoid inclusions of cell type I of Atlantic *Spirastrella*; (C) Atlantic *Spirastrella* cell type II; (D) Atlantic *Spirastrella* cell type III. i, inclusions; n, nucleus. Scale bars: A, 2.4  $\mu\text{m}$ ; B, 0.7  $\mu\text{m}$ ; C, 1.7  $\mu\text{m}$ ; D, 0.76  $\mu\text{m}$ .

in the Saboga population were:  $297\text{--}578 \times 2.6\text{--}15.9 \mu\text{m}$  (mean  $450 \times 8 \pm 50 \times 2.6$ ). The diameter of the head was  $6.8\text{--}13.6 \mu\text{m}$  (mean  $9.9 \pm 1.6$ ).

**Spirasters:** the histogram of length frequency shows a bimodal distribution (Figure 3). In the populations from Galeta and San Blas, the lengths of the first size-class were very similar: respectively  $2\text{--}14 \mu\text{m}$  (mean  $8.5 \pm 2 \mu\text{m}$ ) and  $4\text{--}14 \mu\text{m}$  (mean  $9 \pm 2.8 \mu\text{m}$ ). They have a very short shaft, generally bent only once; a second bend is rarely present. Two groups of spines are present at each extremity and a third one on the convex part. These are robust spines that are often fused. The extremities only

are free and often ramified (Figure 4A,B). In the Pacific population the size of the first class of spirasters  $10\text{--}20 \mu\text{m}$  (mean  $15 \pm 3 \mu\text{m}$ ), is almost twice the size of that observed in Atlantic specimens. The spirasters of the Pacific population have a long shaft bent two to three times and the robust spines, present on the convex part, are free or fused only at the base. The extremities are sometimes ramified (Figure 4C).

The second size-class of spirasters had the same dimensions in the three populations: Atlantic  $15\text{--}66 \mu\text{m}$  (mean  $30 \pm 9 \mu\text{m}$ ); Pacific  $21\text{--}57 \mu\text{m}$  (mean  $32 \pm 7 \mu\text{m}$ ). They show two to four bends and are covered by free robust



**Figure 6.** Electron micrographs showing: (A) Pacific *Spirastrella* cell type I; (B) Pacific *Spirastrella* cell type II; (C) Pacific *Spirastrella* cell type III and archaeocyte; (D) Mediterranean *Spirastrella cunctatrix* cell type I. i, inclusions; n, nucleus; p, phagosome. Scale bars: A, 2.4  $\mu\text{m}$ ; B, 1.1  $\mu\text{m}$ ; C, 1.4  $\mu\text{m}$ ; D, 2.3  $\mu\text{m}$ .

spines starting from the convex part of the bends (Figure 4D,E). The spirasters I are very easily distinguished from young forms of spirasters II (Figure 4F).

#### *Cytology*

The aquiferous system and the anatomy of Atlantic and Pacific populations of *Spirastrella* are quite similar. The

eurypilous choanocyte chambers are spherical and have a volume of  $\sim 8000 \mu\text{m}^3$ . A central cell is present at the apopyle. Two layers can be distinguished in the ectosome: the external layer is  $\sim 70 \mu\text{m}$  thick and is essentially constituted by T-shaped exopinacocytes, collencytes and collagen. The inner layer is  $\sim 120\text{--}150 \mu\text{m}$  thick and is mostly constituted by aggregates of large cells with inclusions. These cells are present with other types of cells

**Table 1.** Gene frequencies and heterozygosity levels for the populations studied. Ten alleles were sampled from each population.  $H_o$  and  $H_e$ -direct count and Hardy–Weinberg mean heterozygosities, respectively.

