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First record of the Mediterranean asteroid *Sclerasterias richardi* (Perrier in Milne-Edwards 1882) in the Azores Archipelago (NE Atlantic Ocean)

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The first occurrence of the Mediterranean fissiparous asteroid *Sclerasterias richardi* (Perrier in Milne-Edwards 1882) is reported from the Azores based upon dredged material off the south coast of São Miguel Island at 135 m depth. This record represents a considerable expansion of the species' geographic range, otherwise reported with certainty only from the Mediterranean Sea. *S. richardi* is capable of producing long-lived planktotrophic larvae with high dispersal potential to reach remote areas such as the Azores. Alternatively, this species is also capable of reproducing asexually through fission, which could insure the maintenance of viable numbers in a stranded population. The presence of *S. richardi* in Azorean waters and its rarity in an otherwise thoroughly investigated area does not necessarily imply a recent arrival nor a human-mediated introduction, as the depths in consideration (80-700 m) are also the least studied in the archipelago.

Key words: Asteroidea, Forcipulatida, fissiparous, Azores.

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INTRODUCTION

Asexual reproduction through fission is a rare phenomenon among sea stars, documented only in 21 (Mladenov 1996) of the 1,900 species known worldwide (Mah & Blake 2012). *Coscinasterias tenuispina* was the only fissiparous asteroid previously known to occur in the Azores (Pereira 1997), a volcanic archipelago located in the NE-Atlantic, half way between the North American and European shores. In this study, we document a second species, *Sclerasterias richardi*, a small asteroid (30 mm maximum documented diameter) known primarily from the Mediterranean Sea (Figure 1), where it lives between 80-710 m on a variety of substrates from sandy, detritic to hard bottoms (Marenzeller 1895; Pruvot 1897; Baldelli 1914; Gallo 1933; Gautier-Michaz 1958; Santarelli 1964; Tortonese 1965; Falconetti et al. 1976; Munar 1984; Borri et al. 1990; Mastrototaro & Mifsud 2008; Mifsud et al. 2009).

Sclerasterias richardi was first described as *Asterias richardi* based on animals collected by the R/V *Travailleur* in Corsican waters (France). Perrier (*in* Milne- Edwards, 1882) soon observed that this six-rayed asteroid was capable of self-