Locus	San Blas	San Blas	Galeta	Pacific
<i>ACP</i>				
A	0.00	0.00	0.00	0.10
B	0.00	0.00	0.00	0.20
C	0.00	0.00	0.00	0.70
D	0.13	0.10	0.00	0.00
E	0.87	0.90	1.00	0.00
<i>AK</i>				
A	0.00	0.00	0.10	0.00
B	0.13	0.30	0.10	0.00
C	0.87	0.70	0.80	0.00
D	0.00	0.00	0.00	0.70
E	0.00	0.00	0.00	0.30
<i>CAT</i>				
A	0.00	0.10	0.00	1.00
B	0.38	0.90	1.00	0.00
C	0.62	0.00	0.00	0.00
<i>EST-1</i>				
A	0.00	0.00	0.30	0.00
B	0.88	1.00	0.70	0.00
C	0.12	0.00	0.00	0.00
D	0.00	0.00	0.00	0.60
E	0.00	0.00	0.00	0.40
<i>EST-2</i>				
A	0.63	0.20	0.10	0.70
B	0.00	0.00	0.20	0.00
C	0.00	0.40	0.00	0.00
D	0.37	0.40	0.70	0.20
E	0.00	0.00	0.00	0.10
<i>G6PDH</i>				
A	0.00	0.00	0.00	1.00
B	0.87	0.90	0.90	0.00
C	0.13	0.10	0.10	0.00
<i>HK</i>				
A	0.75	0.67	0.20	0.00
B	0.25	0.33	0.80	0.70
C	0.00	0.00	0.00	0.30
<i>PGI</i>				
A	1.00	1.00	1.00	0.00
B	0.00	0.00	0.00	1.00
$H_o$	0.31	0.31	0.28	0.35
$H_e$	0.31	0.29	0.24	0.31

with inclusions in the collagen fibrils surrounding the tylostyle tracts. Three types of cells with inclusions could be distinguished by their ultrastructure.

Atlantic populations: type I cells, (Figure 5A), are very large, up to  $15 \times 7 \mu\text{m}$ , and filled by more than 40 osmiophilic ovoid inclusions of  $\sim 1.6 \times 1.3 \mu\text{m}$ . These inclusions are homogeneous but a more osmiophilic zone is visible at the extremities and sometimes all around the inclusions (Figure 5B). Type II cells, (Figure 5C), measure  $\sim 6 \times 5 \mu\text{m}$ , and contain about 15–30 ovoid to spherical osmiophilic  $0.6 \mu\text{m}$ -diameter inclusions. Type III cells, (Figure 5D), are smaller ( $\sim 4.7 \times 4.6 \mu\text{m}$ ) and rarer. The cytoplasm contains spherical or ovoid osmiophilic inclusions and lipid droplets of  $\sim 0.2$ – $0.5 \mu\text{m}$ .

Pacific population: type I cells, (Figure 6A), are elongated and measure up to  $18 \times 5 \mu\text{m}$ . They are filled with up to 50 irregularly shaped inclusions  $\sim 0.9$ – $1.5 \mu\text{m}$  large.

These inclusions are osmiophilic, homogeneous but with some clearer areas irregularly distributed. Type II cells, (Figure 6B), are more or less ovoid in shape ( $6 \times 3 \mu\text{m}$ ). The cytoplasm contains about 30–40 ovoid to spherical osmiophilic, homogeneous inclusions of  $\sim 0.5$ – $0.6 \mu\text{m}$  in diameter. Type III cells, (Figure 6C), are smaller up to  $5 \sim 2 \mu\text{m}$  and rarer. The cytoplasm contains osmiophilic inclusions of  $\sim 0.2 \mu\text{m}$  in diameter, vesicles and lipid droplets of  $0.3$ – $0.4 \mu\text{m}$ .

#### *Allozymes*

Levels of heterozygosity were high in all populations analysed (0.24–0.31; Table 1). No significant deviations from Hardy–Weinberg equilibrium were found in any population [Fisher's exact test (Sokal & Rohlf, 1969), with a Bonferroni transformation of significance levels,

**Table 2.** Pairwise unbiased genetic identities (Nei, 1978; above diagonal) and distances (Nei, 1978; below diagonal) for the populations studied.

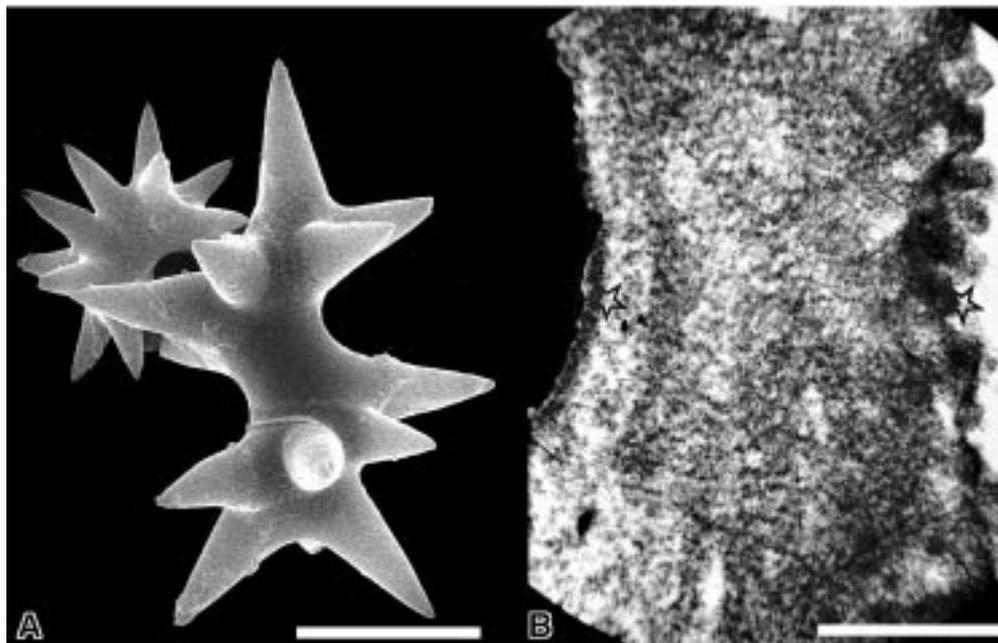
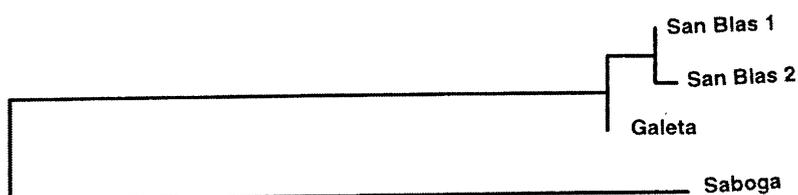
	San Blas 1	San Blas 2	Galeta	Pacific
San Blas 1	–	0.95	0.87	0.13
San Blas 2	0.05	–	0.95	0.10
Galeta	0.14	0.05	–	0.13

(Lessios, 1992)]. The genetic identities found between Atlantic populations varied between 0.87 and 0.95, which are in the range of identities usually found between conspecific populations (Table 2). In contrast, the genetic identities between Atlantic populations and the one from the Pacific varied between 0.10 and 0.13, (Table 2) which is much lower than the lowest values obtained for conspecific populations of any organism (Thorpe & Solé-Cava, 1994).

**Table 3.** Main characters used to distinguish between the three Caribbean *Spirastrella* spp., the Pacific Panamanian one and *Spirastrella cunctatrix* from the Mediterranean. All dimensions are given in micrometres.

Characteristics	<i>Spirastrella</i> spp.					
	<i>S. mollis</i>	<i>S. coccinea</i>	<i>S. cunctatrix</i> Car.	<i>S. hartmani</i> sp. nov.	<i>S. cunctatrix</i> Med.	<i>S. sabogae</i> sp. nov.
Colour	?	orange red	reddish brown	dull salmon/brick	orange salmon	dull salmon/brick
Choanosomal spirasters	?	densely packed	scattered	scattered	densely packed	densely packed
Tylostyle size	310	518/6.1	404/6.4	414/9.8	510/6	450/8
Spirasters	24–48	25–52	7–40	2–14; 15–66	15–41	10–20; 21–57
Spiraster 2 shape angle	abrupt	twisted	twisted	twisted	twisted	twisted
Spine shapes	?	simple	bifid, plurifid	bifid, plurifid	simple	bifid
Inclusion cell I	?	?	?	ovoid, 1.6–1.3	irregular, 2.2–2.7	irregular, 0.9–1.5
Ecology	on corals	outer lagoon	inner lagoon	sea grass beds	cave, dark biotopes	corals

Car., Caribbean; Med., Mediterranean.