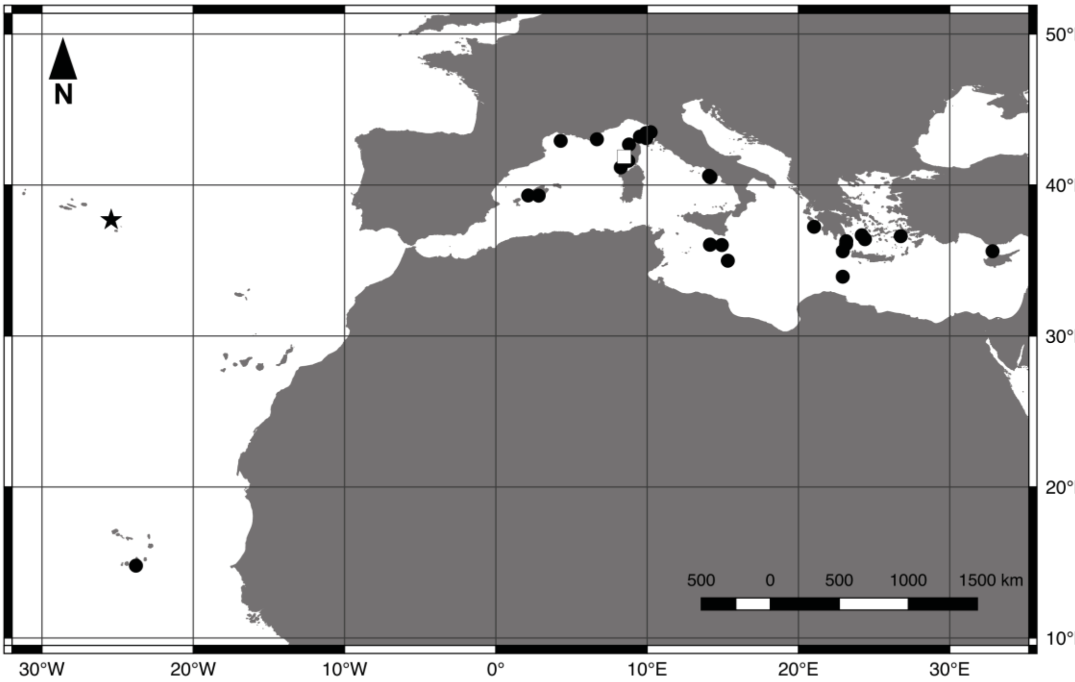

Fig. 1. Geographical distribution of *Sclerasterias richardi* in the Mediterranean Sea and NE Atlantic. The square indicates the type locality (Perrier 1882, in Milne-Edwards 1882), circles the historical records (Marenzeller 1893, 1895; Perrier 1894; Ludwig 1897; Pruvot 1897; Baldelli 1914; Fisher 1928; Gallo 1933; Gautier-Michaz 1958; Santarelli 1964; Tortonese 1965; Falconetti et al. 1976, 1977; Febvre et al. 1981; Munar 1984; Borri et al. 1990; Mastrototaro & Mifsud 2008; Mifsud et al. 2009) and the star the new record from the Azores (DBUA–ECH 357).

division. In a later report, Perrier (1894) further completed his initial description and transferred this species to the genus *Hydrasterias* (family Pedicellasteridae Perrier, 1884). The author also included in the re-description of the type material two other specimens collected by the R/V *Talisman* off the Cape Verde Islands. Fisher (1925, 1928) argued that Perrier's hexamerous forms were representatives of a young fissiparous stage of a pentamerous adult species, probably belonging to the genus *Sclerasterias* (family Asteriidae Gray, 1840), such as the much larger *S. neglecta* (Perrier, 1891) from the Bay of Biscay and the Mediterranean Sea. Tortonese (1965) agreed with Fisher's generic assignment, but considered that further research was needed.

In their revision of the Asteroidea from the Atlantic, Downey (in Clark & Downey 1992) reignited Fisher's concerns by pointing out that the original description of *S. richardi* was inaccurate and based upon immature specimens, thus it should be suppressed. She was possibly unaware of the studies on the sexual reproduction of this species by Falconetti et al. (1976, 1977) and Febvre et al. (1981), which presented *S. richardi* as gonochoristic with a well-marked annual reproductive cycle, from mid-September to mid-October. More recently, Mastrototaro & Mifsud (2008) argued that the unequal number and size of the arms, the presence of multiple madreporites and the documented sexual reproduction suffice to prove that it is a valid species and not a juvenile of *S. neglecta*, a species only known from historical material (Mastrototaro & Mifsud 2008). The debate on the systematic position of this species is still far from being resolved.

MATERIAL AND METHODS

During the 3rd International Workshop of Malacology and Marine Biology, three specimens of *Sclerasterias richardi* were collected by dredging, south of the marina of Vila Franca do Campo, São Miguel Island, Azores (37º41’42”N, 25º25’22”W, 135 m depth, 17 July 2006) (Figure 1).

The specimens were placed in 100% ethanol and included in the echinoderm collection from the Department of Biology of the University of the Azores (DBUA-ECH 357). During our revision of this material, we noticed that the specimens had become completely desiccated and the arms were partially or totally detached from the disc.The terminology used for the morphological structures is adapted after Clark & Downey (1992).

Abbreviations

Rmax: major radius from centre of disc to tip of longest arm; r: minor radius from centre of the disc to interradial edge.

Table 1. Size (Rmax, r) of the specimens from the Azores and corresponding arm length, number of arms and madreporites.

Rmax (mm)	r (mm)	Arm length (mm)	Number of arms	Number of madreporites
6	1.1	3-5	6	2+?
5	0.95	2.5-4	6	2
5	0.96	4	3	2

RESULTS

Systematics

Class ASTEROIDEA de Blainville, 1830
Order Forcipulatida Perrier, 1884

Family Asteriidae Gray, 1840
Genus ?*Sclerasterias* Perrier, 1891
Sclerasterias richardi (Perrier, *in* Milne-Edwards, 1882) (Fig. 2).

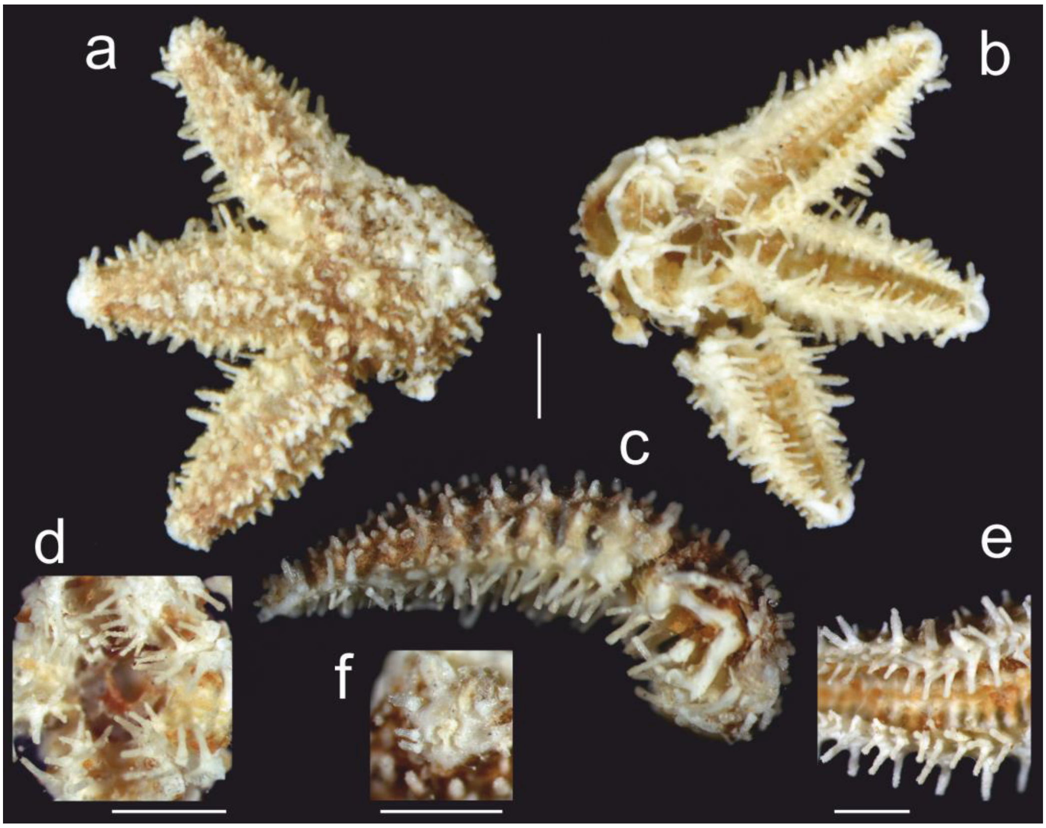

Fig. 2. *Sclerasterias richardi* (Perrier, *in* Milne-Edwards, 1882) (DBUA–ECH 357). a) aboral view; b) oral view; c) lateral view; d) detail of the oral region; e) oral view of the arm; f) S-shaped madreporite. All white scale bars are 1 mm

Description of the specimens: Two animals with six arms of unequal size, three larger and three smaller; one specimen with three arms of similar dimensions to the larger arms of the six-rayed specimens (Table 1). Arms broad, pentagonal in cross-section, narrowing gradually into a round arm tip wholly covered by the terminal plate. Arms weakly attached to the disc.