**Figure 7.** (A) Spirasters I and II of *Spirastrella cunctatrix* from the Mediterranean Sea; (B) polished thin section of the skeleton of *Spirastrella cunctatrix* from the Mediterranean Sea. Spirasters are densely packed in the choanosome and ectosome. They constituted layers at the surface and at the basis (stars). Scale bars: A, 10.5  $\mu$ m; B, 425  $\mu$ m.**Figure 8.** Neighbour joining tree based on Nei's (1978) unbiased pairwise distances between the studied populations of *Spirastrella*.

**Table 4.** Levels of gene divergence observed between sponge species.

Genus	Type	Occurrence	I	D	Reference
<i>Axinella</i>	A	sympatric	0.32	1.14	1
<i>Clathrina</i>	A	sympatric	0.58	0.54	2
<i>Corticium</i>	A	sympatric	0.45	0.80	3
<i>Petrosia</i>	A	sympatric	0.62	0.48	4
<i>Plakina</i>	A	sympatric	0.70	0.36	5
<i>Suberites</i>	A	sympatric	0.66	0.41	6
<i>Tethya</i>	A	sympatric	0.19	1.66	7
<i>Clathrina</i>	A	allopatric	0.21	1.56	8
<i>Oscarella</i>	A	allopatric	0.32	1.14	9
<i>Phyllospongia</i>	A	allopatric	0.47	0.75	10
<i>Plakina</i>	A	allopatric	0.63	0.46	5
<i>Spirastrella</i>	A	allopatric	0.12	2.30	This study
<i>Carteriospongia</i>	B	allopatric	0.62	0.48	11
<i>Phyllospongia</i>	B	allopatric	0.64	0.44	11
Average	A		0.44	0.97	
Average	B		0.63	0.46	

A, different species; B, same species; 1, Solé-Cava et al., 1991b; 2, Klautau et al., 1994; 3, Solé-Cava et al., 1992; 4, Bavestrello & Sarà, 1992; 5, Muricy et al., 1996; 6, Solé-Cava & Thorpe, 1986; 7, Sarà, 1990; 8, Solé-Cava et al., 1991a; 9, Boury-Esnault et al., 1992; 10, Stoddart, 1989; 11, Benzie et al., 1994.

## DISCUSSION

The levels of genetic differentiation found between the Atlantic and Pacific populations of the putative species *Spirastrella* sp. cf. *mollis* were extremely high (Nei's genetic distance,  $D=2.30$ ; Figure 8). This genetic differentiation, together with cytological and morphological differences, clearly demonstrates that they must belong to different biological species (Table 3).

The spicules of Atlantic and Pacific populations of *Spirastrella* sp. cf. *mollis*, are consistently different. The difference in size of the tylostyles is not significant but the shape shows consistent differences especially for the tip, which is irregular in the Atlantic populations and regular in the Pacific one; and for the head, which is respectively spherical and ovoid. Two size-classes of spirasters were found. Spiraster II, the largest class, are identical in size and shape in the Atlantic and Pacific populations whereas spiraster I have significant differences in size (Figure 3) and shape (Figure 4A–C). The spirasters are packed in the ectosome of all studied populations, but they are much more abundant in the choanosome of the Pacific population than on the Atlantic ones (Figure 2A,B).

The main cytological difference is observed comparing the type I cells: in Atlantic populations, they are spherical to ovoid, with a dark zone at the extremities or all around the inclusions (Figure 5A,B). In the Pacific population the inclusions have an irregular polygonal shape, with clear zones irregularly distributed (Figure 6A). These inclusions are larger in the Atlantic populations.

Wulff (1996) pointed out the extreme confusion in the literature for the allocation of West Indies *Spirastrella* specimens to a species. The problem is mostly linked to citations without precise descriptions of skeleton and spicules, with the noteworthy exception of Topsent (1918). Some authors (Laubenfels, 1936b; 1950; Hechtel, 1965) considered there to be only one Caribbean *Spirastrella* sp. similar to the Mediterranean *S. cunctatrix* Schmidt, 1868 and which they named *S. coccinea* (Duchassaing & Miche-

lotti, 1864) because of the law of priority. Hechtel (1965) synonymized also *S. mollis* Verrill, with this putative species. Other authors (Wiedenmayer, 1977; Pulitzer-Finali, 1986) discriminated between two Caribbean closely related species, allocated to *S. coccinea* and *S. cunctatrix* (Table 3). Rützler (1986) considered that the Caribbean specimens allocated to *S. cunctatrix* could be better placed in *S. mollis* to distinguish between Mediterranean and Caribbean species. The description of *S. mollis* is very brief and no dimensions of spicules are given. The type specimen seems to be lost. However, the shape of the spirasters and tylostyles figured in Verrill's paper (1907) and those re-observed by Wulff (1996) on a spicule preparation of a *Spirastrella* specimen from the type locality (Bermuda) indicate that *S. mollis* seems to be a good species, different from the Caribbean *S. cunctatrix*.

Following the hypothesis of Wulff (1996) we consider that the Atlantic specimens reported here, as well as those allocated to *S. cunctatrix* by Topsent (1918), Wiedenmayer (1977) and Pulitzer-Finali (1986) and allocated to *S. coccinea* by Hechtel (1965), are representatives of a third species of Western Atlantic species. *Spirastrella cunctatrix* from the Mediterranean Sea differs in the aspect of the cells with inclusions (type I) (Figure 6D), by the shape of the small spirasters (Figure 7A) which have simple spines never fused and ramified and by the spirasters densely packed in the choanosome as for the Pacific population (Figure 7B, Table 3). *Spirastrella cunctatrix*, considered a cosmopolitan species and with referred specimens from the Mediterranean Sea as well as from the Caribbean Sea and Indian Ocean (Topsent, 1918) is a species complex which needs a precise revision.

On the Pacific coast there are few records of *Spirastrella* species. From the Gulf of California, Dickinson (1945) mentioned *Spirastrella coccinea* in the sense of Laubenfels (1950) and Hechtel (1965), and from southern California Bakus & Green (1987) cited *Spirastrella* sp. Obviously, the *Spirastrella* populations from both sides of the Panama Isthmus have to be assigned to two new species (Table 3).

## DESCRIPTIONS OF THE NEW SPECIES

*Spirastrella hartmani* sp. nov.*Synonymy*

See Wiedenmayer 1977, *Spirastrella cunctatrix*.

*Material*

Holotype deposited at the Museum National d'Histoire Naturelle de Paris: MNHN-NBE-D.1469; type locality: San Blas Island (09°39'N 78°45'W); paratypes at Peabody Museum, Yale University, USA: YPM 21026 and 21027.

*Habitat distribution*

Sea grass beds and reef flat area, 1–5 m depth, San Blas Islands and Galeta.

*Description*

*Shape.* Encrusting species on small pebbles, largest specimens ~15 cm<sup>2</sup> and ~3–5 mm thick.

*Colour.* They are dull salmon on the surface and brick-coloured inside.

*Skeleton (Figure 2A).* The ectosomal skeleton is composed of two layers of spirasters. A very thin external layer is made of spirasters I and an inner one is composed mostly of spirasters II. The spirasters formed also a basal layer in contact with the substrate. Tracts of tylostyles run perpendicularly from the substrate to the surface where they are plumose. The spirasters are also scattered in the choanosome.

*Megascleres.* Tylostyles straight with a spherical head sometimes irregularly shaped with annular swelling below the neck. They are slightly fusiform, the largest width being somewhat distant from the neck. The sharp point is slightly stepped, often blunt or rounded. Dimensions: 223–546 × 5.3–15.9 μm (mean 414 × 9.8 ± 60 × 2.4 μm); head 6.8–15.3 μm (mean 11.3 ± 1.8 μm).

*Microscleres.* Spirasters I have a very short shaft bent generally only once; a second bend may be present. Two groups of spines are present at each extremity and a third one on the convex part. Spines are robust and often appear fused. The extremities are always free and often ramified (Figure 4A,B). Dimensions: 2–14 μm (mean 9 ± 2.6 μm). Spirasters 2 show two to four bends and are covered by free robust spines starting from the convex part of the bends (Figure 4E). Dimensions: 15–66 μm (mean 30 ± 9 μm).

*Etymology*

The name is given in honour to the great spongologist, Professor Willard Hartman.

*Distribution*

San Thomé, Jamaica, Bahamas.

*Spirastrella sabogae* sp. nov.*Material*

Holotype: MNHN: D.NBE.1470; type locality: Saboga Island (08°37.5'N 70°04'W).