Reticular plating on the arms arranged in fairly regular longitudinal plate series (carinal, dorsolateral, superomarginal, inferomarginal, adambulacral); arm plates have a round four-lobbed shape with the lateral arms extending towards the corresponding lobe of the adjacent plates series with exception of the small bridge-like dorsolateral plates that serve as an intermediary link between superomarginal and carinal plates. Papulae occupying the interstices between plates, forming two longitudinal rows on each side of the arm: one between the carinal and the superomarginal plates and one between the superomarginal and the inferomarginal plates; oral papillae absent. Arm spines forming fairly regular longitudinal series. Carinal plates carrying up to three short and round spines bearing small spinelets at their tips. Dorsolateral plates also bearing one small spine proximally but naked distally. Superomarginal plates armed with two spines similar in size and shape to the carinal and dorsolateral ones. Spine number and size gradually reduced to one small spine near the arm tip in both carinal and superomarginal plates. Inferomarginal plates with one or two flattened, spatulate to clavate enlarged spines, arranged obliquely and slightly enlarged towards the tip. Adambulacral plates diplacanthid bearing two spines arranged obliquely with the internal slightly smaller than the external one. These spines are slightly flattened and somewhat enlarged towards a round tip. All specimens with at least two madreporites (S-shaped) near the interradial edges; disc also densely covered with small spines, identical in size and shape to those found on the aboral surface of the arms. Spines of the oral armature arranged in pairs along the lateral sides of the mouth plates and of similar sizes and morphology to the adambulacral ones; adoral carina present. Numerous crossed pedicellariae almost as large as the aboral spines dispersed through the body surface, not forming a wreath around the spines; presence of a slightly enlarged unpaired tooth on the outer face of each valve of the crossed pedicellariae. Straight pedicellariae felipedal, slightly larger than the crossed-pedicellariae and restricted to the interradial area. Valves terminated at their upper extremity by a large recurved tooth. Tube feet biserial (quadraserial at the base of larger arms).

DISCUSSION

In spite of the poor state of preservation of the animals, their identification was possible since agreeing for the most part with Perrier (*in* Milne-Edwards 1882, 1894) as well as with the exhaustive descriptions by Ludwig (1897) and Marenzeller (1893). Our observations also agree with Falconnetti et al. (1976), particularly on the distribution of straight and crossed pedicellaria. In addition, our animals showed multiple madreporites, as documented by Mastrototaro & Mifsud (2008).

Fissiparous asteroid species can be identified by the following features: non-pentamerous symmetry, different (asymmetrical) arm sizes and/or more than a madreporite (Mladenov *et al.* 1986). Among the known asteroid species from the Azores (Pereira 1997), *S. richardi* closely resembles the fissiparous *Coscinasterias tenuispina*, and animals belonging to the former species could be potentially overlooked and confused with juveniles of the latter species. However, their habitats differ sensibly since *C. tenuispina* is a common inhabitant of much shallower waters of the archipelago (≤12 m). Both species can be quickly diagnosed under binocular microscope by the distribution of the crossed pedicellariae (in wreaths around the spines of *C. tenuispina*; dispersed through the body surface of *Sclerasterias richardi*) and number of adambulacral spines (one in *C. tenuispina* and two in *S. richardi*), even at size classes as small as 5 mm maximum radius. *S. richardi* is further distinguished from *C. tenuispina* by the aboral armament, *i.e.*, in the *Coscinasterias* species it is represented by isolated spines, whereas in the genus *Sclerasterias* it can be decorated by multiple spines.