*Habitat distribution*

Extreme low intertidal zone on coral pinnacles in Saboga.

*Description*

*Shape.* Encrusting on corals, largest specimens ~10 cm<sup>2</sup> and ~3–5 mm thick.

*Colour.* They are dull salmon on surface and brick-coloured inside.

*Skeleton (Figure 2B).* The ectosomal skeleton is constituted by two layers of spirasters. A very thin external layer is made of spirasters I and an inner one is constituted mostly of spirasters II. The spirasters are packed also throughout the choanosome. Tracts of tylostyles run perpendicularly from the substrate to the surface, where they are plumose.

*Megascleres.* Tylostyles are straight sometimes slightly flexuous, the head is ovoid or irregularly shaped. The largest width is below the head. The shaft gradually tapers to a sharp point. Dimensions: 297–578 × 2.6–15.9 μm (mean 450 × 8 ± 50 × 2.6 μm). The diameter of the head is 6.8–13.6 μm (mean 9.9 ± 1.6).

*Microscleres (Figure 4C).* Spirasters I have a long shaft bent two–three times. The robust spines, present on the convex part, are free or fused only at the base. The extremities are sometimes ramified. Dimensions: 10–20 μm (mean 15 ± 3 μm). The spirasters II (Figure 9) show two to four bends and are covered by free robust spines starting from the convex part of the bends. Dimensions: 21–57 μm (mean 32 ± 7 μm).

*Etymology*

The name is taken from the island of Saboga (Las Perlas Archipelago), in the Gulf of Panama.

*Distribution*

Taboga, Gulf of Panama.

## CONCLUSION

The levels of gene divergence found between *Spirastrella sabogae* sp. nov. and *S. hartmani* sp. nov. were as high as those usually found between different genera in other groups of invertebrates (Thorpe & Solé-Cava, 1994). Similarly exceptionally high values of gene divergence have been found between other congeneric sponge species (Table 4). Two possible scenarios can be proposed for this phenomenon: (a) sponges have a much higher rate of molecular (at least for allozyme loci) evolution than other metazoans; (b) sponges display a rate of morphological evolution so slow (at least for the set of morphological data generally used in sponge systematics) that the taxonomic rank of 'genus' has a completely different meaning when applied to sponges than to most other organisms (e.g. the 'Ornithology for the copepodologist' discussion in Knowlton, 1993). If the vicariant event that led to the speciation of *Spirastrella sabogae* sp. nov. and *S. hartmani* sp. nov. was indeed the rising of the Isthmus of Panama during the Pliocene (i.e. ~3 × 10<sup>6</sup> y before

present), then it would appear that the rates of molecular evolution in sponges are indeed among the highest of metazoans (i.e. scenario (a) above). This could also be related to the extreme levels of gene variation reported for sponge species (Solé-Cava & Thorpe, 1991), since rates of gene divergence seem to be positively correlated with heterozygosity (Ward & Beardmore, 1977). The barrier to gene flow related to the raising of the Isthmus of Panama may have become effective well before its complete closure, due to changes in sea circulation patterns that were already present in the Miocene (Duque-Caro, 1990). These supposed barriers seem to have had important and differentiated consequences to the restriction to gene flow and consequent speciation in many shallow-water species (Jackson et al., 1993; Knowlton et al., 1993). However, even if we take the earlier date for the appearance of biogeographic reproductive barriers (around 13 million years before present; Duque-Caro, 1990) as the moment of separation of the two species of *Spirastrella*, the resulting rate of allozyme divergence is still very high ( $1 D = 5.65 \times 10^6$  y), among the highest recorded for any animal (Nei, 1987; Thorpe & Solé-Cava, 1994). Possibly both scenarios given above are occurring in the evolution of sponge populations, and their ultimate synergistic effect for their taxonomy is the overview, by morphological systematists, of what is turning out to be a much richer biodiversity in sponges (and possibly other 'lower' marine invertebrates) than considered before. Given the limited number of morphological characters available to the study of marine sponges, such high diversity will probably only be discovered if we pay more attention to detail, within an eclectic framework of systematics methods, including of course the classical methods of morphological measurement, but also with the extensive use of cytological, genetic and ecological approaches.

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