The diplacanthid condition of the adambulacral plates is characteristic *Sclerasterias* (as opposed to the monocanthid of *Coscinasterias*), but not the disperse distribution of crossed-pedicellaria on the surface of the body. In this genus, similar to *Coscinasterias*, the crossed-pedicellaria is normally arranged in wreaths around the spines. However, small animals (R > 22 mm) of the Pacific *S. heteropaes*, *S. alexandri* and *S. euplecta*, may present the pedicellaria distributed in a similar fashion of what was observed in our specimens (Fisher 1925, 1928). In contrast, small animals of European *S. neglecta* and *S. guernei* (R = 15 mm and R = 17 mm, respectively) were described by Perrier (1891, 1896a) as having pedicellaria organized in the typical way, *i.e.*, in wraiths around the spines. Furthermore, no Atlantic *Sclerasterias* but *S. richardi* are known to reproduce asexually through fission, including *S. neglecta* and *S. guernei*, which are known only by pentamerous specimens (Downey in Clark in Downey 1992). In sum, we do not agree with either Fisher (1925, 1928) or Downey (in Clark & Downey 1992) in that *S. richardi* should be suppressed. From the available data (*e.g.*, Ludwig 1897; Falconneti et al. 1976; Mastrototaro & Mifsud 2008), there is no evidence that the small *S. richardi* becomes identical to other NE Atlantic *Sclerasterias* (*e.g.*, crossed-pedicellariae arranged in wreath around the spines) in larger size classes. Furthermore, Falconneti et al. (1976, 1977) and Febvre et al. (1981) showed that asexual reproduction in *S. richardi* is not necessarily lost in animals capable of reproducing sexually. However, we agree that further comparisons between *S. richardi* and other *Sclerasterias* in the Atlantic Ocean and Mediterranean Sea are needed, particularly with material of *S. neglecta* and *S. guernei* of similar size classes.

The specimens herein documented were collected offshore Vila Franca do Campo, where both a marina and a port have been implanted. However, it is unlikely that these specimens represent a human-mediated introduction, considering the depth range reported for *S. richardi* (≥ 80 m, Falconetti et al. 1976). On the other hand, it is not possible to ascertain if this species represents a recent arrival, as the species depth range coincides with the least studied waters in the Azores, *i.e.* between the usual maximum SCUBA diving depth (<40 m) and the minimum depth normally targeted by international oceanographic missions (>200 m). The paucity of specimens collected, notwithstanding the considerable research effort in the frame of international workshops organized by the Sociedade Afonso Chaves and the Department of Biology of the University of the Azores (Martins 2009; Martins & Xavier 2014), clearly indicates that further sampling is needed to answer the open questions on dispersion and colonization herein posited.

The archipelago is under the influence of the Azores Current, part of the North Atlantic subtropical gyre (Santos et al. 1995), which generates a West to East sea-surface current pattern (*i.e.*, from the American to the European coasts). Periodical anomalies temporarily reversing the usual circulation patterns, could function as "windows of opportunity" (*sensu* Ávila et al. 2015) for European or North-African shallow-water taxa to reach the Azores (whether by larval dispersal or rafting). Alternatively, Mediterranean species could potentially use the counter-current system to reach the islands, such as the Mediterranean water outflow that reaches the south-southeast Azorean waters around 800-1,200 m depth, though the influence of meddies (*i.e.*, eddies of Mediterranean provenance) can be detected outside this depth range (Pingree & Le Cann 1993; Tychensky & Carton 1998; Bashmachnikov et al. 2015).

Long-lived planktotrophic larvae (>42 days, 14.5ºC, Falconetti et al. 1977) are adapted for long-distance dispersal and may have facilitated the arrival of colonizers of this species to the Azores from the Mediterranean Sea. Moreover, clone propagation through asexual reproduction could help to maintain effective numbers in a fringe population stranded in a remote island/archipelago. The presence of more than one madreporite and the unequal size and number of arms clearly indicate that these animals were reproducing asexually through fission. However, we could not ascertain as to the sexual status of the specimens, due to the desiccated and partially disarticulated state of the material. Falconetti et al. (1976) data showed that among the smallest sampled size classes (Rmax = 7 mm) some of the animals presented no gonads. However the minimum size at the first maturity is almost unknown. Thus, the possibility that our material represents immature animals cannot be completely discarded leaving open the option that they represent vagrants or elements of an already established population in the Azorean islands.

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